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COMMISSION ON ATOMIC WEIGHTS AND ISOTOPIC ABUNDANCES*

ATOMIC WEIGHTS OF THE ELEMENTS 1983

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Abstract – The biennial review of atomic weight, $A_r(E)$, determinations
and other cognate data have resulted in the following changes in
recommended values (1981 values in parentheses): Helium 4.002602 ± 2
(4.00260 ± 1); Lithium 6.941 ± 2 (6.941 ± 3); Boron 10.811 ± 5 (10.81
± 1); Sulfur 32.066 ± 6 (32.06 ± 1); Calcium 40.078 ± 4 (40.08 ± 1);
Scandium 44.95591 ± 1 (44.9559 ± 1); Chromium 51.9961 ± 6 (51.996
± 1); Zinc 65.39 ± 2 (65.38 ± 1); Gallium 69.723 ± 4 (69.72 ± 1);
Zirconium 91.224 ± 2 (91.22 ± 1); Ruthenium 101.07 ± 2 (101.07 ± 3);
Tin 118.710 ± 7 (118.69 ± 3). These values are incorporated in the
Table of Standard Atomic Weights of the Elements 1983. The Table lists
estimated uncertainties between ±1 and ±9 in the last tabulated figure,
which represents a departure from the practice in prior years of
restricting uncertainties to two alternative values, either ±1 or ±3.
Annotations in Tables 1 and 2 have been changed for several of the
elements and element 107 is included in the table of Relative Atomic
Masses and Half-Lives of Selected Radionuclides for the first time. The
Report summarizes those elements of non-terrestrial origin for which
variations in isotopic composition have been found and categorizes them
by their cause from mass fractionation, nuclear reactions or solar wind.

INTRODUCTION

The Commission on Atomic Weights and Isotopic Abundances met under the chairmanship of Dr.
N.E. Holden on 19–22 August 1983 during the XXXII IUPAC General Assembly in Lyngby,
Denmark. The Commission agreed to continue the practice, initiated in Leuven in 1981, of
presenting its Report for 1983 in two Parts, the first containing the 1983 Table of Standard
Atomic Weights of the Elements and other cognate data, and the second providing the 1983
Table of Isotopic Compositions of the Elements as determined by mass spectrometry.

During the past two years the Commission through its Subcommittee for the Assessment of the
Isotopic Composition of the Elements (SAIC) has continued to monitor the literature and
evaluate the published data on atomic weights and isotopic compositions, element by
element. As a result of this exhaustive review, the recommended values for the standard
atomic weights $A_r(E)$, of twelve elements were changed and a change in footnotes was made for
nine elements. The justifications for these changes are set out in the next Section which
is followed by the definitive Tables of Standard Atomic Weights in alphabetical order in
English (Table 1) and in order of Atomic Number (Table 2).

The Commission at its meeting in Leuven in 1981 decided that its previous practice of
restricting the listed uncertainties to either ±1 or ±3 in the last place should be
abandoned and that, in future, the full range of uncertainties between ±1 and ±9 should be
utilized. From 1983 onwards, the Commission will disseminate standard atomic weights
applicable to all normal materials with the greatest possible precision that can be
reasonably supported by published measurements. Although this new policy permits any

uncertainty between ±1 and ±9, changes in assigned uncertainties will be made only for those Elements where there is convincing evidence that an increase or decrease in the uncertainty corresponds to an increased level of confidence in the implied precision of the tabulated standard atomic weights or permits the Commission to disseminate a more precise atomic weight value. An example of the former situation is given by lithium where the estimated reliability of the standard atomic weight is reflected in the recommended change from 6.941 ± 3 to 6.941 ± 2. The latter situation is exemplified by the more precise value recommended for calcium of 40.078 ± 4 compared with the 1981 value 40.08 ± 1.

The method for listing elements with no stable isotopes in the Tables of Standard Atomic Weights has been changed in the 1983 Report. This change is designed to accommodate the problem that the radioactive elements, with the exception of thorium and uranium, have no unique naturally occurring isotopic composition from which an atomic weight can be calculated with five or more figure accuracy without prior knowledge of the sample; i.e., the concept of a standard atomic weight has little meaning for these elements. Nor is there general agreement on which of the isotopes of the radioactive elements is, or is likely to be, "important". Accordingly, the Table of Standard Atomic Weights 1983 lists the radioactive elements as those for which no stable isotopes exist and no atomic weight is given. Thorium and uranium are the exceptions to this procedure. Thorium has a well-defined (mononuclidic) composition in normal minerals with only rare exceptions. On the other hand, uranium is the only element with no stable isotopes but which has a characteristic terrestrial composition of long-lived isotopes such that a reproducible standard atomic weight can be given for natural samples. The Commission has decided not to republish in 1983 the Table of Atomic Weights to Five Significant Figures (Table 4, Ref. 1) in order to incorporate this change.

CHANGES IN ATOMIC WEIGHT VALUES

Helium

In its 1961 Report the Commission (Ref. 2) recommended the value A_r(He) = 4.0026 for the atomic weight of helium, which was the nuclidic mass of the isotope ^{4}He to four decimal places. The other stable isotope, ^{3}He, is present in natural sources of helium with a smaller abundance than that of any other stable isotope relative to its terrestrial elemental composition. The abundance of ^{3}He in helium is thus so small that it does not affect the atomic weight when stated to just four decimals.

When in 1969 the Commission (Ref. 3) was able to evaluate the natural variations in isotopic abundance for helium, based chiefly on the paper by Mamyrin et al. (Ref. 4), it was possible to recommend the value A_r(He) = 4.00260 ± 1 which still equalled the nuclidic mass of ^{4}He, but now given to five decimals. The uncertainty of ±1 arises from terrestrial variability plus experimental error.

A subsequent absolute determination of the isotopic composition of atmospheric helium by Clarke et al. (Ref. 5) confirmed the Commission's earlier value and yielded a calculated value A_r(He) = 4.0026019. A value to this precision cannot be used for the standard atomic weight of helium because, although atmospheric helium does not vary appreciably at different locations, this is not true for helium from gas wells and inclusions in rocks. Evaluation of the published range of these variations, however, does permit the Commission to include

the sixth decimal in the recommended value for the atomic weight of helium so that the standard value now becomes A_r(He) = 4.002602 ± 2.

For the first time the recommended value for A_r(He) differs from the nuclidic mass of ^{4}He which to the sixth decimal equals 4.002603 u. This still lies in the range of the indicated atomic weight variation, as it should because almost pure ^{4}He can be found in the ores of the naturally occurring radioactive elements, from which only that isotope emanates.

Lithium

The value of A_r(Li) = 6.939 was recommended in the 1961 Report (Ref. 2) based on the chemical determinations of Richards and Willard (Ref. 6). In 1969 the Commission changed the basis for the value to the absolute mass spectrometric data reported by Svec and Anderson (Ref. 7) and others and recommended A_r(Li) = 6.941 ± 3 (Ref. 3). The Commission, in 1983, considered the work of Svec and Anderson as well as the newer absolute mass spectrometric values reported by Flesch et al. (Ref. 8), Callis et al, (Ref. 9), and Michiels and De Bièvre (Ref. 10) which yielded A_r(Li) = 6.9391 ± 2, 6.94015 ± 30 and 6.94069 ± 29, respectively. Because of the slightly superior accuracy, the Commission changed the basis of the value to that published by Michiels and De Bièvre and recommended A_r(Li) = 6.941 ± 2 as the most probable value. The Commission noted the discrepancies among the above measurements, all of which were calibrated using mixtures of separated isotopes, but also noted that the recommended uncertainty of ±2 includes all of the published values.

Boron

In its 1961 Report (Ref. 2) the Commission recommended for the atomic weight of boron A_r(B) = 10.811 ± 3 based on mass spectrometric measurements. In accordance with Commission policy the uncertainty U_r(B) = ± 0.003 was intended to cover the experimental uncertainty plus the then known natural variability. This included boron from Turkey and Searles Lake, California (Ref. 13) which by current best values yield A_r(B) = 10.8086 and 10.8118 respectively.

By 1969 extensive calibrated mass spectrometric measurements by Finley et al. (Ref. 14), De Bièvre (Ref. 11) and Catanzaro et al. (Ref. 12) as well as a mineral survey by Agyei et al. (Ref. 15) indicated a wider variability of natural boron. With a policy of limiting the implied variability in the IUPAC Tables of Atomic Weights to only 1 or 3 in the last significant figure the Commission then decided that it was necessary to reduce the number of significant figures in A_r(B) so that 10.81 ±1 became the recommended IUPAC value. Only now when the Commission permits uncertainties of any single digit number is it possible to revert to A_r(B) = 10.811, but now with U_r(B) = ± 0.005 thereby covering the above more unusual boron sources. When the source of boron is known to be Turkish A_r(B) = 10.809 would be a significantly better value to use, and for Californian boron A_r(B) = 10.812 would also be justifiable as the experimental uncertainties could be made an order of magnitude smaller than the difference between these values and the standard atomic weight.

The change in the standard atomic weight of boron now reduces its uncertainty, which since 1969 had been one of the largest in the IUPAC Tables. This improvement is especially notable since boron assays of precision better than 0.1% are now possible for which the stated uncertainty on the atomic weight was perhaps the largest source of possible error.

Separated boron isotopes are commercially available and inadvertent or undisclosed distribution of artificially modified samples of boron cannot be excluded. The annotation "m" has to be retained for boron. Similarly the annotation "r" has to be retained, because certainly now there exist known sources of boron with a range of $A_r(B)$ values that prevent a more precise standard atomic weight being adopted. Strong evidence exists that in some biological processes partial isotopic fractionation in boron occurs during absorption processes as reported by Schwarcz (Ref. 16). The "g" annotation is added to warn of the existence of highly unusual "natural" sources of boron the atomic weight of which falls outside the implied range, e.g. in the ocean waters.

Sulfur

The value of $A_r(S)$ = 32.064 ± 3 was recommended by the Commission in the 1961 Report (Ref. 2) based on the abundances of sulfur isotopes by Bradt et al. (Ref. 17) and nuclidic masses by Everling et al. (Ref. 18). This value was in excellent agreement with chemical determinations of the atomic weight. In 1969 (Ref. 3) the Commission recommended a change in the value of $A_r(S)$ to 32.06 ± 1. This reduction in the number of significant figures took into account the observed variations in the isotopic abundance of sulfur in natural samples (Refs. 19 and 20). The Commission, at its meeting in 1983, noted that more recent work (Refs. 21, 22 and 23) established a narrower range of $A_r(S)$ values and therefore recommended $A_r(S)$ = 32.066 ± 6 to cover all normal sources.

Calcium

The value of $A_r(Ca)$ = 40.08 for the atomic weight of calcium was adopted by the Commission in its 1961 Report (Ref. 2) and an uncertainty of ±0.01 was added in the 1969 Report (Ref. 3). This value was based on the chemical measurements by Hönigschmid and Kempter (Ref. 24) and isotope abundance measurements by Nier (Ref. 25). The Commission has reviewed these and more recent mass spectrometric measurements and now recommends $A_r(Ca)$ = 40.078 ± 0.004. This more precise value is a result of the new policy of permitting uncertainties other than one or three in the last digit.

Recalculations of the chemical measurements of Hönigschmid and Kempter yield $A_r(Ca)$ = 40.080 for the comparison of calcium chloride to silver and 40.082 for the comparison of calcium chloride to silver chloride. Using atomic masses from Wapstra and Bos (Ref. 26), atomic weights were calculated from the following mass spectrometric measurements:

Year	Investigator	$A_r(Ca)$
1938	Nier (Ref. 25)	40.077
1948	White and Cameron (Ref. 27)	40.079
1960	Omura et al. (Ref. 28)	40.081
1962	Stauffer and Honda (Ref. 29)	40.077
1968	Shima et al. (Ref. 30)	40.081
1971	Coleman (Ref. 31)	40.080
1972	Moore and Machlan (Ref. 32)	40.078
1978	Russell et al. (Ref. 33)	40.076

Further evidence is provided by Deslattes et al. (Ref. 34) who used the X-ray/density method to determine the atomic weight of calcium. Recalculation of these measurements yield $A_r(Ca)$

= 40.079 ± 0.002.

The recommended value, 40.078 ± 0.004, is weighted towards the measurement of isotopic composition by Moore and Machlan (Ref. 32) which is the best measurement in the judgment of the Commission. However, the uncertainty includes all of the chemical, X-ray/density, and mass spectrometric measurements. Although none of the above measurements was calibrated, it would take a large error to exceed the stated uncertainty since calcium is composed of mainly one isotope (96.9% ^{40}Ca).

Scandium

Scandium is a mononuclidic element, for which the Commission in 1961 (Ref. 2) recommended the atomic weight, $\underline{A_r}$(Sc) = 44.956, although the mass of its nuclide was known with far superior accuracy. At that time the Commission had in mind the possiblity of the discovery of stable isomers of neighbouring scandium radioisotopes. In the above reference the Commission referred to a paper placing an experimental limit of 10^{-2} atom percent on the hypothetical presence of ^{46}Sc. On that evidence, an effect on the fifth significant figure in the atomic weight of scandium cannot be ruled out. In 1969, however, the Commission (Ref. 3) considered that viewpoint unduly conservative and recommended $\underline{A_r}$(Sc) = 44.9559 ± 1, because on the basis of theory and experience the likelihood of the existence of such an isomer of ^{46}Sc with a long half-life must be considered as exceedingly remote.

In the nuclidic mass tables published, with encouragement of the International Union of Pure and Applied Physics, by Wapstra and Gove in 1971 (Ref. 35) the mass of ^{45}Sc is given as 44.9559174 ± 22 u. This uncertainty was calculated from the least squares adjustment and is largely a measure of the consistency of mass values for nuclides with similar mass and atomic numbers. For conversion of nuclidic masses to atomic weights of mononuclidic elements the Commission, somewhat arbitrarily, rounds the values to fewer digits, so that the uncertainty in the nuclidic mass table multiplied by six is equal or less than one in the last decimal for the atomic weight value. By this rule no change in the atomic weight value was needed. When, however, in 1977 the nuclidic mass table was revised by Wapstra and Bos (Ref. 26) ^{45}Sc was given a mass of 44.9559136 ± 15 u which by the above rule should lead to $\underline{A_r}$(Sc) = 44.95591 ± 1 with an additional decimal. The Commission, however, at that time did not act for fear of recommending a rounding-off change in the atomic weight of one of the mononuclidic elements which are tabulated to higher precision than is required for the great majority of applications. Such a change is especially undesirable when in future it might have to be reversed due to a very small change in the best value within the estimated uncertainty range.

In a review of that decision in 1983, it was pointed out that in the case of scandium the additional digit now represented reliable accuracy. The mass of ^{45}Sc was closely tied to that of the titanium isotopes which in turn are closely tied to ^{12}C, the isotope that defines the atomic weight scale (Ref. 36). The Commission, moreover, would not feel compelled to change a recommended standard atomic weight value based solely on a rounding off from the new best value differing from a previous value by much less than the estimated uncertainty. This is the reason why at this time the Commission decided against a change in the standard atomic weights of holmium and gold. However, the Commission in the next two years will proceed to review its policy pertaining to the dissemination of the standard atomic weights of mononuclidic elements.

Chromium

The present value for atomic weight of chromium, A_r(Cr) = 51.996 ± 1, was recommended by the Commission in 1969 (Ref. 3) and was based on the work of Shields et al. (Ref. 37) who made a calibrated determination of the isotopic composition using highly enriched isotopes. Based on this work and on the new policy of introducing uncertainties other than ±1 or ±3, the Commission in 1983 decided to reduce the uncertainty of ±1 in the third decimal place to ±6 in the fourth decimal place thus enabling an additional digit in the atomic weight value itself to be quoted giving A_r(Cr) = 55.9961 ± 6.

Zinc

In its 1961 Report (Ref. 2) the Commission recommended A_r(Zn) = 65.37 based on the earlier chemical data of Hönigschmid and von Mack (Ref. 38), Baxter and Grose (Ref. 39), and Baxter and Hodges (Ref. 40). The Commission was aware of isotopic composition data of Hess et al. (Ref. 41), and Leland and Nier (Ref. 42) both of which, with nuclidic masses of Everling et al. (Ref. 43), yielded the higher value of A_r(Zn) = 65.387. Recognizing this unresolved discrepancy the Commission in 1969 (Ref. 3) assessed the uncertainty as ±0.03. Marinenko and Foley (Ref. 44) in 1971 published a coulometric determination which also yielded a higher value A_r(Zn) = 65.377 ± 0.003 whereupon the Commission in its 1971 Report (Ref. 45) changed the recommended value to A_r(Zn) = 65.38 ± 1. Later Rosman (Ref. 46), using a double spike technique to calibrate for fractionation , determined A_r(Zn) = 65.396 ± 0.005 by mass spectrometry.

Faced with the discrepancy between these highly precise values, the Commission now recommends 65.39 ± 0.02 for the atomic weight of zinc. This value is weighted towards the calibrated mass spectrometric measurement of Rosman (Ref. 46), but the uncertainty of ±0.02 includes the coulometric measurement of Marinenko and Foley (Ref. 44). This action makes the atomic weight of zinc one of the least precisely known due entirely to experimental uncertainty. In the Commission's judgement, a more precise value should await new experimental evidence.

Gallium

The value of A_r(Ga) = 69.72 was recommended for the 1961 Table of Relative Atomic Weights (Ref. 2) based on chemical determinations (Refs. 47 and 48) as well as isotopic abundance measurements (Refs. 49 and 50). In 1969 (Ref. 3) the Commission assigned an uncertainty ±0.01 to this atomic weight.

A precise coulometric assay of gallium and arsenic by Marinenko (Ref. 51) led to the value of A_r(Ga) = 69.737 ± 6. This result did not agree with the earlier data or the calibrated mass spectrometric measurement by De Laeter and Rosman (Ref. 52) which yielded the value 69.724 ± 3. De Laeter (Ref. 53) has shown that the isotopic composition of 6 iron meteorite samples and a terrestrial standard were identical to a laboratory standard within experimental error.

The Commission, in 1983, reviewed all the available chemical and isotopic evidence for gallium, including the isotopic fractionation effects which are produced when an electric current is passed through a column of the metal (Ref. 54), and recommended a value of A_r(Ga)

$= 69.723 \pm 4.$

Zirconium

The atomic weight of zirconium has been taken as 91.22 since 1927 and this value was reconfirmed by the 1961 Commission Report (Ref. 2) taking into consideration existing isotopic abundance measurements by White and Cameron (Ref. 55). The uncertainty was assessed as ±0.01 by the Commission in 1969 (Ref. 3). Since then two absolute isotopic compositions have been reported by Minster and Ricard (Ref. 56) yielding A_r(Zr) = 91.224 with an estimated uncertainty of +0.002 and −0.005, and by Nomura et al. (Ref. 57) yielding A_r(Zr) = 91.2235 ± 5.

Shima (Ref. 58) showed that the isotopic composition of nine meteoritic samples and two terrestrial standards were identical to a laboratory standard within experimental error. Minster and Ricard (Ref. 56) have shown that the isotopic compostion of two meteoritic samples, one lunar sample and a terrestrial zircon are identical to a laboratory standard. The Commission, noting the excellent agreement between the two calibrated, or absolute, measurements and the evidence for the lack of any significant natural variations in isotopic composition, recommended a value of A_r(Zn) = 91.224 ± 2.

Ruthenium

The Commission at its meeting in 1983 has reduced the uncertainty associated with the atomic weight of ruthenium from ±0.03 to ±0.02 after considering that no significant variations in isotopic composition of ruthenium have been detected from various natural sources of ruthenium (Refs. 59 and 60), and also the excellent agreement between all the A_r(Ru) values deduced from mass spectrometric measurements (Refs. 59, 61, 62 and 63).

Tin

Tin has ten stable nuclides, the highest number for any element. Measurement of the isotopic composition consequently involves a number of considerable experimental difficulties. The value of A_r(Sn) = 118.69 was recommended for the 1961 Table of Atomic Weights (Ref. 2) based on a number of chemical determinations. In 1969 the Commission assigned an uncertainty of ±0.03 to this atomic weight (Ref. 3). This value of A_r(Sn) was retained despite the fact that a number of uncalibrated mass spectrometric determinations indicated a slightly higher value.

The new value 118.710 ± 7 is based on the first attempt to determine the absolute isotopic composition of tin by Devillers et al. (Ref. 64) using the double spike technique involving the isotopes 116 and 122 which cover the mass range of the major isotope abundances. The isotopic composition of tin determined by Devillers et al. was in excellent agreement with earlier mass spectrometric determinations (Refs. 65 and 66), except for linear mass fractionation effects. Furthermore De Laeter and Jeffery (Ref. 66) have shown that the isotopic composition of 6 meteoritic samples and 11 cassiterite samples are identical to a laboratory standard within experimental error. Since the natural variability is very small, an uncertainty of ±7 adequately covers both experimental uncertainties as well as natural variations.

CHANGES IN FOOTNOTES

Helium

The indicated range for the standard atomic weight of helium has a lower limit of 4.002600 corresponding to a ^{3}He abundance of 3.3 x 10^{-4} atom percent. Included in this range are ^{3}He-enriched sources from deep wells. It does not include some recently discovered (Ref. 67) helium from gases evolved from the mid-Pacific Ocean rise. This helium has a most exceptional abundance of up to 4 x 10^{-3} atom percent corresponding to a high ^{3}He content typical perhaps of mantle helium. The annotation "g" is therefore now appended to helium. In addition the annotation "r" has been added in the 1983 Table of Standards Atomic Weights to indicate that known natural variations of helium prevent the Commission from recommending an atomic weight with an additional decimal.

Boron

The annotation "g" has been added as explained in the earlier section on changes in atomic weight values.

Nitrogen

The A_r(N) value corresponding to the highest measured ^{15}N abundance in soils is equal to 14.00681 (Ref. 68) which falls outside the quoted range 14.0067 ± 1. Accordingly, the annotation "g" is added to nitrogen to take into account this extreme isotopic composition of nitrogen measured in soils.

Magnesium

The annotation "g" was added to magnesium by the Commission in its 1971 Report (Ref. 45) based on a published abstract report of a partial mineral survey by Lepin et al. (Ref. 69) who documented considerable natural variability in sources from the USSR. Since there were no comparable findings in other publications on magnesium such as that by Catanzaro and Murphy (Ref. 70) the Commission concluded that the specimens studied by Lepin et al. must have been exceptional, thereby justifying the annotation "g" in preference to reducing the precision of the tabulated value. A later credible study by Shramm et al. (Ref. 71) found no anomalies in A_r(Mg) values greater than experimental error. The Commission, therefore, decided to make a study of the actual data obtained by Lepin et al. As a result, the Commission now concludes that experimental uncertainties and not atomic weight variability has probably caused a considerable range of the reported values. The annotation "g" is, therefore, now removed from magnesium for lack of strong evidence for its retention.

Silicon

In 1975, the Commission (Ref. 72) recommended the current value for the atomic weight of silicon, A_r(Si) = 28.0855 ± 3 based on the absolute mass-spectrometric measurements by Barnes et al. (Ref. 73) and the Commission's judgment that some of the reported terrestrial variability of the isotopic composition of silicon was excessive. This is borne out by a recent investigation by Douthitt (Ref. 74) who studied silicon in 132 terrestrial materials and comprehensively reviewed the literature. He found that the variability in igneous rocks

is even smaller than the above indicated range but nevertheless, it is real and correlates with oxygen isotopic fractionation. The silicon isotopic fractionation in some clays, marine sediments, and opals is more appreciable, but still within the range implied by the uncertainty of ±0.0003, the Commission's estimate of the combined uncertainty from experimental error plus terrestrial variability. The Commission at this time adds the annotation "r" because it is now well documented that an additional significant figure in the standard atomic weight with a single digit uncertainty would conflict with the actual sample atomic weights of possible sources of silicon.

Dysprosium, Erbium, Ytterbium and Lutetium

Holliger and Devillers (Ref. 75) measured uranium ore zone samples from the natural nuclear reactor, which had been discovered at Oklo in Gabon, West Africa in 1972. The measured isotopic anomalies in these fission product elements require that the annotation "g" be added for these four elements.

THE TABLE OF STANDARD ATOMIC WEIGHTS 1983

The changes referred to above are incorporated into the 1983 Table of Standard Atomic Weights. Following the past practice, the Table is presented both in alphabetical order by English names of the elements (Table 1) and in order of atomic number (Table 2).

In its 1981 Report, the Commission stressed the need for new and more precise determinations of some atomic weights. The financial exigencies faced at present by many research institutions have reduced the number of new atomic weight determinations since 1981. The problem is being compounded by the lack of availability of separated isotopes and for this reason, the Commission wishes to encourage further mass-spectrometric measurements using the double-spike technique which is more accurate than a non-calibrated measurement. Furthermore, since different physical characteristics of isotopes can be used for abundance measurements, there is the promise of continuing flow of new and improved determinations based on optical, magnetic, X-ray and Mössbauer effects.

Table 1. Standard Atomic Weights 1983
(Scaled to $\underline{A}_r$ (^{12}C)=12)

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $\underline{A}_r$(E) given here apply to elements as they exist naturally on earth. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit, unless otherwise noted.

Alphabetical order in English

Names	Symbol	Atomic Number	Atomic Weight	Footnotes			
Actinium*	Ac	89					A
Aluminium	Al	13	26.98154				
Americium*	Am	95					A
Antimony (Stibium)	Sb	51	121.75 ± 3				
Argon	Ar	18	39.948	g		r	
Arsenic	As	33	74.9216				
Astatine*	At	85					A
Barium	Ba	56	137.33	g			
Berkelium*	Bk	97					A
Beryllium	Be	4	9.01218				
Bismuth	Bi	83	208.9804				
Boron	B	5	10.811 ± 5		m	r	
Bromine	Br	35	79.904				
Cadmium	Cd	48	112.41	g			
Caesium	Cs	55	132.9054				
Calcium	Ca	20	40.078 ± 4	g			
Californium*	Cf	98					A
Carbon	C	6	12.011			r	
Cerium	Ce	58	140.12	g			
Chlorine	Cl	17	35.453				
Chromium	Cr	24	51.9961 ± 6				
Cobalt	Co	27	58.9332				
Copper	Cu	29	63.546 ± 3			r	
Curium*	Cm	96					A
Dysprosium	Dy	66	162.50 ± 3	g			
Einsteinium*	Es	99					A
Element 104* (*a*)	Unq	104					A
Element 105* (*b*)	Unp	105					A
Element 106* (*c*)	Unh	106					A
Element 107* (*d*)	Uns	107					A
Erbium	Er	68	167.26 ± 3	g			
Europium	Eu	63	151.96	g			
Fermium*	Fm	100					A
Fluorine	F	9	18.998403				
Francium*	Fr	87					A
Gadolinium	Gd	64	157.25 ± 3	g			
Gallium	Ga	31	69.723 ± 4				
Germanium	Ge	32	72.59 ± 3				
Gold	An	79	196.9665				
Hafnium	Hf	72	178.49 ± 3				
Helium	He	2	4.002602 ± 2	g		r	
Holmium	Ho	67	164.9304				
Hydrogen	H	1	1.00794 ± 7	g	m	r	
Indium	In	49	114.82	g			
Iodine	I	53	126.9045				
Iridium	Ir	77	192.22 ± 3				
Iron	Fe	26	55.847 ± 3				
Krypton	Kr	36	83.80	g	m		
Lanthanum	La	57	138.9055 ± 3	g			
Lawrencium*	Lr	103					A
Lead	Pb	82	207.2	g		r	
Lithium	Li	3	6.941 ± 2	g	m	r	
Lutetium	Lu	71	174.967	g			
Magnesium	Mg	12	24.305				
Manganese	Mn	25	54.9380				
Mendelevium*	Md	101					A
Mercury	Hg	80	200.59 ± 3				
Molybdenum	Mo	42	95.94				
Neodymium	Nd	60	144.24 ± 3	g			
Neon	Ne	10	20.179	g	m		
Neptunium*	Np	93					A
Nickel	Ni	28	58.69				

(*a*)-(*d*) Systematic names: (*a*) Unnilquadium; (*b*) Unnilpentium; (*c*) Unnilhexium; (*d*) Unnilseptium

Table 1.   Standard Atomic Weights 1983   (cont'd)

Names	Symbol	Atomic Number	Atomic Weight	Footnotes		
Niobium	Nb	41	92.9064			
Nitrogen	N	7	14.0067	g		
Nobelium*	No	102				A
Osmium	Os	76	190.2	g		
Oxygen	O	8	15.9994 ± 3	g	r	
Palladium	Pd	46	106.42	g		
Phosphorus	P	15	30.97376			
Platinum	Pt	78	195.08 ± 3			
Plutonium*	Pu	94				A
Polonium*	Po	84				A
Potassium (Kalium)	K	19	39.0983			
Praseodymium	Pr	59	140.9077			
Promethium*	Pm	61				A
Protactinium*	Pa	91				A
Radium*	Ra	88				A
Radon*	Rn	86				A
Rhenium	Re	75	186.207			
Rhodium	Rh	45	102.9055			
Rubidium	Rb	37	85.4678 ± 3	g		
Ruthenium	Ru	44	101.07 ± 2	g		
Samarium	Sm	62	150.36 ± 3	g		
Scandium	Sc	21	44.95591 ± 1			
Selenium	Se	34	78.96 ± 3			
Silicon	Si	14	28.0855 ± 3		r	
Silver	Ag	47	107.8682 ± 3	g		
Sodium (Natrium)	Na	11	22.98977			
Strontium	Sr	38	87.62	g		
Sulfur	S	16	32.066 ± 6		r	
Tantalum	Ta	73	180.9479			
Technetium*	Tc	43				A
Tellurium	Te	52	127.60 ± 3	g		
Terbium	Tb	65	158.9254			
Thallium	Tl	81	204.383			
Thorium*	Th	90	232.0381	g		X
Thulium	Tm	69	168.9342			
Tin	Sn	50	118.710 ± 7			
Titanium	Ti	22	47.88 ± 3			
Tungsten (Wolfram)	W	74	183.85 ± 3			
Uranium*	U	92	238.0289	g	m	Y
Vanadium	V	23	50.9415			
Xenon	Xe	54	131.29 ± 3	g	m	
Ytterbium	Yb	70	173.04 ± 3			
Yttrium	Y	39	88.9059	g		
Zinc	Zn	30	65.39 ± 2	g		
Zirconium	Zr	40	91.224 ± 2	g		

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

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

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

A   Radioactive element that lacks a characteristic terrestrial isotopic composition. One or more well-known isotopes are given in Table 3 with the appropriate mass and half-life.

X   Thorium has a well defined (mononuclidic) composition in minerals with only rare exceptions.   In certain places, however (most notably in ocean water), measurable quantities of ^{230}Th (Ionium) can be found.

Y   Uranium is the only element with no stable isotopes but which has a characteristic terrestrial composition of long-lived isotopes such that a meaningful atomic weight can be given for natural samples.

*   Element has no stable isotopes

TABLE 2. Standard Atomic Weights 1983
(Scaled to $A_r(^{12}C) = 12$)

The atomic weights of many elements are not invariant but depend on the origin and treatment of the material. The footnotes to this Table elaborate the types of variation to be expected for individual elements. The values of $A_r(E)$ given here apply to elements as they exist naturally on earth. When used with due regard to the footnotes they are considered reliable to ±1 in the last digit, unless otherwise noted.

Order of Atomic Number

Atomic Number	Names	Symbol	Atomic Weight	Footnotes		
1	Hydrogen	H	1.00794 ± 7	g	m	r
2	Helium	He	4.002602 ± 2	g		r
3	Lithium	Li	6.941 ± 2	g	m	r
4	Beryllium	Be	9.01218			
5	Boron	B	10.811 ± 5		m	r
6	Carbon	C	12.011			r
7	Nitrogen	N	14.0067	g		
8	Oxygen	O	15.9994 ± 3	g		r
9	Fluorine	F	18.998403			
10	Neon	Ne	20.179	g	m	
11	Sodium (Natrium)	Na	22.98977			
12	Magnesium	Mg	24.305			
13	Aluminium	Al	26.98154			
14	Silicon	Si	28.0855 ± 3			r
15	Phosphorus	P	30.97376			
16	Sulfur	S	32.066 ± 6			r
17	Chlorine	Cl	35.453			
18	Argon	Ar	39.948	g		r
19	Potassium (Kalium)	K	39.0983			
20	Calcium	Ca	40.078 ± 4	g		
21	Scandium	Sc	44.95591 ± 1			
22	Titanium	Ti	47.88 ± 3			
23	Vanadium	V	50.9415			
24	Chromium	Cr	51.9961 ± 6			
25	Manganese	Mn	54.9380			
26	Iron	Fe	55.847 ± 3			
27	Cobalt	Co	58.9332			
28	Nickel	Ni	58.69			
29	Copper	Cu	63.546 ± 3			r
30	Zinc	Zn	65.39 ± 2			
31	Gallium	Ga	69.723 ± 4			
32	Germanium	Ge	72.59 ± 3			
33	Arsenic	As	74.9216			
34	Selenium	Se	78.96 ± 3			
35	Bromine	Br	79.904			
36	Krypton	Kr	83.80	g	m	
37	Rubidium	Rb	85.4678 ± 3	g		
38	Strontium	Sr	87.62	g		
39	Yttrium	Y	88.9059			
40	Zirconium	Zr	91.224 ± 2	g		
41	Niobium	Nb	92.9064			
42	Molybdenum	Mo	95.94			
43	Technetium*	Tc				A
44	Ruthenium	Ru	101.07 ± 2	g		
45	Rhodium	Rh	102.9055			
46	Palladium	Pd	106.42	g		
47	Silver	Ag	107.8682 ± 3	g		
48	Cadmium	Cd	112.41	g		
49	Indium	In	114.82	g		
50	Tin	Sn	118.710 ± 7			
51	Antimony (Stibium)	Sb	121.75 ± 3			
52	Tellurium	Te	127.60 ± 3	g		
53	Iodine	I	126.9045			
54	Xenon	Xe	131.29 ± 3	g	m	
55	Caesium	Cs	132.9054			
56	Barium	Ba	137.33	g		
57	Lanthanum	La	138.9055 ± 3	g		
58	Cerium	Ce	140.12	g		
59	Praseodymium	Pr	140.9077			
60	Neodymium	Nd	144.24 ± 3	g		
61	Promethium*	Pm				A
62	Samarium	Sm	150.36 ± 3	g		

TABLE 2. Standard Atomic Weights 1983 (cont'd)

Atomic Number	Names	Symbol	Atomic Weight	Footnotes		
63	Europium	Eu	151.96	g		
64	Gadolinium	Gd	157.25 ± 3	g		
65	Terbium	Tb	158.9254			
66	Dysprosium	Dy	162.50 ± 3	g		
67	Holmium	Ho	164.9304			
68	Erbium	Er	167.26 ± 3	g		
69	Thulium	Tm	168.9342			
70	Ytterbium	Yb	173.04 ± 3	g		
71	Lutetium	Lu	174.967	g		
72	Hafnium	Hf	178.49 ± 3			
73	Tantalum	Ta	180.9479			
74	Wolfram(Tungsten)	W	183.85 ± 3			
75	Rhenium	Re	186.207			
76	Osmium	Os	190.2	g		
77	Iridium	Ir	192.22 ± 3			
78	Platinum	Pt	195.08 ± 3			
79	Gold	Au	196.9665			
80	Mercury	Hg	200.59 ± 3			
81	Thallium	Tl	204.383			
82	Lead	Pb	207.2	g	r	
83	Bismuth	Bi	208.9804			
84	Polonium*	Po				A
85	Astatine*	At				A
86	Radon*	Rn				A
87	Francium*	Fr				A
88	Radium*	Ra				A
89	Actinium*	Ac				A
90	Thorium*	Th	232.0381	g		X
91	Protactinium*	Pa				A
92	Uranium*	U	238.0289	g	m	Y
93	Neptunium*	Np				A
94	Plutonium*	Pu				A
95	Americium*	Am				A
96	Curium*	Cm				A
97	Berkelium*	Bk				A
98	Californium*	Cf				A
99	Einsteinium*	Es				A
100	Fermium*	Fm				A
101	Mendelevium*	Md				A
102	Nobelium*	No				A
103	Lawrencium*	Lr				A
104	Element 104* (a)	Unq				A
105	Element 105* (b)	Unp				A
106	Element 106* (c)	Unh				A
107	Element 107* (d)	Uns				A

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

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Y Uranium is the only element with no stable isotopes but which has a characteristic terrestrial composition of long-lived isotopes such that a meaningful atomic weight can be given for natural samples

* Element has no stable isotopes

(a)-(d) Systematic names: (a) Unnilquadium; (b) Unnilpentium; (c) Unnilhexium; (d) Unnilseptium

RELATIVE ATOMIC MASSES AND HALF-LIVES OF SELECTED RADIONUCLIDES

The Commission has, for many years, published a Table of Relative Atomic Masses and Half-Lives of Selected Radionuclides. Since the Commission has no prime responsibility for the dissemination of such values, it has not attempted either to record the best precision possible or make its tabulation comprehensive. The radionuclides selected are those judged to be necessary to enable users to calculate the atomic weights of materials of abnormal or changing isotopic composition. There is no general agreement on which of the isotopes of the radioactive elements is, or is likely to be judged "important" and various criteria such as "longest half-life", "production in quantity", "used commercially", etc. will be apposite for different situations. The atomic masses are again those recommended by Wapstra and Bos (Ref. 26) and the half-lives were provided by N.E. Holden (Ref. 76). The latest atomic mass data were surveyed and no significant changes have emerged. However, following the identification of element 107 by α correlation chains in 1981 (Ref. 77), it is included in this year's Table 3 for the first time.

TABLE 3 — Nuclidic Masses and Half-Lives for Selected Isotopes of Elements
Which Have No Stable Isotopes

ATOMIC NUMBER	NAME	ISOTOPE SYMBOL	NUMBER	MASS	HALF-LIFE	*
43	Technetium	Tc	97	96.9064	2.6×10^6	a
			98	97.9072	4.2×10^6	a
			99	98.9063	2.13×10^5	a
61	Promethium	Pm	145	144.9128	18	a
			147	146.9151	2.6234	a
84	Polonium	Po	209	208.9824	102	a
			210	209.9829	138.38	d
85	Astatine	At	210	209.9871	8.1	h
			211	210.9875	7.21	h
86	Radon	Rn	211	210.9906	14.6	h
			220	220.0114	55.6	s
			222	222.0176	3.824	d
87	Francium	Fr	223	223.0197	22	m
88	Radium	Ra	223	223.0185	11.43	d
			224	224.0202	3.66	d
			226	226.0254	1600	a
			228	228.0311	5.76	a
89	Actinium	Ac	227	227.0278	21.773	a
90	Thorium	Th	230	230.0331	7.54×10^4	a
			232	232.0381	1.40×10^{10}	a
91	Protactinium	Pa	231	231.0359	3.28×10^4	a
92	Uranium	U	233	233.0396	1.592×10^5	a
			234	234.0409	2.45×10^5	a
			235	235.0439	7.04×10^8	a
			236	236.0456	2.342×10^7	a
			238	238.0508	4.468×10^9	a

TABLE 3 - Nuclidic Masses and Half-Lives for Selected Isotopes of Elements
Which Have No Stable Isotopes (cont'd)

ATOMIC NUMBER	NAME	SYMBOL	ISOTOPE NUMBER	MASS	HALF-LIFE	*
93	Neptunium	Np	237	237.0482	2.14×10^6	a
			239	239.0529	2.350	d
94	Plutonium	Pu	238	238.0496	87.7	a
			239	239.0522	2.41×10^4	a
			240	240.0538	6.56×10^3	a
			241	241.0568	14.34	a
			242	242.0587	3.76×10^5	a
			244	244.0642	8.2×10^7	a
95	Americium	Am	241	241.0568	432	a
			243	243.0614	7.37×10^3	a
96	Curium	Cm	243	243.0614	28.5	a
			244	244.0627	18.11	a
			245	245.0655	8.5×10^3	a
			246	246.0672	4.7×10^3	a
			247	247.0703	1.58×10^7	a
			248	248.0723	3.4×10^5	a
97	Berkelium	Bk	247	247.0703	1.4×10^3	a
			249	249.0750	3.3×10^2	d
98	Californium	Cf	249	249.0748	351	a
			250	250.0764	13.1	a
			251	251.0796	9.0×10^2	a
			252	252.0816	2.64	a
99	Einsteinium	Es	252	252.0828	472	d
100	Fermium	Fm	257	257.0951	100.5	d
101	Mendelevium	Md	256	256.0939	76	m
			258	258.0986	55	d
102	Nobelium	No	259	259.1009	58	m
103	Lawrencium	Lr	260	260.1054	3	m
104	Unnilquadium	Unq	261	(261)	65	s
105	Unnilpentium	Unp	262	(262)	34	s
106	Unnilhexium	Unh	263	(263)	0.9	s
107	Unnilseptium	Uns	262	(262)	.115	s

* a = year; d = day; h = hour; m = minute; s = second

NOTE: The isotopes selected above for listed radioactive elements are those
believed to be the most frequently found now or in the near future.

NON-TERRESTRIAL DATA

The isotopic abundances of elements from non-terrestrial sources form a rapidly expanding body of knowledge. Information about non-terrestrial isotopic abundances can be obtained from mass spectrometric analyses of meteoritic and lunar material, from space probes, from astronomical observations and from cosmic ray analysis.

The classic picture of the presolar nebula was that of a hot, well-mixed cloud of isotopically uniform composition. However, it has now been established that the isotopic composition of many elements in non-terrestrial materials is different from terrestrial materials. These anomalies may reflect primordial heterogeneities and therefore offer the possibility of identifying specific astrophysical and cosmochemical processes. They may also enable modes of nucleosynthesis and their associated parameters to be identified. Excellent reviews describing isotopic anomalies in non-terrestrial materials are given by Anders (Ref. 78), Begemann (Ref. 79) and Wasserburg et al. (Ref. 80).

Although this Commission does not attempt to review systematically the literature on the isotopic composition of non-terrestrial materials, it is important to realise that, although most of the reported isotopic anomalies are small, there are a number of variations that are quite large. For this reason, scientists dealing with non-terrestrial samples should exercise caution when the isotopic composition or atomic weight of a non-terrestrial sample is required.

The following summary lists those elements in which variations in isotopic composition have been found. This information has been classified in terms of the major process involved in modifying the isotopic composition of the element concerned.

A. Mass Fractionation

Mass-dependent fractionation can occur both before and after the formation of the solar system. Evidence of mass fractionation has been found in non-terrestrial samples of the following elements:-

    H, Li, C, O, N, Ne, Mg, Si, S, Ar, Ca, Kr, Sr, Cd, Xe and Ba

In most cases the mass fractionation is < 1% per mass unit, but in some special cases, such as the production of organic matter, variations in H as large as 25% per mass unit have been reported by Robert and Epstein (Ref. 81).

B. Nuclear Reactions

    (i) Nucleosynthesis: Isotopic anomalies in this category are usually < 1% and have been found in separated phases or minor components in certain meteorites. Evidence of nucleosynthetic anomalies has been reported in the following elements:

    C, N, O, Ne, Mg, Si, S, Ca, Ti, Kr, Sr, Xe, Ba, Nd and Sm

    (ii) Spallation Reactions: Nuclear reactions produced by high energy cosmic ray bombardment can alter the isotopic composition of certain elements from that found in

terrestrial materials. Evidence for spallation-produced isotopic anomalies have been reported in the following elements:

He, Li, N, Ne, Mg, S, Ar, K, Ca, Ti, V, Cr, Kr and Xe

Some of these variations can be quite large. For example in some iron meteorites $^7Li/^6Li$ ratios as low as 1.25 (compared with the terrestrial ratio of 12.33) have been reported by Hintenberger et al. (Ref. 82), whilst the $^{21}Ne/^{20}Ne$ ratio is 1.00 (compared with the terrestrial value of 0.00298) by Hintenberger and Wänke (Ref. 83).

(iii) Low Energy Neutron Irradiation: Bombardment of the lunar surface by cosmic rays produces a flux of neutrons which, when thermalised, can be captured by nuclides with high cross sections to produce anomalous isotopic ratios. Russ (Ref. 84) has reported $^{158}Gd/^{157}Gd$ ratios in lunar soil of 1.6162 compared to the terrestrial value of 1.5866. Evidence for low energy neutron irradiation has been reported for the following elements:

Kr, Cd, Xe, Sm and Gd

(iv) Radioactive decay products:

(a) When the Solar System had evolved to the point where the meteorites had become closed isotopic systems some 4.6 x 10^9 years ago, some radioactive isotopes, now extinct in the Solar System, were still present. Enrichments have been reported in ^{26}Mg, ^{107}Ag, ^{129}Xe and ^{142}Nd caused by the decay of the extinct radionuclides ^{26}Al, ^{107}Pd, ^{129}I and ^{146}Sm respectively.

(b) Enrichments in the daughter products of radioactive nuclides which are commonly used for age determinations will also be found in non-terrestrial materials. Thus enrichments in ^{40}Ar and ^{40}Ca (from ^{40}K), $^{87}Sr(^{87}Rb)$, $^{138}Ce(^{188}La)$, $^{143}Nd(^{147}Sm)$, $^{176}Hf(^{176}Lu)$, $^{187}Os(^{187}Re)$ and ^{206}Pb, ^{207}Pb, ^{208}Pb and $^4He(^{235}U$, ^{238}U, $^{232}Th)$ will occur.

(c) Enrichments in $^{131-136}Xe$ have been reported in meteoritic materials as the result of the decay of fission products of ^{238}U and ^{244}Pu, Alexander et al. (Ref. 85).

(d) Argon is enriched in ^{40}Ar in terrestrial samples because it has been produced in the radioactive decay of ^{40}K in the earth's crust, some of which has diffused into the atmosphere. The $^{40}Ar/^{36}Ar$ ratio measured in K-depleted meteorites is 2.9 x 10^{-4}, Gobel et al. (Ref. 86), as compared with the terrestrial value of 295.6. Similar enrichment processes have enriched helium in its heavier isotope ^4He. In this case the source of ^4He is the α-decay of U and Th in the earth, some of which has diffused into the atmosphere. The solar system abundance ratio of $^4He/^3He$ is 7.03 x 10^3, Anders and Ebihara, (Ref. 87) as compared with a terrestrial value of 7.25 x 10^5.

Similar enrichments in $^4He/^3He$ have been shown to occur in the Martian atmosphere, Hostetler, (Ref. 88).

C. Solar Wind

Lunar samples have shown evidence of isotopic modification because of ancient and recent solar wind or solar flare implantation. Secular variations in the composition of the solar wind have also been postulated by Kerridge (Ref. 89). Solar wind components leading to anomalous isotopic composition have been found in the following elements:

H, He, C, N, Ne, Ar, Kr and Xe

OTHER PROJECTS OF THE COMMISSION

At its meeting in Lyngby, the Commission endorsed the draft of the revised Table of Atomic Weights to Four Significant Figures. Such a table was prepared originally for the IUPAC Committee on Teaching of Chemistry and published in their "International Newsletter on Chemical Education" (Ref. 90). The abbreviated Table has the virtue that it is unlikely that the values quoted to four significant figures will be altered in subsequent revisions by more than their indicated uncertainties. The previous table has been used widely especially through its reproduction for chemical text books in many languages.

The Subcommittee for the Assessment of Isotopic Composition (SAIC) within the Commission on Atomic Weights and Isotopic Abundances has completed its comprehensive element-by-element review of all measurements for deriving isotopic compositions and the best values which are consistent with the Table of Standard Atomic Weights (see Part 2 of the Commission's Report). The Review was endorsed by the Commission at Lyngby and it will be published as a separate report in the Journal of Pure and Applied Chemistry. The membership of SAIC during the period 1981-1983 was P. De Bièvre (Chairman), I.L. Barnes (Secretary), R. Hagemann, N.E. Holden, J.R. DeLaeter, T.J. Murphy, H.S. Peiser and H.G. Thode with additional assistance from E. Roth and M. Shima. The Subcommittee, having completed its task, has now been dissolved.

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