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**ATOMIC WEIGHTS OF THE ELEMENTS  
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*Prepared for publication by*

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## ATOMIC WEIGHTS OF THE ELEMENTS 1983

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  $4.002602 \pm 2$  ( $4.00260 \pm 1$ ); Lithium  $6.941 \pm 2$  ( $6.941 \pm 3$ ); Boron  $10.811 \pm 5$  ( $10.81 \pm 1$ ); Sulfur  $32.066 \pm 6$  ( $32.06 \pm 1$ ); Calcium  $40.078 \pm 4$  ( $40.08 \pm 1$ ); Scandium  $44.95591 \pm 1$  ( $44.9559 \pm 1$ ); Chromium  $51.9961 \pm 6$  ( $51.996 \pm 1$ ); Zinc  $65.39 \pm 2$  ( $65.38 \pm 1$ ); Gallium  $69.723 \pm 4$  ( $69.72 \pm 1$ ); Zirconium  $91.224 \pm 2$  ( $91.22 \pm 1$ ); Ruthenium  $101.07 \pm 2$  ( $101.07 \pm 3$ ); Tin  $118.710 \pm 7$  ( $118.69 \pm 3$ ). These values are incorporated in the Table of Standard Atomic Weights of the Elements 1983. The Table lists estimated uncertainties between  $\pm 1$  and  $\pm 9$  in the last tabulated figure, which represents a departure from the practice in prior years of restricting uncertainties to two alternative values, either  $\pm 1$  or  $\pm 3$ . 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  $\pm 1$  or  $\pm 3$  in the last place should be abandoned and that, in future, the full range of uncertainties between  $\pm 1$  and  $\pm 9$  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  $\pm 1$  and  $\pm 9$ , 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  $6.941 \pm 3$  to  $6.941 \pm 2$ . The latter situation is exemplified by the more precise value recommended for calcium of  $40.078 \pm 4$  compared with the 1981 value  $40.08 \pm 1$ .

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  $A_r(\text{He}) = 4.0026$  for the atomic weight of helium, which was the nuclidic mass of the isotope  $^4\text{He}$  to four decimal places. The other stable isotope,  $^3\text{He}$ , 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  $^3\text{He}$  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  $A_r(\text{He}) = 4.00260 \pm 1$  which still equalled the nuclidic mass of  $^4\text{He}$ , but now given to five decimals. The uncertainty of  $\pm 1$  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  $A_r(\text{He}) = 4.0026019$ . 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  $A_r(\text{He}) = 4.002602 \pm 2$ .

For the first time the recommended value for  $A_r(\text{He})$  differs from the nuclidic mass of  $^4\text{He}$  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  $^4\text{He}$  can be found in the ores of the naturally occurring radioactive elements, from which only that isotope emanates.

### Lithium

The value of  $A_r(\text{Li}) = 6.939$  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  $A_r(\text{Li}) = 6.941 \pm 3$  (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  $A_r(\text{Li}) = 6.9391 \pm 2$ ,  $6.94015 \pm 30$  and  $6.94069 \pm 29$ , 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  $A_r(\text{Li}) = 6.941 \pm 2$  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  $\pm 2$  includes all of the published values.

### Boron

In its 1961 Report (Ref. 2) the Commission recommended for the atomic weight of boron  $A_r(\text{B}) = 10.811 \pm 3$  based on mass spectrometric measurements. In accordance with Commission policy the uncertainty  $U_r(\text{B}) = \pm 0.003$  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  $A_r(\text{B}) = 10.8086$  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  $A_r(\text{B})$  so that  $10.81 \pm 1$  became the recommended IUPAC value. Only now when the Commission permits uncertainties of any single digit number is it possible to revert to  $A_r(\text{B}) = 10.811$ , but now with  $U_r(\text{B}) = \pm 0.005$  thereby covering the above more unusual boron sources. When the source of boron is known to be Turkish  $A_r(\text{B}) = 10.809$  would be a significantly better value to use, and for Californian boron  $A_r(\text{B}) = 10.812$  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  $A_r(\text{B})$  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  $A_r(\text{S}) = 32.064 \pm 3$  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  $A_r(\text{S})$  to  $32.06 \pm 1$ . 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  $A_r(\text{S})$  values and therefore recommended  $A_r(\text{S}) = 32.066 \pm 6$  to cover all normal sources.

### Calcium

The value of  $A_r(\text{Ca}) = 40.08$  for the atomic weight of calcium was adopted by the Commission in its 1961 Report (Ref. 2) and an uncertainty of  $\pm 0.01$  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  $A_r(\text{Ca}) = 40.078 \pm 0.004$ . 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  $A_r(\text{Ca}) = 40.080$  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:

| <u>Year</u> | <u>Investigator</u>             | <u><math>A_r(\text{Ca})</math></u> |
|-------------|---------------------------------|------------------------------------|
| 1938        | Nier (Ref. 25)                  | 40.077                             |
| 1948        | White and Cameron (Ref. 27)     | 40.079                             |
| 1960        | Omura <u>et al.</u> (Ref. 28)   | 40.081                             |
| 1962        | Stauffer and Honda (Ref. 29)    | 40.077                             |
| 1968        | Shima <u>et al.</u> (Ref. 30)   | 40.081                             |
| 1971        | Coleman (Ref. 31)               | 40.080                             |
| 1972        | Moore and Machlan (Ref. 32)     | 40.078                             |
| 1978        | Russell <u>et al.</u> (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  $A_r(\text{Ca})$

$$= 40.079 \pm 0.002.$$

The recommended value,  $40.078 \pm 0.004$ , 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%  $^{40}\text{Ca}$ ).

### Scandium

Scandium is a mononuclidic element, for which the Commission in 1961 (Ref. 2) recommended the atomic weight,  $A_r(\text{Sc}) = 44.956$ , although the mass of its nuclide was known with far superior accuracy. At that time the Commission had in mind the possibility 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  $^{46}\text{Sc}$ . 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  $A_r(\text{Sc}) = 44.9559 \pm 1$ , because on the basis of theory and experience the likelihood of the existence of such an isomer of  $^{46}\text{Sc}$  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  $^{45}\text{Sc}$  is given as  $44.9559174 \pm 22$  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)  $^{45}\text{Sc}$  was given a mass of  $44.9559136 \pm 15$  u which by the above rule should lead to  $A_r(\text{Sc}) = 44.95591 \pm 1$  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  $^{45}\text{Sc}$  was closely tied to that of the titanium isotopes which in turn are closely tied to  $^{12}\text{C}$ , 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,  $A_r(\text{Cr}) = 51.996 \pm 1$ , 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  $\pm 1$  or  $\pm 3$ , the Commission in 1983 decided to reduce the uncertainty of  $\pm 1$  in the third decimal place to  $\pm 6$  in the fourth decimal place thus enabling an additional digit in the atomic weight value itself to be quoted giving  $A_r(\text{Cr}) = 55.9961 \pm 6$ .

### Zinc

In its 1961 Report (Ref. 2) the Commission recommended  $A_r(\text{Zn}) = 65.37$  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  $A_r(\text{Zn}) = 65.387$ . Recognizing this unresolved discrepancy the Commission in 1969 (Ref. 3) assessed the uncertainty as  $\pm 0.03$ . Marinenko and Foley (Ref. 44) in 1971 published a coulometric determination which also yielded a higher value  $A_r(\text{Zn}) = 65.377 \pm 0.003$  whereupon the Commission in its 1971 Report (Ref. 45) changed the recommended value to  $A_r(\text{Zn}) = 65.38 \pm 1$ . Later Rosman (Ref. 46), using a double spike technique to calibrate for fractionation, determined  $A_r(\text{Zn}) = 65.396 \pm 0.005$  by mass spectrometry.

Faced with the discrepancy between these highly precise values, the Commission now recommends  $65.39 \pm 0.02$  for the atomic weight of zinc. This value is weighted towards the calibrated mass spectrometric measurement of Rosman (Ref. 46), but the uncertainty of  $\pm 0.02$  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  $A_r(\text{Ga}) = 69.72$  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  $\pm 0.01$  to this atomic weight.

A precise coulometric assay of gallium and arsenic by Marinenko (Ref. 51) led to the value of  $A_r(\text{Ga}) = 69.737 \pm 6$ . 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  $69.724 \pm 3$ . 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  $A_r(\text{Ga})$

=  $69.723 \pm 4$ .

### 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  $\pm 0.01$  by the Commission in 1969 (Ref. 3). Since then two absolute isotopic compositions have been reported by Minster and Ricard (Ref. 56) yielding  $A_r(\text{Zr}) = 91.224$  with an estimated uncertainty of  $+0.002$  and  $-0.005$ , and by Nomura *et al.* (Ref. 57) yielding  $A_r(\text{Zr}) = 91.2235 \pm 5$ .

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 composition 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  $A_r(\text{Zr}) = 91.224 \pm 2$ .

### Ruthenium

The Commission at its meeting in 1983 has reduced the uncertainty associated with the atomic weight of ruthenium from  $\pm 0.03$  to  $\pm 0.02$  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  $A_r(\text{Ru})$  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  $A_r(\text{Sn}) = 118.69$  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  $\pm 0.03$  to this atomic weight (Ref. 3). This value of  $A_r(\text{Sn})$  was retained despite the fact that a number of uncalibrated mass spectrometric determinations indicated a slightly higher value.

The new value  $118.710 \pm 7$  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  $\pm 7$  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  $^3\text{He}$  abundance of  $3.3 \times 10^{-4}$  atom percent. Included in this range are  $^3\text{He}$ -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  $4 \times 10^{-3}$  atom percent corresponding to a high  $^3\text{He}$  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  $A_r(\text{N})$  value corresponding to the highest measured  $^{15}\text{N}$  abundance in soils is equal to 14.00681 (Ref. 68) which falls outside the quoted range  $14.0067 \pm 1$ . 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  $A_r(\text{Mg})$  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,  $A_r(\text{Si}) = 28.0855 \pm 3$  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  $\pm 0.0003$ , 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  $A_r(^{12}\text{C})=12$ )

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  $\pm 1$  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 $\pm$ 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 $\pm$ 5   | m r       |
| Bromine            | Br     | 35            | 79.904           |           |
| Cadmium            | Cd     | 48            | 112.41           | g         |
| Caesium            | Cs     | 55            | 132.9054         |           |
| Calcium            | Ca     | 20            | 40.078 $\pm$ 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 $\pm$ 6  |           |
| Cobalt             | Co     | 27            | 58.9332          |           |
| Copper             | Cu     | 29            | 63.546 $\pm$ 3   | r         |
| Curium*            | Cm     | 96            |                  | A         |
| Dysprosium         | Dy     | 66            | 162.50 $\pm$ 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 $\pm$ 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 $\pm$ 3   | g         |
| Gallium            | Ga     | 31            | 69.723 $\pm$ 4   |           |
| Germanium          | Ge     | 32            | 72.59 $\pm$ 3    |           |
| Gold               | Au     | 79            | 196.9665         |           |
| Hafnium            | Hf     | 72            | 178.49 $\pm$ 3   |           |
| Helium             | He     | 2             | 4.002602 $\pm$ 2 | g r       |
| Holmium            | Ho     | 67            | 164.9304         |           |
| Hydrogen           | H      | 1             | 1.00794 $\pm$ 7  | g m r     |
| Indium             | In     | 49            | 114.82           | g         |
| Iodine             | I      | 53            | 126.9045         |           |
| Iridium            | Ir     | 77            | 192.22 $\pm$ 3   |           |
| Iron               | Fe     | 26            | 55.847 $\pm$ 3   |           |
| Krypton            | Kr     | 36            | 83.80            | g m       |
| Lanthanum          | La     | 57            | 138.9055 $\pm$ 3 | g         |
| Lawrencium*        | Lr     | 103           |                  | A         |
| Lead               | Pb     | 82            | 207.2            | g r       |
| Lithium            | Li     | 3             | 6.941 $\pm$ 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 $\pm$ 3   |           |
| Molybdenum         | Mo     | 42            | 95.94            |           |
| Neodymium          | Nd     | 60            | 144.24 $\pm$ 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     |           |
| 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.

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\* Element has no stable isotopes

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

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  $\pm 1$  in the last digit, unless otherwise noted.

## Order of Atomic Number

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

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

| <u>Atomic Number</u> | <u>Names</u>      | <u>Symbol</u> | <u>Atomic Weight</u> | <u>Footnotes</u> |
|----------------------|-------------------|---------------|----------------------|------------------|
| 63                   | Europlium         | 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                |

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\* 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  $\alpha$  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  | $2.6 \times 10^6$     | a |
|               |              |                | 98     | 97.9072  | $4.2 \times 10^6$     | a |
|               |              |                | 99     | 98.9063  | $2.13 \times 10^5$    | 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 | $7.54 \times 10^4$    | a |
|               |              |                | 232    | 232.0381 | $1.40 \times 10^{10}$ | a |
| 91            | Protactinium | Pa             | 231    | 231.0359 | $3.28 \times 10^4$    | a |
| 92            | Uranium      | U              | 233    | 233.0396 | $1.592 \times 10^5$   | a |
|               |              |                | 234    | 234.0409 | $2.45 \times 10^5$    | a |
|               |              |                | 235    | 235.0439 | $7.04 \times 10^8$    | a |
|               |              |                | 236    | 236.0456 | $2.342 \times 10^7$   | a |
|               |              |                | 238    | 238.0508 | $4.468 \times 10^9$   | 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 NUMBRER | MASS     | HALF-LIFE          | * |
|---------------|--------------|--------|-----------------|----------|--------------------|---|
| 93            | Neptunium    | Np     | 237             | 237.0482 | $2.14 \times 10^6$ | a |
|               |              |        | 239             | 239.0529 | 2.350              | d |
| 94            | Plutonium    | Pu     | 238             | 238.0496 | 87.7               | a |
|               |              |        | 239             | 239.0522 | $2.41 \times 10^4$ | a |
|               |              |        | 240             | 240.0538 | $6.56 \times 10^3$ | a |
|               |              |        | 241             | 241.0568 | 14.34              | a |
|               |              |        | 242             | 242.0587 | $3.76 \times 10^5$ | a |
|               |              |        | 244             | 244.0642 | $8.2 \times 10^7$  | a |
| 95            | Americium    | Am     | 241             | 241.0568 | 432                | a |
|               |              |        | 243             | 243.0614 | $7.37 \times 10^3$ | a |
| 96            | Curium       | Cm     | 243             | 243.0614 | 28.5               | a |
|               |              |        | 244             | 244.0627 | 18.11              | a |
|               |              |        | 245             | 245.0655 | $8.5 \times 10^3$  | a |
|               |              |        | 246             | 246.0672 | $4.7 \times 10^3$  | a |
|               |              |        | 247             | 247.0703 | $1.58 \times 10^7$ | a |
|               |              |        | 248             | 248.0723 | $3.4 \times 10^5$  | a |
| 97            | Berkelium    | Bk     | 247             | 247.0703 | $1.4 \times 10^3$  | a |
|               |              |        | 249             | 249.0750 | $3.3 \times 10^2$  | d |
| 98            | Californium  | Cf     | 249             | 249.0748 | 351                | a |
|               |              |        | 250             | 250.0764 | 13.1               | a |
|               |              |        | 251             | 251.0796 | $9.0 \times 10^2$  | 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  ${}^7\text{Li}/{}^6\text{Li}$  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  ${}^{21}\text{Ne}/{}^{20}\text{Ne}$  ratio is 1.00 (compared with the terrestrial value of 0.00298) by Hintenberger and Wanke (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  ${}^{158}\text{Gd}/{}^{157}\text{Gd}$  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  $4.6 \times 10^9$  years ago, some radioactive isotopes, now extinct in the Solar System, were still present. Enrichments have been reported in  ${}^{26}\text{Mg}$ ,  ${}^{107}\text{Ag}$ ,  ${}^{129}\text{Xe}$  and  ${}^{142}\text{Nd}$  caused by the decay of the extinct radionuclides  ${}^{26}\text{Al}$ ,  ${}^{107}\text{Pd}$ ,  ${}^{129}\text{I}$  and  ${}^{146}\text{Sm}$  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  ${}^{40}\text{Ar}$  and  ${}^{40}\text{Ca}$  (from  ${}^{40}\text{K}$ ),  ${}^{87}\text{Sr}$  ( ${}^{87}\text{Rb}$ ),  ${}^{138}\text{Ce}$  ( ${}^{188}\text{La}$ ),  ${}^{143}\text{Nd}$  ( ${}^{147}\text{Sm}$ ),  ${}^{176}\text{Hf}$  ( ${}^{176}\text{Lu}$ ),  ${}^{187}\text{Os}$  ( ${}^{187}\text{Re}$ ) and  ${}^{206}\text{Pb}$ ,  ${}^{207}\text{Pb}$ ,  ${}^{208}\text{Pb}$  and  ${}^4\text{He}$  ( ${}^{235}\text{U}$ ,  ${}^{238}\text{U}$ ,  ${}^{232}\text{Th}$ ) will occur.

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

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

Similar enrichments in  ${}^4\text{He}/{}^3\text{He}$  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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