INTERNATIONAL UNION OF
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DIVISION OF INORGANIC CHEMISTRY
COMMISSION ON ATOMIC WEIGHTS

# ATOMIC WEIGHTS OF THE ELEMENTS 1969

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# CONTENTS

## 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.

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† 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 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 $^{12}C$ atom; that is, by $1{\cdot}660\,432 \times 10^{-27}$ 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 consituent 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 ± 1 in that digit. If this uncertainty is between ± 1 and ± 3 units, the last digit is printed in small-sized type. If the calculated uncertainty should be larger than ± 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[1]. 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[2] 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 ± 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[3] find the abundances of $^{85}$Rb and $^{87}$Rb to be 72·1654 ± 0·0132 and 27·8346 ± 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[4]. 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[5]. 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[6] 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.

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 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. Spernol 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 ±1 in the last given digit. If this last digit is set in small type, the estimated uncertainty is ±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[7] for heavy nuclides, and from A. H. Wapstra and N. B. Gove[4] for other atomic masses.

By the data from Wapstra *et al.*[4, 7] 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 $^{40}$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 $^{12}C = 12$

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 ± 1 in the last digit, or ± 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[a] | Molybdenum | Mo | 42 | 95·94 |
| Americium | Am | 95 | | Neodymium | Nd | 60 | 144·24 |
| Antimony | Sb | 51 | 121·75 | Neon | Ne | 10 | 20·179[c] |
| Argon | Ar | 18 | 39·948[b,c,d,g] | Neptunium | Np | 93 | 237·0482[b,f] |
| Arsenic | As | 33 | 74·9216[a] | Nickel | Ni | 28 | 58·71 |
| Astatine | At | 85 | | Niobium | Nb | 41 | 92·9064[a] |
| Barium | Ba | 56 | 137·34 | 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 | 208·9806[a] | Oxygen | O | 8 | 15·9994[b,c,d] |
| Boron | B | 5 | 10·81[c,d,e] | Palladium | Pd | 46 | 106·4 |
| Bromine | Br | 35 | 79·904[c] | Phosphorus | P | 15 | 30·9738[a] |
| Cadmium | Cd | 48 | 112·40 | Platinum | Pt | 78 | 195·09 |
| Caesium | Cs | 55 | 132·9055[a] | Plutonium | Pu | 94 | |
| Calcium | Ca | 20 | 40·08 | Polonium | Po | 84 | |
| Californium | Cf | 98 | | Potassium | K | 19 | 39·102 |
| Carbon | C | 6 | 12·011[b,d] | Praseodymium | Pr | 59 | 140·9077[a] |
| Cerium | Ce | 58 | 140·12 | Promethium | Pm | 61 | |
| Chlorine | Cl | 17 | 35·453[c] | Protactinium | Pa | 91 | 231·0359[a,f] |
| Chromium | Cr | 24 | 51·996[c] | Radium | Ra | 88 | 226·0254[a,f,g] |
| Cobalt | Co | 27 | 58·9332[a] | Radon | Rn | 86 | |
| Copper | Cu | 29 | 63·546[c,d] | Rhenium | Re | 75 | 186·2 |
| Curium | Cm | 96 | | Rhodium | Rh | 45 | 102·9055[a] |
| Dysprosium | Dy | 66 | 162·50 | Rubidium | Rb | 37 | 85·4678[c] |
| 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[a] |
| Fermium | Fm | 100 | | Selenium | Se | 34 | 78·96 |
| Fluorine | F | 9 | 18·9984[a] | Silicon | Si | 14 | 28·086[d] |
| Francium | Fr | 87 | | Silver | Ag | 47 | 107·868[c] |
| Gadolinium | Gd | 64 | 157·25 | Sodium | Na | 11 | 22·9898[a] |
| Gallium | Ga | 31 | 69·72 | Strontium | Sr | 38 | 87·62[g] |
| Germanium | Ge | 32 | 72·59 | Sulfur | S | 16 | 32·06[d] |
| Gold | Au | 79 | 196·9665[a] | Tantalum | Ta | 73 | 180·9479[b] |
| Hafnium | Hf | 72 | 178·49 | Technetium | Tc | 43 | 98·9062[f] |
| Helium | He | 2 | 4·00260[b,c] | Tellurium | Te | 52 | 127·60 |
| Holmium | Ho | 67 | 164·9303[a] | Terbium | Tb | 65 | 158·9254[a] |
| Hydrogen | H | 1 | 1·0080[b,d] | Thallium | Tl | 81 | 204·37 |
| Indium | In | 49 | 114·82 | Thorium | Th | 90 | 232·0381[a,f] |
| Iodine | I | 53 | 126·9045[a] | Thulium | Tm | 69 | 168·9342[a] |
| 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[b] | Uranium | U | 92 | 238·029[b,c,e] |
| Lawrencium | Lr | 103 | | Vanadium | V | 23 | 50·9414[b,c] |
| Lead | Pb | 82 | 207·2[d,g] | Wolfram | W | 74 | 183·85 |
| Lithium | Li | 3 | 6·941[c,d,e] | Xenon | Xe | 54 | 131·30 |
| Lutetium | Lu | 71 | 174·97 | Ytterbium | Yb | 70 | 173·04 |
| Magnesium | Mg | 12 | 24·305[c] | Yttrium | Y | 39 | 88·9059[a] |
| Manganese | Mn | 25 | 54·9380[a] | Zinc | Zn | 30 | 65·37 |
| Mendelevium | Md | 101 | | Zirconium | Zr | 40 | 91·22 |

[a] Mononuclidic element.

[b] Element with one predominant isotope (about 99–100% abundance).

[c] Element for which the atomic weight is based on calibrated measurements.

[d] Element for which variation in isotopic abundance in terrestrial samples limits the precision of the atomic weight given.

[e–g] See page 012 for these footnotes.

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

Based on the Assigned Relative Atomic Mass of $^{12}C$ = 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 ± 1 in the last digit or ± 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[b,d] | 53 | Iodine | I | 126·9045[a] |
| 2 | Helium | He | 4·00260[b,c] | 54 | Xenon | Xe | 131·30 |
| 3 | Lithium | Li | 6·941[c,d,e] | 55 | Caesium | Cs | 132·9055[a] |
| 4 | Beryllium | Be | 9·01218[a] | 56 | Barium | Ba | 137·34 |
| 5 | Boron | B | 10·81[c,d,e] | 57 | Lanthanum | La | 138·9055[b] |
| 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 | 15·9994[b,c,d] | 60 | Neodymium | Nd | 144·24 |
| 9 | Fluorine | F | 18·9984[a] | 61 | Promethium | Pm | |
| 10 | Neon | Ne | 20·179[c] | 62 | Samarium | Sm | 150·4 |
| 11 | Sodium | Na | 22·9898[a] | 63 | Europium | Eu | 151·96 |
| 12 | Magnesium | Mg | 24·305[c] | 64 | Gadolinium | Gd | 157·25 |
| 13 | Aluminium | Al | 26·9815[a] | 65 | Terbium | Tb | 158·9254[a] |
| 14 | Silicon | Si | 28·086[d] | 66 | Dysprosium | Dy | 162·50 |
| 15 | Phosphorus | P | 30·9738[a] | 67 | Holmium | Ho | 164·9303[a] |
| 16 | Sulfur | S | 32·06[d] | 68 | Erbium | Er | 167·26 |
| 17 | Chlorine | Cl | 35·453[c] | 69 | Thulium | Tm | 168·9342[a] |
| 18 | Argon | Ar | 39·948[b,c,d,g] | 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[a] | 73 | Tantalum | Ta | 180·9479[b] |
| 22 | Titanium | Ti | 47·90 | 74 | Wolfram (Tungsten) | W | 183·85 |
| 23 | Vanadium | V | 50·9414[b,c] | 75 | Rhenium | Re | 186·2 |
| 24 | Chromium | Cr | 51·996[c] | 76 | Osmium | Os | 190·2 |
| 25 | Manganese | Mn | 54·9380[a] | 77 | Iridium | Ir | 192·22 |
| 26 | Iron | Fe | 55·847 | 78 | Platinum | Pt | 195·09 |
| 27 | Cobalt | Co | 58·9332[a] | 79 | Gold | Au | 196·9665[a] |
| 28 | Nickel | Ni | 58·71 | 80 | Mercury | Hg | 200·59 |
| 29 | Copper | Cu | 63·546[c,d] | 81 | Thallium | Tl | 204·37 |
| 30 | Zinc | Zn | 65·37 | 82 | Lead | Pb | 207·2[d,g] |
| 31 | Gallium | Ga | 69·72 | 83 | Bismuth | Bi | 208·9806[a] |
| 32 | Germanium | Ge | 72·59 | 84 | Polonium | Po | |
| 33 | Arsenic | As | 74·9216[a] | 85 | Astatine | At | |
| 34 | Selenium | Se | 78·96 | 86 | Radon | Rn | |
| 35 | Bromine | Br | 79·904[c] | 87 | Francium | Fr | |
| 36 | Krypton | Kr | 83·80 | 88 | Radium | Ra | 226·0254[a,f,g] |
| 37 | Rubidium | Rb | 85·4678[c] | 89 | Actinium | Ac | |
| 38 | Strontium | Sr | 87·62[g] | 90 | Thorium | Th | 232·0381[a,f] |
| 39 | Yttrium | Y | 88·9059[a] | 91 | Protactinium | Pa | 231·0359[a,f] |
| 40 | Zirconium | Zr | 91·22 | 92 | Uranium | U | 238·029[b,c,e] |
| 41 | Niobium | Nb | 92·9064[a] | 93 | Neptunium | Np | 237·0482[b,f] |
| 42 | Molybdenum | Mo | 95·94 | 94 | Plutonium | Pu | |
| 43 | Technetium | Tc | 98·9062[f] | 95 | Americium | Am | |
| 44 | Ruthenium | Ru | 101·07 | 96 | Curium | Cm | |
| 45 | Rhodium | Rh | 102·9055[a] | 97 | Berkelium | Bk | |
| 46 | Palladium | Pd | 106·4 | 98 | Californium | Cf | |
| 47 | Silver | Ag | 107·868[c] | 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 | | | | |

[a–d] See page 011 for these footnotes.

[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.

[f] Most commonly available long-lived isotope; see 'Table of Selected Radioactive Isotopes.'

[g] 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.

| *Atomic Number* | *Name* | *Symbol* | *Isotope* | *Half-Life** | *Decay Mode†* |
|---|---|---|---|---|---|
| 43 | Technetium | Tc | 97 | 2·6 . $10^{6}$ y | EC |
| 43 | Technetium | Tc | 99 | 2·14 . $10^{5}$ y | $\beta^-$ |
| 61 | Promethium | Pm | 145 | 18·0 y | EC |
| 61 | Promethium | Pm | 147 | 2·62 y | $\beta^-$ |
| 84 | Polonium | Po | 209 | 1·0 . $10^{2}$ 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 | $\beta^-$ |
| 88 | Radium | Ra | 226 | 1·60 . $10^{3}$ y | α |
| 89 | Actinium | Ac | 227 | 21·8 y | $\beta^-$, α |
| 90 | Thorium | Th | 232 | 1·41 . $10^{10}$y | α |
| 91 | Protactinium | Pa | 231 | 3·26 . $10^{4}$ y | α |
| 92 | Uranium | U | 233 | 1·60 . $10^{5}$ y | α |
| 92 | Uranium | U | 234 | 2·47 . $10^{5}$ y | α |
| 92 | Uranium | U | 235 | 7·0 . $10^{8}$ y | α |
| 92 | Uranium | U | 238 | 4·5 . $10^{9}$ y | α |
| 93 | Neptunium | Np | 237 | 2·14 . $10^{6}$ y | α |
| 94 | Plutonium | Pu | 238 | 87 y | α |
| 94 | Plutonium | Pu | 239 | 24·3 . $10^{3}$ y | α |
| 94 | Plutonium | Pu | 240 | 6·6 . $10^{3}$ y | α |
| 94 | Plutonium | Pu | 241 | 14·2 y | $\beta^-$ |
| 94 | Plutonium | Pu | 242 | 3·86 . $10^{5}$ y | α |
| 94 | Plutonium | Pu | 244 | 8·2 . $10^{7}$ y | α, s.f. |
| 95 | Americium | Am | 241 | 435 y | α |
| 95 | Americium | Am | 243 | 7·4 . $10^{3}$ y | α |
| 96 | Curium | Cm | 242 | 164 d | α |
| 96 | Curium | Cm | 243 | 32 y | α, EC |
| 96 | Curium | Cm | 244 | 18·1 y | α |
| 96 | Curium | Cm | 245 | 8·3 . $10^{3}$ y | α |
| 96 | Curium | Cm | 246 | 4·7 . $10^{3}$ y | α, s.f. |
| 96 | Curium | Cm | 247 | 1·6 . $10^{7}$ y | α |
| 96 | Curium | Cm | 248 | 3·5 · $10^{5}$ y | α, s.f. |
| 96 | Curium | Cm | 250 | 1·1 . $10^{4}$ y | s.f. |
| 97 | Berkelium | Bk | 247 | 1·4 . $10^{3}$ y | α |
| 97 | Berkelium | Bk | 249 | 3·1 . $10^{2}$ d | $\beta^-$ |
| 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 . $10^{2}$ 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

| *Name* | *Symbol* | *Atomic Number* | *Mass Number* | *Atomic Mass* |
|---|---|---|---|---|
| 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 |

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