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ATOMIC WEIGHTS  
OF THE ELEMENTS  
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**DIVISION OF INORGANIC CHEMISTRY**  
**COMMISSION ON ATOMIC WEIGHTS\***  
**ATOMIC WEIGHTS OF THE ELEMENTS†**

**I. INTRODUCTION**

The current report is the first one since that issued in 1961 to include any general discussion of problems in the Commission's area of responsibility. In that year, the provisional decision of 1959 was confirmed—to change the scale of atomic weights to one based on the number 12 as the assigned relative atomic mass of the carbon isotope 12. The provisional character of the earlier actions hinged on a similar action by the International Union of Pure and Applied Physics, which was taken by that Union in 1960. The change of scale necessitated a complete recalculation of the Table of Atomic Weights. This necessity, in turn, prompted a comprehensive review of the many changes in atomic weight values that had been adopted since the last previous general revision in 1925.

The biennial reports of the Commission since 1961 have dealt only with a limited number of recommended changes in the Table. The relatively small amount of relevant experimental work published in the interval has left unanswered questions about the reliability of many atomic weight values. Pending the appearance of such new measurements, the Commission has attempted this year to assess the uncertainties of all values in the Table, so that users may be able to distinguish their relative magnitudes. The discussion of this new treatment, together with matters of related interest, constitutes a large part of the following text of the 1969 Report.

**II. HISTORICAL PERSPECTIVE**

The fundamental concept of Dalton's atomic theory was that matter can be differentiated into a limited number of elemental species, each composed of identical and immutable particles characterized, among other properties, by unique mass. The identification of all the elemental species and the determination of their characteristic atomic masses (relative to a common standard) constituted two of the great tasks of chemistry throughout the nineteenth century and the early decades of the twentieth. Realization of the importance (to chemical communication) of agreement on atomic weights led first to the formation of national committees in several of the leading countries and a little later to the establishment of the International Commission, which has dealt with the subject ever since through the publication of tables of recommended values. These tables have received world-wide acceptance.

\* *Titular Members*: N. N. Greenwood, Chairman (U.K.); E. Wichers, past Chairman (U.S.A.); H. S. Peiser, Secretary (U.S.A.); J. Guéron, past Secretary (Belgium); A. E. Cameron (U.S.A.); S. Fujiwara (Japan); E. Roth (France); J. Spaepen (Belgium); H. G. Thode (Canada); A. H. Wapstra (Netherlands); *Associate Members*: G. N. Flerov (U.S.S.R.); H. J. Svec (U.S.A.).

† Final version of the report adopted on 2–3 July 1969 at Cortina d'Ampezzo, Italy.

The discovery of natural radioactivity, of the existence of stable isotopic variants of elements, and of the transmutability of elements, have made it necessary to qualify many of the concepts on which the work of the Commission was historically based. Geological events, laboratory handling, and industrial processes can change isotopic composition. The time has long passed when such changes could always be ignored when compared with experimental uncertainties in atomic weight values. Moreover, a rapid increase in human handling of extraterrestrial materials can be expected. In keeping with these developments, the Commission has modified continually its modes of operation and reporting. Because its biennial reports now serve widely diversified interests in the field of chemistry, it is deemed desirable in the current report to include a brief retrospective view of their evolution since the Commission was first created, near the beginning of the present century, and to foreshadow some of the problems which face the Commission, and indeed, every student of chemistry in the years ahead.

### III. EXPLANATION OF TERMS

#### Atomic Weight

From time to time, it has been suggested that the designation 'atomic weight' should be replaced by 'atomic mass' on the grounds that the latter is the property of primary interest and that this property does not have the dimensions of a force. It has also been proposed that the modifier 'relative' be added. In 1961 the Commission, in fact, recommended the adoption of both changes. The addition of 'relative' was approved, but not the change to 'mass', by higher administrative bodies in IUPAC.

This question has been reviewed at the current meetings of the Commission with the conclusion—agreed to with misgivings by some members—that the traditional designation 'atomic weight' should be retained. The reasons for this decision are as follows:

(a) The term 'atomic weight' has a traditional meaning that is well understood by those who use the Table. It is unambiguous when qualified by the language of this explanatory statement.

(b) The term 'atomic mass' (whether absolute or relative) should be reserved for nuclides as distinguished from elements. A table of 'Atomic Masses' is published with the encouragement of the Commission on Atomic Masses and Related Constants (IUPAP). To avoid confusion, the term 'atomic mass' should be reserved for that use. To use the same term for the quantity that is of interest in most chemical usage, it would have to be modified to indicate (i) that the number represents for most elements the average mass of a mixture of nuclides and (ii) that this mixture is a naturally occurring one. Even if these precautions were taken, confusion would not be eliminated and errors would result because of the very similarity of many numbers expressing atomic weights and atomic masses of elemental and nuclidic species, respectively.

(c) The modifier 'relative' is essentially redundant. The concept of relativity is implicit in the chemist's understanding of the term.

(d) Change to 'atomic mass' would not remove the basic objection that 'atomic weight' can mislead students on the 'dimensions' of the numbers in the tables. On the contrary, the danger that students may assign units of

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mass in error is greater if we speak of atomic mass than that they assign units of force if we speak of atomic weight. In fact, the values should be regarded as dimensionless. To convert to the *Système International*, the values given must be multiplied by one twelfth of the mass of a  $^{12}\text{C}$  atom; that is, by  $1.660\,432 \times 10^{-27}$  kg (or revisions of this value).

(e) Once we accept the 'atomic weight' value as pure ratio, the equality with 'atomic mass' (in the chemist's sense) depends only on the linearity of the relations between inertial mass, gravitational mass, and weight force. The requirement that atomic weight comparisons are deemed as made in the same gravitational field is self evident.

### Isotope

The etymological derivation of this word connotes plural forms. However, the term is often mistakenly used to refer not to one of two or more forms of an element, but to an inherently singular form. Correct usage is to say, for example, 'sodium has no known natural isotope'; incorrect usage, 'sodium exists in nature as a single isotope.' The latter situation can be described as 'anisotopic', that is, 'without isotopes'. Alternative language would be to say that sodium (in nature) is mononuclidic and that an element that exists in several isotopic forms is polynuclidic.

### Nuclide

This is a useful word, proposed by T. P. Kohman, to designate an atomic species composed of a unique number of protons together with a unique number of neutrons. It does not seem to have gained uniform acceptance, because of a supposed likely confusion with nucleus. It is used occasionally in this Report, usually in the adjective form, nuclidic, as in mononuclidic or polynuclidic.

### Differences in Atomic Weight Values

A 'significant difference' between atomic weight values for two experimental determinations or applicable to two isotopic compositions is a difference greater than one unit in the last digit of the atomic weight value for a specified element.

Discrepancies and uncertainties in atomic weight values are best stated in atomic weight units, rather than as fractions, percentages, parts per million, etc.

### 'Normal' Material

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: (a) its radiogenic source; (b) its extraterrestrial origin; (c) artificial alteration; (d) mutation; or (e) a rare geological occurrence in small quantity.

## IV. VARIATIONS IN ISOTOPIC COMPOSITION

The discovery that most chemical elements exist in nature as isotopic mixtures, many of which are known to vary in composition, makes it necessary to modify the historical concept of atomic weights as constants

of nature. Even though isotopes have not been observed in nature for some elements (currently 21 in number), it appears more logical to consider that isotopic mixtures represent the normal rather than the exceptional state of an element. The Commission considers that this attitude will promote an awareness that uncertainties in the values given in the International Table are no longer, as in earlier times, to be regarded as resulting only from errors in the measurement of the value, but that they also arise from natural variations in isotopic composition.

Carried to its logical extreme, this view would mean that an atomic weight characterizes only a particular specimen of the element in question. Fortunately, this potentially extreme situation will seldom be encountered and for most of the purposes of chemistry, atomic weights can still be regarded as constants of nature, within limits. The Commission regards one of its functions to be to define these limits numerically, wherever possible, and in general to append to the information given in its Report, all pertinent caveats. In assessing variations in isotopic composition, the Commission will continue to disregard other than 'normal' materials.

To arrive at the recommended value for an atomic weight the Commission will use weighting procedures so that the value will be optimized for materials in world science, chemical technology and trade, rather than represent an estimated geochemical average.

## V. SYSTEMATIC TREATMENT OF UNCERTAINTIES

Uncertainties in values for atomic weights arise not only from experimental errors of measurement, random or systematic, but also from variations in the relative abundances of the isotopes in the (isotopic) mixtures that constitute most of the elements as they exist in nature. In recent years, the Commission has appended to the Table information about the magnitudes, when known, of uncertainties arising from these two separate sources. However, the Commission now considers that the matter of primary interest to most users of the Table is the magnitude of the total uncertainty rather than its source or sources. Consequently, in the current Report, the publication of the separate supplementary tables of uncertainties resulting from experimental errors and variable isotopic compositions has been discontinued and the total estimated uncertainty indicated in the following manner. When adequate information is contained in the source publication, the estimated uncertainty is taken as three times the standard deviation of the experimental measurements from which the atomic weight value is calculated, plus the maximum difference between the stated value and that for any reliably observed normal material (see Section III for exclusions). Since this treatment makes no provision for systematic errors of measurement, such errors can be dealt with only by careful scrutiny of the source information for evidence that they (unless actually determined) are negligible in comparison with the random errors. Fortunately, modern procedures applicable to the determination of atomic weights and a general awareness among practitioners of the necessity for avoiding significant systematic errors facilitate the Commission's task of exercising critical judgments of the reliability of source information. No doubt some of these judgments will be found to be wrong, as time goes on.

It has been well known to the Commission, and to many users of the Table as well, that the tabulated values have had a considerable range of reliability. To aid users in recognizing the relative reliability of a particular value, the Commission has introduced a means of discrimination designed to supplement the information supplied by the number of significant figures used for each value. If the last digit of decimals is printed in the normal-type size, the estimated total uncertainty of the value does not exceed  $\pm 1$  in that digit. If this uncertainty is between  $\pm 1$  and  $\pm 3$  units, the last digit is printed in small-sized type. If the calculated uncertainty should be larger than  $\pm 3$  in a terminal digit, the number of digits will be decreased by one.

## VI. CHANGES OF VALUES BASED ON NEW EXPERIMENTAL WORK

### Lithium

The atomic weight of lithium recommended in the 1961 revision of the Table of Atomic Weights was 6.939 and was based upon recalculation of the chemical ratios determined by Richards and Willard<sup>1</sup>. There were no calibrated determinations of the isotopic composition at that time. Recently, some mass spectrometric measurements were reported which showed that lithium was variable in isotopic composition in nature. Svec and Anderson<sup>2</sup> have reported measurements of the absolute abundance of the lithium isotopes in natural sources. From their work the atomic weight of lithium is taken as 6.941 (with a limit of  $\pm 0.002$  to account for the variability with origin and to some extent with variability introduced in purification procedures).

### Rubidium

In a recent investigation of the isotopes of rubidium, Catanzaro, Murphy, Garner and Shields<sup>3</sup> find the abundances of <sup>85</sup>Rb and <sup>87</sup>Rb to be 72.1654  $\pm$  0.0132 and 27.8346  $\pm$  0.0132 atom per cent, respectively. The formal treatment of random errors and the evidence for the exclusion of significant systematic errors justifies recommending 85.4678 as the value for the atomic weight. The atomic masses of the rubidium isotopes were taken from the current atomic mass table of Wapstra and Gove<sup>4</sup>. The new value agrees with the formerly listed value, 85.47 within its more limited precision. The earlier value was based on the comparison of rubidium chloride with silver and of rubidium bromide with silver and silver bromide by Archibald, Hooley, and Phillips, confirmed by mass spectrometric measurements by Nier (see 1961 Report).

### Lead

The isotopic composition of 'common' lead is variable because different ore bodies have received different contributions of radiogenic lead from uranium and thorium decay. In the revision of the Table of Atomic Weights in 1961, the value of 207.19 was chosen as representing lead likely to be encountered in normal laboratory work.

The isotopic compositions of lead ores from all over the world have been tabulated in three groups in an article by J. S. Brown<sup>5</sup>. World-wide,

Paleozoic to Recent: 207·220 to 207·271; World-wide, Precambrian: 207·213 to 207·293; Mississippi Valley Type Deposits: 207·198 to 207·207.

The six 'common' leads for which Catanzaro, Murphy, Shields and Garner<sup>6</sup> have published atomic weights range from 207·184 to 207·241.

In view of the rather wide range shown in these publications, the Commission recommends that the value in the Table be revised to 207·2. If a more precise atomic weight of a given specimen of lead is needed, the isotopic composition of the material must be ascertained to assist in this determination.

## VII. OTHER RECOMMENDED CHANGES IN THE TABLE

The newly adopted systematic treatment of uncertainties resulted in a large number of changes in the values published in the 1967 Table. In fact, only 27 of the 83 values in that Table remain unchanged in the new Table. The changes fall into groups as follows:

### Decreased Apparent Precision

Six values appear with a smaller number of significant figures than in 1967. These elements are hydrogen, boron, carbon, sulfur, samarium, and lead (discussed more fully in the previous section). For the first four of these, the respective uncertainties, due to natural variations in isotopic abundance, were formerly stated in a supplementary table, now discontinued: For samarium, the change resulted from a new evaluation of work previously published (see 1961 Report).

There are 28 additional elements for which the review of probable uncertainties resulted in changing the last digit from normal to small type. For five of these: oxygen, neon, silicon, iron, and copper, the uncertainties were previously stated in supplementary tables. For the remaining 23, the use of small type for the last digit provides a convenient classification of elements whose atomic weight values are considered to have an intermediate degree of reliability between that implied by the use of a given number of significant figures as opposed to the use of one fewer digit. Apart from the warning to users of the Table suggested by this classification, it is to be hoped that the need for new determinations for several elements will thereby be made apparent. The 23 elements in the group are: argon, potassium, titanium, nickel, zinc, germanium, selenium, molybdenum, ruthenium, tin, antimony, tellurium, barium, neodymium, gadolinium, dysprosium, erbium, ytterbium, hafnium, wolfram (tungsten), platinum, mercury, and thallium.

In this connection, attention should also be drawn to four elements whose atomic weights are now stated to only a single decimal place. They are palladium, samarium, osmium, and rhenium.

### Increased Precision

The values for the following 20 elements are given in the 1969 Table with a larger number of significant figures than in the 1967 Table: helium, beryllium, scandium, vanadium, rubidium, yttrium, niobium, rhodium, caesium, lanthanum, praseodymium, terbium, holmium, thulium, tantalum, iridium, gold, bismuth, thorium and uranium.

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Of the foregoing, 13 are mononuclidic elements whose atomic weights, in the absence of known natural isotopes, can be considered identical with the atomic masses of the only known naturally occurring nuclides of the respective elements. These atomic masses can be determined much more precisely than can the atomic weights of polynuclidic elements. In the 1969 Table these values are uniformly given to four decimal places, except for beryllium for which a comparable precision requires that five decimal places be used.

For the remaining elements, except helium, rubidium and uranium, the added digit is in small type. Of these exceptions, the value for rubidium shows two additional digits; the second is in small type.

### VIII. NEW LISTINGS

In recent years, the International Table has not included values for the atomic weights of radioactive elements, except thorium and uranium, on the ground that they were seldom encountered in laboratory practice. Because this situation is changing, atomic weight values appear in the 1969 Table for four other radioactive elements that are now technologically important in the form of single nuclidic species. They are technetium-99, radium-226, protactinium-231, and neptunium-237. This is considered to be a desirable departure from the previous general rule of omitting atomic weight values for radioactive elements.

### IX. DISCUSSION OF FOOTNOTES TO THE TABLE OF ATOMIC WEIGHTS

Many of the values in the Table are referenced to one or more of seven footnotes that provide information that is of special interest or significance. These footnotes should invariably be included when the Table is reprinted in text, or reference books or related publications.

*Footnote a: 'Mononuclidic element'*

This footnote implies great accuracy of atomic weight value, as has been discussed in this and previous Commission reports (see for example, that for 1961). (See also comment in paragraph 2 of Section XI.)

*Footnote b: 'Element with one predominant isotope (about 99–100% abundance)'*

The implication of this footnote is that errors or variations in relative abundance measurements will have a rather small effect on the atomic weight values.

*Footnote c: 'Element for which the atomic weight is based on calibrated measurements'*

This footnote implies confidence in reliability of atomic weight value through careful physical measurements based on comparisons with synthetic mixtures of almost pure isotopes. To this date, the only atomic weight values that in the Commission's judgment qualify for this annotation have been derived from mass spectrometry.

*Footnote d: 'Element for which variation in isotopic abundance in terrestrial samples limits the precision of the atomic weight given'*

Whereas at the present time only a few atomic weights of lighter elements (and those of copper and lead) are qualified by this footnote, one must

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expect an ever increasing number of atomic weight values to require this annotation. This trend is a natural consequence of greater precision of experimental determination and of progressively increasing information on variable isotopic composition of normal materials. It is most difficult to assess the reliability of many atomic weight values in the absence of good information on isotopic variability. The Commission has been conscious of the possible systematic errors that may be involved. Germanium is an example of such an element, which for this or other reasons is likely to need an upward adjustment when better data become available. It is, however, a well established principle of the Commission to revise values only on the basis of published work that in the judgment of the Commission advances significantly the confidence to be placed in the value.

*Footnote e: 'Element for which users are cautioned against the possibility of large variations in atomic weight due to inadvertent or undisclosed artificial isotopic separation in commercially available materials'*

The seriousness of the hazard must be stressed for users of atomic weight values qualified by footnote *e*. The atomic weight values given in the Table are neither adjusted nor is their implied accuracy limited to include significant human interference in isotopic abundance. Suppliers of an otherwise well characterized chemical containing as a major constituent one of the elements so annotated should consider the desirability of either supplying the relevant atomic weight value or certifying the virgin source of the raw material plus a statement of the extent to which subsequent processing is expected to have changed the isotopic abundance.

In this Report this footnote applies only to lithium, boron, and uranium. It can be foreseen, however, that advancing technology will gradually introduce such complications for other elements. Time is not far off, for example, when fission products will be introduced into normal trade. The Commission on Atomic Weights clearly must keep this situation under careful and continuing review.

*Footnote f: 'Most commonly available long-lived isotope; see Table of Selected Radioactive Isotopes'*

The situation described by footnote *f* is similar in effect to that covered by footnote *e*. The user is warned that materials containing this element may display an unusual atomic weight value. Whereas for footnote *e*, such material arose through isotopic separation, footnote *f* concerns materials with differing histories of radioactive, fission, or other nuclear processes. Footnote *f* concerns developments that will become more critical with continuing advance of nuclear technology.

*Footnote g: 'In some geological specimens this element has a highly anomalous isotopic composition, corresponding to an atomic weight significantly different from that given'*

The significance of this footnote is clear, and its application to lead and strontium (from rubidium-containing geological sources) is not difficult to justify.

The Commission must attempt to state the atomic weight values so that they are as precise as possible. At the same time, they must be sufficiently imprecise so that all normal specimens fall within the implied tolerance

range. In other words, large quantities of available materials should not lie outside the tolerance range. The difficult judgment has to be made when only a small fraction of normal material falls outside the tolerance range. The Commission has decided in such cases not to discard useful accuracy applicable to the great majority of practical conditions, but to exclude from the definition of 'normal', geological oddities.

## X. SELECTED RADIOACTIVE ISOTOPES

In addition to its primary purpose of providing internationally recommended values for atomic weights, the International Table is also useful as a convenient listing of the names, symbols, and atomic numbers of all the chemical elements. For this reason, it is included in many chemical textbooks and handbooks. In the International Table, atomic weights are given only for those radioactive elements, whether natural or artificial, that are important in chemical technology and for which such an atomic weight is, in practice at least, unique. The radioactive elements are also listed in a supplemental table that provides current information on the half-lives of selected isotopes, together with the modes of disintegration of these isotopes. The supplemental table is updated in each biennial report. In the 1969 Report, the Commission has introduced, on an experimental basis, one innovation: where more than one isotope of a radioactive element is held to be of technical importance, each has been listed.

For the updating of this table, the Commission is particularly grateful to colleagues of J. Spaepen at the Geel Laboratories of Euratom and to A. Spornol in particular who carried out the literature compilation which can be obtained by request from the Commission Secretary.

The values of the half-lives are in general uncertain to  $\pm 1$  in the last given digit. If this last digit is set in small type, the estimated uncertainty is  $\pm 3$  in this digit.

## XI. ATOMIC MASSES OF SELECTED ISOTOPES

Certain of the chemical elements, as obtained from commercial sources, are likely to have isotopic compositions that differ markedly from those in natural sources. Notable examples are lithium, boron, and uranium. If either the isotopic composition or the atomic weight is a matter of concern, users of these elements should measure or otherwise ascertain the isotopic composition of the material at hand. Atomic weights can be calculated by using the supplemental Table of Atomic Masses of the pertinent isotopes. The relevant figures are taken from A. H. Wapstra, C. Kurzeck, and A. Anisimoff<sup>7</sup> for heavy nuclides, and from A. H. Wapstra and N. B. Gove<sup>4</sup> for other atomic masses.

By the data from Wapstra *et al.*<sup>4, 7</sup> and the error analyses of these authors there is in most cases a little additional accuracy which is being disregarded in the tables in this Report. Users requiring the greatest available accuracy in atomic mass values should therefore consult the referenced papers.

When these values are used as intended, that is for the atomic weights of elements, there exists the possibility of small systematic error from undiscovered stable isotopes present in very small amounts.

## XII. NEW TECHNIQUES FOR ATOMIC WEIGHT DETERMINATIONS

The Commission has set itself the task to keep currently informed on a number of new physical and physical-chemical techniques that may lead to significant atomic weight determinations.

At the current session, it heard a discussion by one of its members, Dr Shizuo Fujiwara, on his atomic mass determination of  $^{40}\text{Ar}$  by ion cyclotron resonance. This work is at least close to being limited by uncertainties in the accuracy of the available values of fundamental physical constants such as Avogadro's Number, the magnetic dipole moment of the proton, etc. The atomic mass value could thus be used alternatively to help refine the fundamental constants.

Even for the evaluation of isotopic abundances resonance methods may become applicable. The Commission therefore looks forward to active future developments in atomic weight evaluations by possible significant challenges from a diversity of methods.

## XIII. ERRATUM IN TABLE OF ATOMIC WEIGHTS 1967

In the 1967 Table [Comptes Rendus XXIV Conference, IUPAC, 1967; *Pure Appl. Chem.* **18**, 569 (1969)], the uncertainty relating to the value for copper was erroneously entered in the list of experimental uncertainties (footnote b). It should have been entered among the uncertainties governed by variations in natural abundances (footnote a). The reference in the table at the copper value was correctly given to footnote a.

# XIV. Table of Atomic Weights 1969. Alphabetical Order in English

Based on the Assigned Relative Atomic Mass of  $^{12}\text{C} = 12$

The values 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  $\pm 1$  in the last digit, or  $\pm 3$  if that digit is in small type.

Name	Symbol	Atomic Number	Atomic Weight	Name	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89		Mercury	Hg	80	200.59
Aluminium	Al	13	26.9815 <sup>a</sup>	Molybdenum	Mo	42	95.94
Americium	Am	95		Neodymium	Nd	60	144.24
Antimony	Sb	51	121.75	Neon	Ne	10	20.179 <sup>c</sup>
Argon	Ar	18	39.948 <sup>b,c,d,g</sup>	Neptunium	Np	93	237.0482 <sup>b,t</sup>
Arsenic	As	33	74.9216 <sup>a</sup>	Nickel	Ni	28	58.71
Astatine	At	85		Niobium	Nb	41	92.9064 <sup>a</sup>
Barium	Ba	56	137.34	Nitrogen	N	7	14.0067 <sup>b,c</sup>
Berkelium	Bk	97		Nobelium	No	102	
Beryllium	Be	4	9.01218 <sup>a</sup>	Osmium	Os	76	190.2
Bismuth	Bi	83	208.9806 <sup>a</sup>	Oxygen	O	8	15.9994 <sup>b,c,d</sup>
Boron	B	5	10.81 <sup>c,d,e</sup>	Palladium	Pd	46	106.4
Bromine	Br	35	79.904 <sup>c</sup>	Phosphorus	P	15	30.9738 <sup>a</sup>
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.09
Caesium	Cs	55	132.9055 <sup>a</sup>	Plutonium	Pu	94	
Calcium	Ca	20	40.08	Polonium	Po	84	
Californium	Cf	98		Potassium	K	19	39.102
Carbon	C	6	12.011 <sup>b,d</sup>	Praseodymium	Pr	59	140.9077 <sup>a</sup>
Cerium	Ce	58	140.12	Promethium	Pm	61	
Chlorine	Cl	17	35.453 <sup>c</sup>	Protactinium	Pa	91	231.0359 <sup>a,t</sup>
Chromium	Cr	24	51.996 <sup>c</sup>	Radium	Ra	88	226.0254 <sup>a,t,g</sup>
Cobalt	Co	27	58.9332 <sup>a</sup>	Radon	Rn	86	
Copper	Cu	29	63.546 <sup>c,d</sup>	Rhenium	Re	75	186.2
Curium	Cm	96		Rhodium	Rh	45	102.9055 <sup>a</sup>
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.4678 <sup>c</sup>
Einsteinium	Es	99		Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Samarium	Sm	62	150.4
Europium	Eu	63	151.96	Scandium	Sc	21	44.9559 <sup>a</sup>
Fermium	Fm	100		Selenium	Se	34	78.96
Fluorine	F	9	18.9984 <sup>a</sup>	Silicon	Si	14	28.086 <sup>d</sup>
Francium	Fr	87		Silver	Ag	47	107.868 <sup>c</sup>
Gadolinium	Gd	64	157.25	Sodium	Na	11	22.9898 <sup>a</sup>
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62 <sup>g</sup>
Germanium	Ge	32	72.59	Sulfur	S	16	32.06 <sup>d</sup>
Gold	Au	79	196.9665 <sup>a</sup>	Tantalum	Ta	73	180.9479 <sup>b</sup>
Hafnium	Hf	72	178.49	Technetium	Tc	43	98.9062 <sup>t</sup>
Helium	He	2	4.00260 <sup>b,c</sup>	Tellurium	Te	52	127.60
Holmium	Ho	67	164.9303 <sup>a</sup>	Terbium	Tb	65	158.9254 <sup>a</sup>
Hydrogen	H	1	1.0080 <sup>b,d</sup>	Thallium	Tl	81	204.37
Indium	In	49	114.82	Thorium	Th	90	232.0381 <sup>a,t</sup>
Iodine	I	53	126.9045 <sup>a</sup>	Thulium	Tm	69	168.9342 <sup>a</sup>
Iridium	Ir	77	192.22	Tin	Sn	50	118.69
Iron	Fe	26	55.847	Titanium	Ti	22	47.90
Krypton	Kr	36	83.80	Tungsten	W	74	183.85
Lanthanum	La	57	138.9055 <sup>b</sup>	Uranium	U	92	238.029 <sup>b,e,e</sup>
Lawrencium	Lr	103		Vanadium	V	23	50.9414 <sup>b,c</sup>
Lead	Pb	82	207.2 <sup>d,g</sup>	Wolfram	W	74	183.85
Lithium	Li	3	6.941 <sup>c,d,e</sup>	Xenon	Xe	54	131.30
Lutetium	Lu	71	174.97	Ytterbium	Yb	70	173.04
Magnesium	Mg	12	24.305 <sup>c</sup>	Yttrium	Y	39	88.9059 <sup>a</sup>
Manganese	Mn	25	54.9380 <sup>a</sup>	Zinc	Zn	30	65.37
Mendelevium	Md	101		Zirconium	Zr	40	91.22

<sup>a</sup> Mononuclidic element.

<sup>b</sup> Element with one predominant isotope (about 99–100% abundance).

<sup>c</sup> Element for which the atomic weight is based on calibrated measurements.

<sup>d</sup> Element for which variation in isotopic abundance in terrestrial samples limits the precision of the atomic weight given.

<sup>e-g</sup> See page 012 for these footnotes.

## XV. Table of Atomic Weights 1969. Order of Atomic Number

Based on the Assigned Relative Atomic Mass of  $^{12}\text{C} = 12$

The values 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  $\pm 1$  in the last digit or  $\pm 3$  if that digit is in small type

Atomic Number	Name	Symbol	Atomic Weight	Atomic Number	Name	Symbol	Atomic Weight
1	Hydrogen	H	1.0080 <sup>b,d</sup>	53	Iodine	I	126.9045 <sup>a</sup>
2	Helium	He	4.00260 <sup>b,c</sup>	54	Xenon	Xe	131.30
3	Lithium	Li	6.941 <sup>c,d,e</sup>	55	Cesium	Cs	132.9055 <sup>a</sup>
4	Beryllium	Be	9.01218 <sup>a</sup>	56	Barium	Ba	137.34
5	Boron	B	10.81 <sup>c,d,e</sup>	57	Lanthanum	La	138.9055 <sup>b</sup>
6	Carbon	C	12.011 <sup>b,d</sup>	58	Cerium	Ce	140.12
7	Nitrogen	N	14.0067 <sup>b,c</sup>	59	Praseodymium	Pr	140.9077 <sup>a</sup>
8	Oxygen	O	15.9994 <sup>b,c,d</sup>	60	Neodymium	Nd	144.24
9	Fluorine	F	18.9984 <sup>a</sup>	61	Promethium	Pm	
10	Neon	Ne	20.179 <sup>c</sup>	62	Samarium	Sm	150.4
11	Sodium	Na	22.9898 <sup>a</sup>	63	Europium	Eu	151.96
12	Magnesium	Mg	24.305 <sup>c</sup>	64	Gadolinium	Gd	157.25
13	Aluminium	Al	26.9815 <sup>a</sup>	65	Terbium	Tb	158.9254 <sup>a</sup>
14	Silicon	Si	28.086 <sup>d</sup>	66	Dysprosium	Dy	162.50
15	Phosphorus	P	30.9738 <sup>a</sup>	67	Holmium	Ho	164.9303 <sup>a</sup>
16	Sulfur	S	32.06 <sup>d</sup>	68	Erbium	Er	167.26
17	Chlorine	Cl	35.453 <sup>c</sup>	69	Thulium	Tm	168.9342 <sup>a</sup>
18	Argon	Ar	39.948 <sup>b,c,d,g</sup>	70	Ytterbium	Yb	173.04
19	Potassium	K	39.102	71	Lutetium	Lu	174.97
20	Calcium	Ca	40.08	72	Hafnium	Hf	178.49
21	Scandium	Sc	44.9559 <sup>a</sup>	73	Tantalum	Ta	180.9479 <sup>b</sup>
22	Titanium	Ti	47.90	74	Wolfram (Tungsten)	W	183.85
23	Vanadium	V	50.9414 <sup>b,c</sup>	75	Rhenium	Re	186.2
24	Chromium	Cr	51.996 <sup>c</sup>	76	Osmium	Os	190.2
25	Manganese	Mn	54.9380 <sup>a</sup>	77	Iridium	Ir	192.22
26	Iron	Fe	55.847	78	Platinum	Pt	195.09
27	Cobalt	Co	58.9332 <sup>a</sup>	79	Gold	Au	196.9665 <sup>a</sup>
28	Nickel	Ni	58.71	80	Mercury	Hg	200.59
29	Copper	Cu	63.546 <sup>c,d</sup>	81	Thallium	Tl	204.37
30	Zinc	Zn	65.37	82	Lead	Pb	207.2 <sup>d,g</sup>
31	Gallium	Ga	69.72	83	Bismuth	Bi	208.9806 <sup>a</sup>
32	Germanium	Ge	72.59	84	Polonium	Po	
33	Arsenic	As	74.9216 <sup>b</sup>	85	Astatine	At	
34	Selenium	Se	78.96	86	Radon	Rn	
35	Bromine	Br	79.904 <sup>c</sup>	87	Francium	Fr	
36	Krypton	Kr	83.80	88	Radium	Ra	226.0254 <sup>a,t,g</sup>
37	Rubidium	Rb	85.4678 <sup>c</sup>	89	Actinium	Ac	
38	Strontium	Sr	87.62 <sup>g</sup>	90	Thorium	Th	232.0381 <sup>a,t</sup>
39	Yttrium	Y	88.9059 <sup>a</sup>	91	Protactinium	Pa	231.0359 <sup>a,t</sup>
40	Zirconium	Zr	91.22	92	Uranium	U	238.029 <sup>b,c,e</sup>
41	Niobium	Nb	92.9064 <sup>a</sup>	93	Neptunium	Np	237.0482 <sup>b,t</sup>
42	Molybdenum	Mo	95.94	94	Plutonium	Pu	
43	Technetium	Tc	98.9062 <sup>f</sup>	95	Americium	Am	
44	Ruthenium	Ru	101.07	96	Curium	Cm	
45	Rhodium	Rh	102.9055 <sup>a</sup>	97	Berkelium	Bk	
46	Palladium	Pd	106.4	98	Californium	Cf	
47	Silver	Ag	107.868 <sup>c</sup>	99	Einsteinium	Es	
48	Cadmium	Cd	112.40	100	Fermium	Fm	
49	Indium	In	114.82	101	Mendelevium	Md	
50	Tin	Sn	118.69	102	Nobelium	No	
51	Antimony	Sb	121.75	103	Lawrencium	Lr	
52	Tellurium	Te	127.60				

<sup>a-d</sup> See page 011 for these footnotes.

<sup>e</sup> Element for which users are cautioned against the possibility of large variations in atomic weight due to inadvertent or undisclosed artificial isotopic separation in commercially available materials.

<sup>f</sup> Most commonly available long-lived isotope; see "Table of Selected Radioactive Isotopes."

<sup>g</sup> In some geological specimens this element has a highly anomalous isotopic composition, corresponding to an atomic weight significantly different from that given.

# XVI. Table of Selected Radioactive Isotopes

## Order of Atomic Number

This table lists selected isotopes of the chemical elements, whether occurring in nature or known only through synthesis, that are commonly classed as radioactive. The listed isotopes include the one of longest known half-life and others of recognized interest. Decay modes with intensities below 0.01% are not mentioned.

<i>Atomic Number</i>	<i>Name</i>	<i>Symbol</i>	<i>Isotope</i>	<i>Half-Life*</i>	<i>Decay Mode†</i>
43	Technetium	Tc	97	2.6 . 10 <sup>6</sup> y	EC
43	Technetium	Tc	99	2.14 . 10 <sup>5</sup> y	β <sup>-</sup>
61	Promethium	Pm	145	18.0 y	EC
61	Promethium	Pm	147	2.62 y	β <sup>-</sup>
84	Polonium	Po	209	1.0 . 10 <sup>2</sup> y	α, EC
84	Polonium	Po	210	138.4 d	α
85	Astatine	At	210	8.3 h	EC, α
86	Radon	Rn	222	3.82 d	α
87	Francium	Fr	223	22 m	β <sup>-</sup>
88	Radium	Ra	226	1.60 . 10 <sup>3</sup> y	α
89	Actinium	Ac	227	21.8 y	β <sup>-</sup> , α
90	Thorium	Th	232	1.41 . 10 <sup>10</sup> y	α
91	Protactinium	Pa	231	3.26 . 10 <sup>4</sup> y	α
92	Uranium	U	233	1.60 . 10 <sup>5</sup> y	α
92	Uranium	U	234	2.47 . 10 <sup>5</sup> y	α
92	Uranium	U	235	7.0 . 10 <sup>8</sup> y	α
92	Uranium	U	238	4.5 . 10 <sup>9</sup> y	α
93	Neptunium	Np	237	2.14 . 10 <sup>6</sup> y	α
94	Plutonium	Pu	238	87 y	α
94	Plutonium	Pu	239	24.3 . 10 <sup>3</sup> y	α
94	Plutonium	Pu	240	6.6 . 10 <sup>3</sup> y	α
94	Plutonium	Pu	241	14.2 y	β <sup>-</sup>
94	Plutonium	Pu	242	3.86 . 10 <sup>5</sup> y	α
94	Plutonium	Pu	244	8.2 . 10 <sup>7</sup> y	α, s.f.
95	Americium	Am	241	435 y	α
95	Americium	Am	243	7.4 . 10 <sup>3</sup> y	α
96	Curium	Cm	242	164 d	α
96	Curium	Cm	243	3.2 y	α, EC
96	Curium	Cm	244	18.1 y	α
96	Curium	Cm	245	8.3 . 10 <sup>3</sup> y	α
96	Curium	Cm	246	4.7 . 10 <sup>3</sup> y	α, s.f.
96	Curium	Cm	247	1.6 . 10 <sup>7</sup> y	α
96	Curium	Cm	248	3.5 . 10 <sup>5</sup> y	α, s.f.
96	Curium	Cm	250	1.1 . 10 <sup>4</sup> y	s.f.
97	Berkelium	Bk	247	1.4 . 10 <sup>3</sup> y	α
97	Berkelium	Bk	249	3.1 . 10 <sup>2</sup> d	β <sup>-</sup>
98	Californium	Cf	251	900 y	α
98	Californium	Cf	252	2.64 y	α, s.f.
98	Californium	Cf	254	60.5 d	s.f. α
99	Einsteinium	Es	253	20 d	α
99	Einsteinium	Es	254	2.7 . 10 <sup>2</sup> d	α
100	Fermium	Fm	257	80 d	α, s.f.
101	Mendelevium	Md	257	3.0 h	EC, α, s.f.
101	Mendelevium	Md	258	54 d	EC, α, s.f.
102	Nobelium	No	255	185 s	α, EC
103	Lawrencium	Lr	256	35 s	α

\* s, second; m, minute; h, hour; d, day; y, year

† EC, electron capture; s.f., spontaneous fission

## XVII. Table of Atomic Masses of Selected Isotopes

<i>Name</i>	<i>Symbol</i>	<i>Atomic Number</i>	<i>Mass Number</i>	<i>Atomic Mass</i>
Hydrogen	H	1	1	1-00782
Deuterium	D	1	2	2-01410
Tritium	T	1	3	3-01605
Helium	He	2	3	3-01603
			4	4-00260
Lithium	Li	3	6	6-01512
			7	7-01600
Boron	B	5	10	10-0129
			11	11-0093
Carbon	C	6	12	12 exactly
			13	13-0034
			14	14-0032
Nitrogen	N	7	14	14-0031
			15	15-0001
Oxygen	O	8	16	15-9949
			17	16-9991
			18	17-9992
Sulfur	S	16	32	31-9721
			33	32-9715
			34	33-9679
			36	35-9671
Promethium	Pm	61	143	142-9110
			145	144-9128
			147	146-9152
Lead	Pb	82	204	203-9731
			206	205-9745
			207	206-9759
			208	207-9766
Uranium	U	92	233	233-0396
			234	234-0410
			235	235-0439
			236	236-0456
			238	238-0508
Plutonium	Pu	94	238	238-0496
			239	239-0522
			240	240-0538
			241	241-0569
			242	242-0588
			244	244-0642
Curium	Cm	96	242	242-0589
			244	244-0628
			246	246-0672
			247	247-0704
			248	248-0724

## XVIII. References

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