PHYSICAL AND INORGANIC CHEMISTRY

Report of the International Commission on Atomic Weights* (1961)

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Introduction

Since early in this century the atomic weights of chemical elements have been referred to oxygen, with assigned integral atomic weight of 16. The discovery by Giauque and Johnston (G2) in 1929, that oxygen contains small amounts of isotopes of mass numbers 17 and 18, and later observations that the proportions of these isotopes are slightly variable, made the element oxygen somewhat unsatisfactory as a reference species for chemical determinations of atomic weights and unacceptable for a scale of nuclidic masses. For the latter purpose, a new scale, based on 16 as the nuclidic mass of oxygen 16, became firmly established as the one to which physical measurements of nuclidic masses were referred.

By 1940 the proportions of ^{17}O and ^{18}O in oxygen had been so well established that from that year forward the International Commission used the divisor 1.000275 to convert values based on the physical scale to values used in the International Table of Atomic Weights. Thus, in actual practice, if not by formal definition, there has been, since 1940, an exact relationship between the two scales. Uncertainties in atomic weights arising from variability in the composition of oxygen were relatively unimportant until the increasing accuracy of physical measurements made it possible to improve the exactness with which the atomic weights of the simple, or mononuclidic, elements could be stated.

The problems created by having two scales so nearly alike have led to discussions (W6, B4) over a period of years about the possibility of

adopting a unified scale. To do this would require abandoning one of the existing scales in favor of the other or abandoning both for a new scale. It was clear that abandoning the physical scale in favor of the chemical scale would be unacceptable for various reasons to those who used it—in particular, because on the chemical scale no single nuclide would have an integral mass and the useful device of the absolute mass unit as $^1/_{16}$ of the atomic mass of ^{16}O would be sacrificed. The other alternative, of adopting the physical scale exclusively, was known to be unacceptable to many chemists because this change would introduce a systematic error of nearly 3 parts in 10,000 into all data recorded on a gram-equivalent or molar basis.

At the conclusion of the Commission's meeting in Paris in 1957 no satisfactory solution had been found, and a decision was deferred. However, soon after the Paris meeting two members of the Commission, in correspondence with E. Wichers, then its President, independently suggested consideration of a nuclide, other than ^{16}O, as a reference species for a new, unified scale. J. Mattauch, on the basis of an earlier discussion with A. O. C. Nier, pointed out that ^{12}C, with assigned mass 12, might be as acceptable a reference species for physicists as ^{16}O, especially since it was already the commonly used operational standard for mass spectroscopy. Its adoption would require no greater systematic changes in the table of atomic weights than would an earlier proposal to adopt the element fluorine, with assigned atomic weight 19, a proposal which was unacceptable to physicists. A scale based on $^{19}F = 19$ would have made atomic weights larger by about 4 parts in 100,000. The ^{12}C scale results in a change of the same magnitude but in the opposite direction. A. Ölander pointed out that an isotopic species, such as ^{12}C, should be just as acceptable to chemists as the element fluorine but that ^{18}O, with assigned mass of 18, might be preferable because it would involve an

even smaller systematic change in the table of atomic weights. These suggestions were recorded in an addendum to the Commission's report for 1957 and furnished the basis for further exploration of the possibility of adopting a unified scale.

At the 1959 meeting of the Commission, during the 20th Conference of IUPAC at Munich, the Commission recommended the adoption of ^{12}C, with assigned integral mass of 12, as the reference species for a new scale, provided the International Union of Pure and Applied Physics acted similarly to adopt the ^{12}C scale in the place of the ^{16}O scale. This action was taken by IUPAP at its General Assembly in Ottawa in 1960.

In anticipation of the final adoption of the new scale, the Commission in 1959 assigned to A. E. Cameron and E. Wichers the task of preparing a revised table of atomic weights for consideration by the Commission in 1961. Dr. Cameron was elected a member in 1959 to succeed Prof. A. O. C. Nier. Dr. Wichers, who was succeeded as President by Prof. T. Batuecas, continued as an associate member of the Commission. Drs. Cameron and Wichers divided between them the task of an element-by-element review in accordance with their respective specialized interests in the physical and chemical work from which atomic weights are derived, and collaborated in preparing the portion of this report that contains the material on which the Commission based its recommendations. Prof. Batuecas reviewed the experimental work on the density of neon and recalculated the atomic weight of this element.

Dr. Cameron was assisted in his work by Prof. A. O. C. Nier, who also continued as an associate member of the Commission, and by Mr. E. J. Spitzer of the Oak Ridge National Laboratory. Dr. Wichers received extensive assistance in his part of the work from Dr. D. Norman Craig and was aided also by Dr. Daniel Leussing, both members of the staff of the National Bureau of Standards.

Prior to the Montreal meeting of the Commission, Drs. Cameron and Wichers met to discuss the results of their individual reviews of experimental evidence and prepared a table of recommended values which was transmitted to the President of the Commission for distribution among the members. When the Commission convened at Montreal the recommendations were examined in detail and, with some modifications, incorporated in the proposed 1961 Table of Atomic Weights, based on 12 as the assigned nuclidic mass of ^{12}C. This table was submitted to the Committee of the Inorganic Section and, on recommendation of that Committee, was approved by the Council of the Union.

In submitting its report the Commission also recommended that its name be changed to the Commission on Atomic Masses, and that the table be known as the Table of Relative Atomic Masses rather than the Table of Atomic Weights. The Committee of the Inorganic Section withheld endorsement of these recommendations pending their referral to the Commission on Inorganic Nomenclature. After consideration of this question by correspondence, the Commission on Nomen-clature recommended retaining the name "Commission on Atomic Weights" and changing the title "Table of Atomic Weights" to "Table of Relative Atomic Weights." These terms are, therefore, used in this report.

Review of Nuclidic Masses and Isotopic Abundances

When the General Assembly of IUPAP adopted the mass scale based on ^{12}C = 12, on 8 September, 1960, the newly formed "Commission on Nuclidic Masses" was instructed to arrange for the wide and rapid distribution of the Mass Table based upon this reference nuclide. The table is a complete and consistent list of nuclidic masses computed with least squares methods from all the significant experimental data available from doublet measurements and from Q-values. This extensive compilation made by Everling, König, Mattauch and Wapstra (E2) (1960) has been the principal source of values for the recalculation of atomic weights, based upon physical measurements. In the region from samarium through thallium, masses from the recent determinations by Bhanot, Johnson and Nier (B41) (1960) have been used. These data were not available to Everling, König, Mattauch and Wapstra for inclusion in their 1960 compilation. (A revision of the Table of Relative Nuclidic Masses by the same authors has appeared in 1962 and includes these data.) These two sources of nuclidic masses will be referred to repeatedly in this report and will be designated EKMW (1960) and BJN (1960).

The scale conversion factor between the ^{16}O and ^{12}C scales of nuclidic masses from the adjustment by EKMW (E3) (1961) is

$$1 \text{ u} = (1.000317917 \pm 0.000000017)\text{MU}(^{16}\text{O} = 16)$$

and the reciprocal of this is 0.999682184 ± 17. This factor has been used to convert the masses of BJN (1960), which were given by them on the ^{16}O scale, to the ^{12}C scale.

In the case of the simple or "mononuclidic" elements the mass values and the values of the relative atomic weights are identical, and the latter are given in this report to a minimum of five digits. In no case is the last digit uncertain if the element is truly mononuclidic. For many of these elements careful mass spectrometric observations have been made and very low limits of abundances have been established for the existence of other stable nuclides of the elements. In all cases radioactive nuclides are known to exist in adjacent mass positions, and the existence of undiscovered stable isotopes is considered very unlikely.

In the case of the polynuclidic elements the uncertainty in the values of the relative atomic weights arises entirely from limitations in the accuracy of the isotopic abundance measurements. These have been tabulated to December 1958 in Nuclear Data Tables (N9) (1959). These tables are referred to in the text as NDT (1959). Isotopic abundances are stated in atom per cent. References to the original literature are cited except where the original literature is not readily accessible, or where a number of isotopic determinations have been averaged to give the abundances used

in the atomic weight calculation. In these cases the reference is to NDT (1959).

In only a limited number of cases have "absolute" mass spectrometric abundance measurements been made by standardizing the mass spectrometer with calibration mixtures prepared from separated isotopes of high chemical and isotopic purity. The elements for which this has been done are notably boron, nitrogen, chlorine, argon, chromium, silver and uranium. Determinations of this kind are urgently needed for many other elements for which atomic weights cannot be stated presently with the desired accuracy. Work of this kind is hardly less exacting than were the classical determinations of atomic weights by chemical measurements.

In the selection of abundance measurements upon which to base the calculated atomic weights, it has been necessary to exercise some judgment. Preference has been given, in general, to measurements made specifically for the determination of natural abundances rather than to those made incidentally to other studies. Observations in which an attempt was made to estimate systematic errors by measurement of another element in the same mass region for which the abundances are well established, while not absolute, are nevertheless to be preferred. Where no judgment was made between published measurements, the unweighted average of the results was used. In many cases it was observed that the published abundances did not add to exactly 100%. If the original ratios were available the abundances were recalculated. If these ratios could not be found, the practice was to prorate the discrepancy over all of the masses. The last small discrepancy was added to or subtracted from the mass or masses nearest the center of mass of the system.

Review of Chemical Determinations

During the past 25 years the determination of atomic weights by mass spectrometric measurements and by the calculation of mass changes involved in nuclear reactions has assumed constantly increasing importance. Today such measurements supply virtually the only new evidence bearing on the selection of values for the International Table of Relative Atomic Weights. Prior to the current revision, evidence derived from physical measurements provided the primary or exclusive basis for revisions of the atomic weights of 32 elements. In the 1961 table, this number is considerably larger and includes all of the elements regarded as mononuclidic. For some of the remaining elements listed in the table, values derived from physical measurements agree within their estimated limits of accuracy with those based on recalculated chemical determinations. There remain a small number of elements for which the values derived from physical measurements differ significantly from those derived from chemical measurements. These physically derived values were not regarded as sufficiently reliable to displace the recalculated chemical values.

Because silver, chlorine, and bromine have been so extensively involved in the chemical determination of atomic weights, a thorough reappraisal of these key elements was essential for the preparation of this report. The discussion of this critical review follows.

Ratios of Silver to Chlorine and Silver to Bromine

The combining weights of silver with chlorine and of silver with bromine were determined with high precision both by Richards and Baxter and their associates at Harvard, and by Hönigschmid and his associates at Munich. Richards and Wells (R6) (1905) dissolved weighed amounts of silver, precipitated silver chloride with hydrochloric acid, and collected, fused, and weighed the chloride. In seven of ten determinations the silver chloride was transferred twice in the course of the operation. The ratio AgCl/Ag was 1.328667, with a standard deviation of the mean of 0.000010. Three of the determinations were made without transfer of the silver chloride from the vessel in which it was formed. For these three the observed ratio was 1.328673, with a standard deviation of 0.000014.

In nine experiments Hönigschmid and Chan (H23) (1927) reduced weighed amounts of chlorine with arsenite and titrated the chloride nephelometrically with silver nitrate prepared from weighed amounts of silver. They obtained, thereby, 1.328668 for the ratio of (Ag + Cl)/Ag with a standard deviation of 0.000002 for the mean. In addition they collected and weighed the silver chloride in eight of the experiments. The results of these experiments, subsequently corrected by Hönigschmid (H28) (1931) for errors arising from the solubility of silver chloride, yielded a slightly different value, 1.328682, with a standard deviation of 0.000002. Because questions can be raised about the validity of their calculated corrections this result deserves less consideration than the other, which involved no corrections.

A third ratio for AgCl/Ag can be computed as the quotient of the ratios AgNO₃/Ag and AgNO₃/AgCl. The ratio AgNO₃/Ag as determined by Hönigschmid, Zintl and Thilo (H24) (1927) was 1.5747906, with 0.0000022 as the standard deviation of the mean of 14 determinations. Hönigschmid and Schlee (H40) (1936) measured the ratio AgNO₃/AgCl by converting the nitrate to chloride without transfer. The observed value was 1.1852410, with a standard deviation of the mean of eight measurements of 0.0000008. The ratio AgCl/Ag obtained as the quotient of the two ratios given above is 1.328667, with a standard deviation of 0.000002. Since the two ratios involving AgNO₃ were measured in the same laboratory, it is reasonable to assume that the nitrate was prepared in the same way and thus that uncertainties about its exact composition are minimized. It may be noted that this calculated ratio agrees exactly with that obtained from the first seven determinations of Richards and Wells and almost exactly with the first of the two ratios derived from the results of Hönigschmid and Chan.

The combining weight of silver with bromine was also determined in both the Harvard and Munich laboratories. Baxter (B5) (1906), after converting weighed amounts of silver to silver nitrate, precipitated the silver with hydrobromic acid, and collected and weighed the silver bromide. The observed ratio AgBr/Ag was 1.740788, with a

standard deviation of 0.000007 for the mean of 18 determinations. Another value for this ratio can be calculated from the results, given in the same publication, of 13 experiments in which silver bromide was converted to silver chloride. If the ratio for AgBr/AgCl so obtained (1.310170) is multiplied by the previously mentioned ratio for AgCl/Ag (1.328667), the ratio for AgBr/Ag is 1.740780. This ratio differs by only 5 parts in one million from the one obtained by the synthesis of silver bromide.

Hönigschmid and Zintl (H18) (1923) reduced weighed amounts of bromine with ammonium arsenite, titrated the bromide ion with weighed amounts of silver, and collected and weighed the silver bromide. The mean difference between the weight of the silver bromide and the sum of the weights of silver and bromine used was 0.5 part per million. The ratio AgBr/Ag thus obtained was 1.740785. The standard deviation of the mean of 8 determinations was 0.000006. The ratio agrees within the indicated precision with that obtained by Baxter.

The Atomic Weights of Silver, Chlorine and Bromine

The excellent agreement of the Harvard and Munich determinations of the combining ratios of silver, chlorine and bromine provides very strong evidence that the values 107.880, 79.916 and 35.457, which have been accepted for many years as the atomic weights of silver, bromine and chlorine are in a very reliable relation to one another. The accuracy of the values depends, however, on the accuracy of the relationship of any one of them to 16 as the assigned atomic weight of oxygen on the chemical scale. The classical effort to determine this relationship to oxygen was directed to silver. The value 107.880, which has been accepted for many years, was derived from the ratio AgNO$_3$/Ag, which was measured both at Harvard and at Munich with very good agreement. Other investigations, which tended toward a lower value, never resulted in a change in the International Table. The most extensive revision of the Table of Atomic Weights prior to the current one occurred in 1925. In that year the International Committee on Chemical Elements (A5) reported as follows: "We have retained the old value for the secondary standard, Ag = 107.880 although we are of the opinion that this value is slightly higher than the true one. If a more probable value (between 107.870 and 107.876) had been adopted for this secondary standard, many atomic weights dependent upon it (about 42 in number) would be lowered in the same proportion. Since the difference is of slight importance for most purposes, we believe it advisable to avoid the inconvenience of a change until more certain evidence has been obtained."

Changes in atomic weights are indeed an inconvenience to those who employ these quantities in their daily work. Reluctance to make changes without compelling evidence has always characterized the actions of the International Commission. The present situation, in which the adoption of a new scale resulted automatically in changes in atomic weights expressed to a precision of 1 part in

25000 or more provides the justification for the complete revision that the commission undertook this year.

The following discussion deals with seven determinations that were selected as the most reliable of those that can be used to derive the atomic weight of silver. All the reported data were recalculated on the basis of the currently recommended values for the atomic weights of nitrogen, oxygen and iodine and the ratio for AgCl/Ag discussed above. The atomic weights are derived from physical measurements and are accurately known. The ratio AgCl/Ag, 1.328667, also appears to be accurate. In addition to the seven chemical determinations, two recent mass spectrometric determinations, in which calibration standards were employed, are included.

SILVER CONVERTED TO SILVER NITRATE.— Richards and Forbes (R7) (1907): The observed ratio (1.574800) used in the recalculation was not adjusted, as it was by the authors, for supposed but unconfirmed traces of impurities in the silver nitrate. The operation involved no transfer of material. The value obtained is 107.8721, with a standard deviation of the mean of 0.0003. The variation of the isotopic composition of natural oxygen introduces an uncertainty not greater than ±0.0005.

SILVER NITRATE CONVERTED TO SILVER.— Hönigschmid, Zintl and Thilo (H24) (1927): The observed ratio for AgNO$_3$/Ag was 1.574790. The operation involved no transfer. The value obtained is 107.8740, with a standard deviation of the mean of 0.0004.

SYNTHESIS OF SILVER IODIDE.—Baxter and Lundstedt (B38) (1940): The synthesis was accomplished by dissolving silver in nitric acid, reducing iodine to hydriodic acid with hydrazine, combining the solutions, collecting the silver iodide, and weighing it after fusion. One transfer was involved. The observed ratio, I/Ag, was 1.176433, from which the atomic weight of silver is 107.8722, with a standard deviation of the mean of 0.0004.

CONVERSION OF SILVER IODIDE TO SILVER CHLORIDE.—The conversion of silver iodide to silver chloride was twice investigated in Hönigschmid's laboratory and twice in Baxter's. Each of the experimental values for this ratio is combined for the purposes of the present calculation with the value of the AgCl/Ag ratio, 1.328667, to avoid using an assigned value for the atomic weight of chlorine. The combined ratios give silver relative to iodine, which is mononuclidic.

AgI/AgCl Ratios

Hönigschmid and Striebel (H17) (1931); ratio, 1.638077; Ag = 107.8698, eight determinations, standard deviation 0.0003.

Hönigschmid and Striebel (H31) (1932); ratio, 1.638078 Ag = 107.8697, 16 determinations, standard deviation 0.0002.

Baxter and Titus (B37) (1940); ratio, 1.638064; Ag = 107.8714, 12 determinations, standard deviation 0.0004.

Baxter and Lundstedt (B39) (1940); ratio, 1.638072; Ag = 107.8704, 10 determinations, standard deviation 0.00014.

The average of the four values for silver obtained from these ratios is 107.8703 (AgCl/Ag = 1.328667).

The seven determinations discussed above yield the following values for the atomic weight of silver:

Richards and Forbes, Ag/AgNO₃	107.8721
Hönigschmid, Zintl and Thilo, AgNO₃/Ag	107.8740
Baxter and Lundstedt, AgI/Ag	107.8722
Hönigschmid and Striebel, AgI/AgCl	107.8698
Hönigschmid and Striebel, AgI/AgCl	107.8697
Baxter and Titus, AgI/AgCl	107.8714
Baxter and Lundstedt, AgI/AgCl	107.8704

There appears to be no justification for discriminating among these results on the basis of their relative precision or of suspected sources of systematic errors.

Both of the recent determinations of the isotopic abundance ratio of silver were based on calibrations with synthesized mixtures of the separated isotopes ^{107}Ag and ^{109}Ag. The results reported in terms of the atomic weight of silver on the ^{12}C scale (masses from EKMW) (1960) are:

(a) Shields, Craig and Dibeler (S5) (1960); Ag = 107.8685, with an estimated uncertainty of ±0.0013.

(b) Crouch and Turnbull (C7) (1962); Ag = 107.8694, with an estimated uncertainty of ±0.0026. (The estimated uncertainties assigned to these values are not merely measures of precision, as are the standard deviations given for the values derived from chemical ratios, but include judgments concerning possible systematic errors. The estimates are for a confidence level of 95%.)

Because no valid judgment is possible concerning the relative accuracy of the individual values the Commission recommended that 107.870 ± 0.003 be taken as the atomic weight of silver for the 1961 Table of Relative Atomic Weights. It is to be hoped that further experimental work will lead to an increase in the accuracy that can be assigned to the atomic weight of this key element. It may be noted that 0.004 of the change of 0.010 from the previously accepted value is due to the change of scale. The remainder results from recalculation of experimental work applicable to the element and the inclusion of measurements involving silver iodide, as well as the recent mass spectrometric measurements.

The recommended values for the atomic weights of chlorine and bromine were derived from the new value for silver and the combining weight ratios previously discussed. The values thus obtained are 35.453 ± 0.001 for chlorine and 79.909 ± 0.002 for bromine. The changes from the previously accepted values for these elements are proportional to the change for silver.

Reliability of the Ratios of Chlorides and Bromides to Silver

The method that has been most extensively used for the chemical determination of atomic weights is to determine the weight of silver that is equivalent to a known weight of the chloride or bromide of an element. In brief, the procedure was as follows: after the approximately equivalent amounts of silver and the chosen halide had been allowed to react in solution, the equivalence point was determined by successive additions of small amounts of silver or halide ion, as needed, until a further addition of either ion produced equal opalescence in two portions of the solution. Efforts were made to minimize the occlusion of either of the reacting ions in the silver halide precipitate, and there was evidence that this necessary condition could be closely approached by using relatively dilute solutions and by prolonged contact of the silver

halide with the supernatant solution. Opalescence was measured by a device known as the nephelometer. The entire procedure came to be known as the Harvard method because it was developed at Harvard University by Richards and Baxter and their associates. However, it was used by many other investigators, notably by Hönigschmid and his associates at Munich.

In many investigations the precipitated silver halide was collected and weighed, with appropriate corrections, if required, for the amount left in solution. When this procedure was followed, the investigation yielded not only ratios between the chosen halide and silver but between the chosen halide and the corresponding silver halide. It is clear that whereas the reliability of the first of these ratios required only an exact stoichiometric relation between silver and halogen in the precipitate, that is, a precipitate free of occluded silver or halide ions, the second ratio required also that the precipitate be free of significant amounts of any impurity that would not be volatilized during the preparation of the precipitate for weighing. That this condition was often fulfilled is evident from the many instances of close agreement in the values for atomic weights derived from the two ratios.

Although the "Harvard" method was thought by its users to be free of significant systematic errors, the degree of its accuracy was never determined objectively. In comparatively recent years it has been shown that the criterion of "equal opalescence," as marking the equivalence point, was not entirely valid. Scott (S2) (1961) has published a critical discussion of the procedure. He concludes that errors amounting to a few parts in one hundred thousand may occur and that the sign of the error depends upon whether the silver or the halide ion is in excess when the equivalence point is approached. He points out that few of the publications in which the procedure was involved contain the detailed information needed to judge the sign of the error or to estimate its magnitude. However, it appears that the usual laboratory practice tended to produce an approximate balance of these small errors in a series of determinations.

The very high accuracy of the atomic weights of mononuclidic elements derived from physical methods provides a new and reliable means for judging the accuracy of the chemical determinations for these elements. Table I compares atomic weights derived from physical measurements with those derived from halide–silver and halide–silver halide ratios in the Harvard and Munich laboratories for all the mononuclidic elements studied there.* Limiting the data used in the table to those obtained at Harvard and Munich is not intended to disparage the work of other investigators who used the "Harvard" method. It is believed that the validity of this test of the method's accuracy is enhanced by using only the data obtained by the two most experienced groups.

* A similar comparison was made about ten years ago by Arthur F. Scott and Max Bettman (*Chem. Rev.*, **50**, 363 (1952)). Because the physically derived values for mononuclidic elements were known with considerably less accuracy at that time than at present, less decisive conclusions could be drawn about the reliability of the chemically derived values.

TABLE I

COMPARISON OF CHEMICAL WITH PHYSICAL VALUES FOR
FIFTEEN MONONUCLIDIC ELEMENTS

Element	Physical value	Chemical value[a]	Error, %	Laboratory	Year
Na	22.9898	22.9951	+0.023	H	1905
Mn	54.9380	54.927	− .020	H	1906
P	30.9738	31.017	+ .14	H	1912
Pr	140.907	140.913	+ .004	H	1915
Th	232.038	232.097	+ .025	M	1916
Sc	44.956	45.095	+ .31	M	1919
Al	26.9815	26.959	− .083	H	1920
Bi	208.980	208.976	− .002	M	1921
Co	58.9332	58.939	+ .010	H	1924
Y	88.905	88.919	+ .016	M	1927
As	74.9216	74.904	− .023	H	1933
Nb	92.906	92.904	− .002	M	1934
Ho	164.930	164.928	− .001	M	1940
P	30.9738	30.969	− .016	M	1940
Cs	132.905	132.901	− .003	H	1940
Be	9.0122	9.0123	+ .001	M	1947

[a] These values are not necessarily referred to in the element-by-element review.

In those instances in which work on a given element was repeated in the same laboratory only the more recent value is given in the belief that the investigator regarded it as the better one. The large error in the chemically derived value for scandium must almost certainly be ascribed to other sources of error than those inherent in the method. The most likely source of error in this instance is inadequate purity of the scandium bromide. It is possible, but hardly useful, to speculate about the factors that caused the rather large errors in the values for aluminum, arsenic, and phosphorus. No plausible explanation can be offered for the error in the value for sodium, an element that would seem to be exceptionally well suited to the method.

The errors listed in the table are divided equally between positive and negative ones. This tends to confirm the opinion of Scott that errors in the determination of the equivalence points were as likely to be of one sign as the other. In spite of a few relatively large discrepancies, the results appear to justify a considerable degree of confidence in atomic weights derived from halide–silver ratios. By extension they may be regarded as offering useful evidence concerning the probable reliability of chemical determinations by the "Harvard" method for elements whose complex isotopic composition complicates the physical determination. Such evidence is presented in Table II for fourteen elements, of which all but two have five or more isotopes. Column 3 of the table lists the atomic weights calculated from the masses of the nuclides and their abundances. Column 4 gives the values derived from chemical determinations of halide–silver or halide–silver halide ratios. Column 5 lists atomic weights derived from other types of chemical ratios for the seven elements for which such measurements have been made. The agreement between the values in columns 4 and 5 tends to support the conclusion previously drawn from Table I—that the "Harvard" procedure can be regarded as highly trustworthy.

TABLE II

COMPARISON OF CHEMICAL WITH PHYSICAL VALUES FOR
FOURTEEN POLYNUCLIDIC ELEMENTS

Element	No. of nuclides	Physical value	Chemical value Harvard ratio	Other ratios
Ti	5	47.88	47.90	
Ni	5	58.71	58.69	58.70
Cu	2	63.547	63.54	63.54
		63.550		
Zn	5	65.387	65.37	65.37
Ge	5	72.628	72.59	
Se	6	78.97	78.95	78.95
		78.99		
Mo	7	95.90	95.94	
		95.94		
Cd	8	112.42	112.40	112.40
		112.43		
Sn	10	118.73	118.69	118.69
Te	8	127.63	127.60	127.60
Ba	7	137.33	137.34	
		137.34		
W	5	183.85	183.91	
Hg	7	200.61	200.59	
Tl	2	204.38	204.37	

In appraising the reliability of an atomic weight derived from any chemical determination, consideration must always be given to errors from sources other than those inherent in the experimental ratio, particularly those associated with the purity or stoichiometry of the compounds used. In reviewing the literature on atomic weights, many examples can be found of large errors resulting from incorrect assumptions about stoichiometric composition. These errors usually were unsuspected until some other procedure, chemical or physical, was applied to the determination of the atomic weight. Earlier revisions, especially during the period 1949 to 1955, have corrected most, if not all, significant errors arising from this source. Unfortunately, in this review it was seldom possible to find completely satisfactory evidence of the purity of the compounds used. Methods of evaluating purity that are commonplace today were not available even a few years ago. The lack of these advantages was offset, however, by the skill and experience of the investigators and their customary practice of repeating purification processes well beyond the stage at which impurities were no longer detected.

With the need for accurate knowledge of atomic weights so largely met for most of the elements, it is questionable whether chemists will again devote themselves to the exacting requirements of the chemical determination of these constants. However, investigators who may choose to enter this field have at their disposal better means of preparing pure substances and of evaluating their purity, and of determining the purity and completeness of reactions, than were available to the earlier workers. Further, the elements most in need of further study are now more easily identified by noting the existing discrepancies between chemical and physical measurements.

In distinction from chemical investigations of atomic weights, measurements of isotopic abundances are being made in many laboratories. Such

measurements have increased rapidly in accuracy since they were first applied to the determination of atomic weights. It is to be expected that they will continue to become more reliable as means are found to eliminate or to measure the various systematic errors that are inherent in the technique in its present stage of development. Further improvement in the accuracy of atomic weights must be expected largely from this direction.

It is possible that in some instances another physical method may provide useful information on atomic weights, particularly to resolve discrepancies such as those shown in Table II. Crystal lattice measurements of substances of "known" atomic or molecular weight have heretofore been used, together with measurements of density, to derive Avogadro's number by means of the equation $N = nM/dv$ in which M is the atomic or molecular weight of the substance, d its density, n the number of atoms or molecules in the unit cell of the crystal, and v the volume of the unit cell. If N is taken as known, the same measurements yield M. Thus far this method has had little usefulness for the derivation of atomic weights. To yield results comparable in accuracy with other methods the crystals used must be not only of very high chemical purity but also physically excellent. Moreover it would appear difficult to defend experimental values based on X-ray spacing and density determinations carried out on different specimens. On large single crystals the density determination is not likely to be too demanding, but precise spacings are more readily obtained from powdered specimens. Until recently the limited accuracy with which Avogadro's number was known added significantly to the uncertainties inherent in this method of atomic weight determination.

In view of the several exacting requirements imposed on the method it is not surprising that the results thus far obtained from it have not contributed to the selection of values for atomic weights that have been included in the International Table. It is to be hoped that the currently active research on the solid state of matter will result in the availability of crystalline preparations of a sufficiently high degree of purity and crystallographic perfection, and that improvements in these respects and in the measurement of crystal lattice dimensions will prove to make the method useful.

Element-by-Element Review

In the following review the elements are listed in order of atomic number. The stable nuclides of the elements are listed and the recommended atomic weight is given. Evidence pertinent to the selection of the atomic weight is briefly presented. When a previous atomic weight is stated, it is understood that it is on the old scale, oxygen = 16.

The compilation of nuclidic masses by Everling, König, Mattauch and Wapstra (E2) (1960) is referred to in the text as EKMW (1960) because of frequent citation. Similarly, the publication by Bhanot, Johnson and Nier (B41) (1960) is designated as BJN (1960) and Nuclear Data Tables (N9) (1959) as NDT (1959).

1   Hydrogen: ^{1}H, ^{2}H
        Atomic Weight 1.00797 ± 0.00001

For the 1938 Table the value of 1.0081 was adopted for hydrogen, based upon mass spectrometry by Aston (A6) (1936), and by Bainbridge and Jordan (B1) (1937). The value was changed to 1.0080 in 1940 based upon the ^{1}H/^{2}H ratio measured by many workers. The deuterium content of natural hydrogen has been shown by Friedman (F2) (1953) to vary from 0.0135% to 0.0154% in fresh waters and from 0.0149% to 0.0156% in salt waters. The average of 0.0145% was chosen for the calculation of the atomic weight using the nuclidic masses from EKMW (1960). The natural variation corresponds to a range in the atomic weight of ±0.00001. For other mixtures of hydrogen and deuterium it is necessary to calculate the atomic weight from the composition. The masses for such computation are ^{1}H = 1.007825; ^{2}H = 2.014102.

2   Helium: ^{3}He, ^{4}He   Atomic Weight 4.0026

In the 1938 Table the value of 4.003 was adopted for helium, based upon the mass spectrometry of Aston (A6) (1936) and Bainbridge and Jordan (B1) (1937). The ^{3}He content in atmospheric helium is 0.000137% according to Nier (N1) (1959), and about $^1/_{10}$ this amount in well helium. The effect of this minor isotope upon the atomic weight of helium is negligible. The mass is from EKMW (1960).

3   Lithium: ^{6}Li, ^{7}Li   Atomic Weight 6.939

The recommended atomic weight of lithium has been 6.940 since 1925, based upon chemical ratios determined by Richards and Willard (R9) (1910). The recalculated ratios are:

		Ratio	Atomic weight
Comparison of chloride with Ag (R9)	LiCl/Ag	0.392992	6.9390
Comparison of chloride with AgCl (R9)	LiCl/AgCl	0.295786	6.9399
Chloride converted to perchlorate (R9)	$2O_2$/LiCl	1.50968	6.9385

The average, 6.939, is recommended for the present table.

The abundance measurements of Cameron (C1) (1955) upon the Li_2I^+ ion produced by electron bombardment of vapor subliming from LiI indicate some variability of composition in nature. With masses of 6.01513 and 7.01600 from EKMW (1960), the calculated atomic weight varies between 6.942 and 6.943. Commercial sources of lithium are found to vary over a wider range. No "absolute" mass spectrometric measurements have been reported.

4   Beryllium: ^{9}Be   Atomic Weight 9.0122

The atomic weight of beryllium was changed from 9.02 to 9.013 in the 1949 Table, based upon the ratios of beryllium chloride to silver and to silver chloride and the ratios of beryllium bromide to silver and silver bromide determined by Hönigschmid and Johannsen (H57) (1946–1947). An upper limit of 0.001 for the existence of ^{8}Be has

been set by Nier (N3) (1937). For the present table the recommended value is the mass from EKMW (1960).

5 Boron: ^{10}B, ^{11}B Atomic Weight 10.811 ± 0.003

The atomic weight of 10.82 which appeared first in the 1925 Table was the result of comparisons of boron trichloride and boron tribromide with silver by Hönigschmid and Birckenbach (H15) (1922) and Baxter and Scott (B20) (1923). The possibility of alteration of the boron isotopic composition during the extensive purification of the halides and the strong indication from mass spectrometry that the composition of boron in nature is variable make the validity of this atomic weight dubious. In recent work by McMullen, Cragg and Thode (M7) (1961), the absolute ^{11}B/^{10}B in four samples of Searles Lake borax has been determined. Standards were carefully prepared from highly enriched and impoverished ^{10}B and used to establish the correction necessary for systematic errors in the mass spectrometry. An earlier observation by Thode, Macnamara, Lossing and Collins (T1) (1948) that the isotopic composition of boron in nature is variable has been confirmed with a new suite of minerals as well as by remeasurement of the samples used previously. McMullen in private communication to A. E. Cameron (23 June, 1961) reports the absolute ^{11}B/^{10}B for the earlier series of minerals to be from 3.95 to 4.15 with an accuracy estimated to be ±1% of the ratio. The suite of minerals now being measured gives a range of absolute ^{11}B/^{10}B from 3.95 to 4.10 with an accuracy somewhat better than ±1.0%.

For compositions corresponding to these ratios: ^{11}B = 79.798, ^{10}B = 20.202; and ^{11}B = 80.392, ^{10}B = 19.608, respectively, the atomic weights are 10.808 and 10.814 calculated with masses from EKMW (1960). The average, 10.811, is recommended for inclusion in the present table with a range of ±0.003 because of variation in natural isotopic composition.

The atomic weight of other than natural boron should be calculated from the measured isotopic composition using the EKMW (1960) masses: ^{10}B = 10.012939 and ^{11}B = 11.009305.

6 Carbon: ^{12}C, ^{13}C Atomic Weight 12.01115 ± 0.00005

The former value of 12.011 was adopted in 1953 based primarily upon masses determined by Li, Whaling, Fowler and Lauritsen (L5) (1951) from observations of energy changes accompanying nuclear reactions and upon the determination of the isotopic composition by Nier (N8) (1950). It replaced a value of 12.010 adopted in 1938 based upon work of Baxter and Hale (B34) (1937) upon hydrocarbon combustion.

The abundance of ^{13}C in nature varies from 1.1088% to 1.1151% according to Craig (C6) (1953). The nuclidic mass of ^{12}C is the exact number 12 and of ^{13}C is 13.003354 from EKMW (1960). The extremes of the natural variation give calculated atomic weights of 12.01119 and 12.01112, which are averaged to give a recommended value of 12.01115 with a range of ±0.00005.

7 Nitrogen: ^{14}N, ^{15}N Atomic Weight 14.0067

The previous value for nitrogen, 14.008, was introduced in the 1920 Table as a slight revision of 14.01 which had been recommended for the 1907 Table, based upon measurements by Gray (G4) (1905) of the densities of nitric oxide and nitrogen and the analysis of the oxide.

The absolute ^{14}N/^{15}N ratio in atmospheric nitrogen has been determined by Junk and Svec (J2) (1958) to be 272 ± 0.3 by mass spectrometry. With nuclidic masses of ^{14}N = 14.003074 and ^{15}N = 15.000108 from EKMW (1960) the calculated atomic weight is 14.0067. Variations of up to 1.5% in the ^{14}N/^{15}N ratio in nitrogen of other origin have been demonstrated by Hoering (H10) (1955) and by Parwel, Ryhage and Wickman (P2) (1957). Variation of this magnitude causes an uncertainty of only 0.00005 in the atomic weight.

8 Oxygen: ^{16}O, ^{17}O, ^{18}O Atomic Weight 15.9994 ±0.0001

The atomic weight of oxygen for the present table, 15.9994, is calculated from the abundances of ^{17}O and ^{18}O in atmospheric oxygen of 0.0374% and 0.2039%, respectively, determined by Nier (N8) (1950). The nuclidic masses from EKMW (1960) are ^{16}O = 15.994915, ^{17}O = 16.999134 and ^{18}O = 17.999160. Various workers have shown that the ^{18}O content in fresh waters may be as much as 3% less than in atmospheric oxygen and 2.3% less in salt water (R1) (1954) (D6) (1958). A variation of 3% in the ^{18}O/^{16}O ratio corresponds to a range of ±0.00012 in the calculated atomic weight and probably adequately covers that encountered in normal chemical procedures. Epstein (E1) (1959) reports that the ^{18}O/^{16}O ratios in nature may vary as much as 10% between the extremes of glacier ice found near the poles and that in atmospheric carbon dioxide. It is thus possible that a variation of ±0.0003 may occur in the atomic weight. Epstein also discusses the observed variations in ^{18}O/^{16}O in minerals, where the deviations are not as extreme.

9 Fluorine: ^{19}F Atomic Weight 18.9984

The rounded value of 19.0 was adopted in the 1919–20 Table and 19.00 first appeared in 1925 based upon the simultaneous determination of the atomic weights of boron and fluorine using sodium tetraborate, by Smith and Van Haagen (S9) (1918). The borax was converted to sulfate, carbonate, nitrate, chloride and fluoride. The recommended value for the present table is the mass 18.9984, from EKMW (1960).

10 Neon: ^{20}Ne, ^{21}Ne, ^{22}Ne Atomic Weight 20.183

The recommended atomic weight of neon has been 20.183 since 1928, based upon gas density measurements made by Baxter and Starkweather (B27) (1928) and by Baxter (B26) (1928). The results were recalculated by Prof. T. Batuecas to give 20.183, which was recommended for inclusion in the present table.

Three measurements of the isotopic composition of neon are cited in NDT (1959). The results are not in good agreement. It is possible that, because of the method of extracting neon from atmospheric gases, fractionation may have occurred.

11   Sodium: ^{23}Na   Atomic Weight 22.9898

The previous value for the atomic weight, 22.991, was adopted for the 1953 Table, based upon a mass measurement by Henglein (H4) (1951), and upon reaction energy calculations by Dr. K. Way (private communication) and by Li (L6) (1952). It replaced a value which had been unchanged since 1905. For the present table the value, 22.9898, is the mass from EKMW (1960). White, Collins and Rourke (W4) (1956) have set upper limits for the existence of ^{21}Na as 0.000001% and ^{22}Na as 0.000003%.

12   Magnesium: ^{24}Mg,   Atomic Weight 24.312
         ^{25}Mg, ^{26}Mg

The atomic weight of magnesium has been stated as 24.32 since the entire Table was recalculated in 1909. It was based upon chemical ratios measured by Richards and Parker (R5) (1897). The isotopic abundances measured by White and Cameron (W5) (1948) by electron bombardment of magnesium metal vapor, with masses from EKMW (1960), give a calculated atomic weight of 24.312, which is recommended in preference to the older chemical value.

13   Aluminum: ^{27}Al   Atomic Weight 26.9815

The chemically derived value for the atomic weight of aluminum that had been in use since 1925 was replaced in 1951 by the value 26.98, which was based on mass measurements by Mattauch and Ewald (M3) (1943) and by Motz (M9) (1951). White, Collins and Rourke (W4) (1956) have established upper limits of 0.00015% for the existence of ^{25}Al and ^{26}Al and of 0.00005% for ^{28}Al, ^{29}Al, and ^{30}Al. For the present table the recommended value is 26.9815 from EKMW (1960).

14   Silicon: ^{28}Si, ^{29}Si,   Atomic Weight 28.086
         ^{30}Si   ± 0.001

In the 1951 Table the recommended atomic weight of silicon was changed from 28.06, based upon chemical ratios, to 28.09 based upon nuclidic masses of Duckworth, et al., (D3) (1950), and the average of three isotopic compositions cited by Bainbridge and Nier (B2) (1951). The calculated value was 28.086. For the present table, the seven mass spectrometric determinations reported in NDT (1959) were averaged to give ^{28}Si = 92.21%; ^{29}Si = 4.70%; and ^{30}Si = 3.09%. With masses from EKMW (1960) the calculated atomic weight is 28.086, to which is assigned a range of ±0.001 because of the 1.3% variation in the ^{28}Si/^{30}Si in nature reported by Allenby (A2) (1954).

15   Phosphorus: ^{31}P   Atomic Weight 30.9738

The previous atomic weight, 30.975, was adopted in 1951 based upon nuclear reaction data supplemented by mass spectrometric measurements re-

ported by Motz (M9) (1951) and was in close agreement with the most recent chemical determinations of Hönigschmid and Hirschbold-Wittner (H49) (1940). Upper limits for the possible existence of stable isotopes from masses 28 to 34 were set at 0.002% by Kerwin (K2) (1954). The recommended atomic weight is the mass 30.9738 from EKMW (1960).

16   Sulfur: ^{32}S, ^{33}S,   Atomic Weight 32.064
         ^{34}S, ^{36}S   ±0.003

In 1947 the Commission recommended the value of 32.066 for sulfur based upon chemical ratios. The demonstration of the variability of isotopic composition of this element in nature led, in 1951, to the recommendation that the atomic weight be published with a stated variability of ±0.003. The chemical measurements have been recalculated.

	Observed ratio	Atomic weight
Synthesis of silver sulfide (H30) (1931)	Ag$_2$S/2Ag 1.148621	32.0635
Synthesis of silver sulfide (H54) (1942)	Ag$_2$S/2Ag 1.148621	32.0635
Conversion of Na$_2$CO$_3$ to Na$_2$SO$_4$ (R10) (1915)	Na$_2$SO$_4$/Na$_2$CO$_3$ 1.340155	32.0644

The measurements which prove the variability of the sulfur isotopic composition in nature have been reviewed by Rankama (R1) (1954) and by Duckworth (D7) (1958). The abundances of the sulfur isotopes in virgin Texas sulfur determined by Bradt, Mohler and Dibeler (B42) (1956) and by Macnamara and Thode (M1) (1950) in meteoritic sulfur with masses from EKMW (1960) both give a calculated atomic weight of 32.064. The agreement between the chemical and physical measurements is excellent, and 32.064 is recommended for the present table with a range of ±0.003.

17   Chlorine: ^{35}Cl, ^{37}Cl   Atomic Weight 35.453
                                          ± 0.001

The recommended atomic weight of chlorine, 35.453, is based directly upon the atomic weight of silver by silver–silver chloride ratios determined chemically. The uncertainty stated derives entirely from the uncertainty assigned to the atomic weight of silver. Recent absolute mass spectrometric measurements of the abundance of the chlorine isotopes by Shields, Garner, Murphy and Dibeler (S6) (1962) give ^{35}Cl = 75.7705 (+0.035; −0.046%) and ^{37}Cl = 24.2295 (−0.035; +0.046%). With masses from EKMW (1960) the calculated atomic weight is 35.4527 ± 0.0007. Standards were prepared from ^{35}Cl and ^{37}Cl of high chemical and isotopic purity and used to correct for systematic error in mass spectrometry. The agreement between chemical and physical methods is excellent.

Recent results of Meyerson (M8) (1961) for the abundances observed in the mass spectra of certain chlorine containing organic compounds give ^{35}Cl = 75.80% ± 0.06 (av. deviation). From this the calculated atomic weight is 35.452 in good agreement with the results of Shields, Garner, Murphy and Dibeler.

18   Argon: ^{36}Ar, ^{38}Ar,   Atomic Weight 39.948
          ^{40}Ar

The previous value for argon, 39.944, was introduced in 1931 based upon gas density measurements by Baxter and Starkweather (B29) (1929). The value 39.948 is recommended for the present table based upon the isotopic abundances ^{36}Ar = 0.337%; ^{38}Ar = 0.063% and ^{40}Ar = 99.600% measured by Nier (N8) (1950), and masses from EKMW (1960). Discrimination effects in the mass spectrometer were eliminated by calibrating with carefully prepared mixtures of high isotopic purity ^{36}Ar and ^{40}Ar.

19   Potassium: ^{39}K,   Atomic Weight 39.102
          ^{40}K, ^{41}K

The previous value, 39.10, was recommended in 1951, based upon abundance measurements by Nier (N8) (1950) and masses determined by Collins, Nier and Johnson (C3) (1951). It replaced chemically measured values which over many years have ranged from 39.094 to 39.104. With Nier's abundances of ^{39}K = 93.083%, ^{40}K = 0.012% and ^{41}K = 6.905% and masses from EKMW (1960), the calculated atomic weight is 39.102, which is recommended for the present table. The abundance data of Reuterswärd (R3) (1956) give a calculated atomic weight of 39.101.

20   Calcium: ^{40}Ca, ^{42}Ca, Atomic Weight 40.08
          ^{43}Ca, ^{44}Ca, ^{46}Ca, ^{48}Ca

In the 1931 Table the atomic weight of calcium was changed from 40.07 to 40.08, based upon the ratios of calcium chloride to silver and silver chloride measured by Hönigschmid and Kempter (H29) (1931). The ratios have been recalculated.

		Observed ratio	Atomic weight
Comparison of chloride with silver (H29) (1931)	CaCl$_2$/ 2Ag	0.514451	40.082
Comparison of chloride with silver chloride (H29) (1931)	CaCl$_2$/ 2AgCl	0.387200	40.083

An atomic weight of 40.078 was calculated from the abundances measured by Nier (N5) (1938) and masses from EKMW (1960). The Commission recommended the value, 40.08.

21   Scandium: ^{45}Sc   Atomic Weight 44.956

The previous atomic weight, 44.96, based upon a mass measurement by Collins, Nier and Johnson (C3) (1951) was first used in the 1951 Table. Leland (L4) (1950) has set upper limits of % abundance of 0.001 for ^{41}Sc; 0.0002 for ^{42}Sc and ^{43}Sc; 0.0005 for ^{44}Sc; 0.002 for ^{46}Sc; 0.01 for ^{47}Sc; and 0.0002 for ^{48}Sc and ^{49}Sc by mass spectrometric measurement. For the present table the atomic weight recommended is 44.956 from EKMW (1960).

22   Titanium: ^{46}Ti, ^{47}Ti, Atomic Weight 47.90
          ^{48}Ti, ^{49}Ti, ^{50}Ti

The chemical ratios of Baxter and Butler (B24) (1926) and of Baxter and Butler (B25) (1928) upon which the atomic weight of 47.90 has been based since 1927 have been recalculated.

		Observed ratio	Atomic weight
Comparison of TiCl$_4$ with Ag (B24) (1926)	TiCl$_4$/4Ag	0.439680	47.901
Comparison of TiBr$_4$ with Ag (B25) (1928)	TiBr$_4$/4Ag	0.851788	47.893

The averaged abundances determined by Mattraw and Pachucki (M5) (1952) and Hogg (H12) (1954) with masses from EKMW (1960) give a calculated atomic weight of 47.88. The Commission recommended 47.90 for inclusion in the present table.

23   Vanadium: ^{50}V, ^{51}V   Atomic Weight 50.942

The atomic weight of vanadium has been taken as 50.95 since a slight revision was made in the 1931 Table. It was based upon chemical ratios determined by Scott and Johnson (S3) (1930), by Briscoe and Little (B44) (1914) and by McAdam (M6) (1910), which have been recalculated.

		Observed ratio	Atomic weight
Conversion of NaVO$_3$ to NaCl (M6) (1910)	NaVO$_3$/ NaCl	2.08639	50.946
Comparison of VOCl$_3$ with silver (B44) (1914)	VOCl$_3$/ 3Ag	0.535537	50.947
Comparison of VOCl$_3$ with AgCl (B44) (1914)	VOCl$_3$/ 3AgCl	0.403075	50.951
Comparison of VOCl$_3$ with silver (S3) (1930)	VOCl$_3$/ 3Ag	0.535529	50.944
Comparison of VOCl$_3$ with AgCl (S3) (1930)	VOCl$_3$/ 3AgCl	0.403088	50.957

The abundance of ^{50}V is 0.24% by averaging the determinations by Hess and Inghram (H8) (1949), Leland (L2) (1949), and by White, Collins and Rourke (W4) (1956). The latter workers also set upper limits of 0.0001% for ^{48}V and 0.00005% for ^{49}V. With masses from EKMW (1960) the calculated atomic weight is 50.942, which is recommended for the present table.

24   Chromium: ^{50}Cr,   Atomic Weight 51.996
          ^{52}Cr, ^{53}Cr, ^{54}Cr   ± 0.001

The atomic weight of chromium has been taken as 52.01 since 1925, based upon the ratios Ag$_2$CrO$_4$/ 2AgCl and Ag$_2$CrO$_4$/2AgBr measured by Baxter, Mueller and Hines (B6) (1909) and the ratio Ag$_2$Cr$_2$O$_7$/2AgBr measured by Baxter and Jesse (B7) (1909). Recalculation gives 51.997 and 52.007, respectively, for chromium by the two determinations.

Flesch, Svec and Staley (F1) (1960) have measured the abundances of the chromium isotopes in 18 chromites of various geological origins and found no variation within the limits of accuracy of the measurements, which were put upon an absolute basis by the use of separated isotopes. From their % abundances of ^{50}Cr = 4.352 ± 0.024; ^{52}Cr = 83.764 ± 0.036; ^{53}Cr = 9.509 ± 0.027; and ^{54}Cr = 2.375 ± 0.018, and masses from EKMW (1960) the calculated atomic weight is 51.9963 ± 0.0013 where the uncertainty arises entirely from the abundance measurements. The Commission recommended 51.996 ± 0.001 for the present table.

25   Manganese: ^{55}Mn   Atomic Weight 54.9380

In 1953 the atomic weight was revised from 54.93 to 54.94 on the basis of mass measurements by Collins, Nier and Johnson (C4) (1952). Upper limits of 0.0004% for ^{53}Mn and of 0.0003% for ^{54}Mn have been set by White, Collins and Rourke (W4) (1956). The accuracy with which the mass of ^{55}Mn is expressed in EKMW (1960) allows the additional significant figures in the recommended atomic weight, 54.9380.

26   Iron: ^{54}Fe, ^{56}Fe,   Atomic Weight 55.847
^{57}Fe, ^{58}Fe   ± 0.003

The atomic weight of iron was changed from 55.84 to 55.85 in 1940 on the basis of chemical determinations made by Hönigschmid and Liang (H48) (1939). The recalculated ratios are:

		Observed ratio	Atomic weight
Comparison of ferrous bromide with silver (H48) (1939)	FeBr$_2$/ 2Ag	0.999645	55.845
Comparison of ferrous bromide with AgBr (H48) (1939)	FeBr$_2$/ 2AgBr	0.574244	55.844

As recalculated the results of this work are in remarkable agreement with a direct determination by Baxter and Hoover (B9) (1912) of the combining weight of iron with oxygen. The average of 12 experiments gave for the ratio 2Fe/Fe$_2$O$_3$, 0.6994277, and for the atomic weight 55.8456. This work is cited primarily because of its historical significance.

Some support for the change was afforded by Nier's (N6) (1939) determination of the isotopic composition which, with the packing fraction then available, gave a calculated atomic weight of 55.851. For the present table it was felt desirable to attach another significant figure to the value but this did not seem justified by the chemical evidence. With % abundances of ^{54}Fe = 5.82; ^{56}Fe = 91.66; ^{57}Fe = 2.19 and ^{58}Fe = 0.33, which are the average of the determinations reported by Valley and Anderson (V1) (1941) and by White and Cameron (W5) (1948) and masses from EKMW (1960) the calculated atomic weight is 55.847. Valley and Anderson found no differences between various terrestrial and meteoritic samples. The abundances reported by Hibbs (H9) (1949) give a calculated atomic weight of 55.846. The Commission felt it wise to assign, somewhat arbitrarily, an uncertainty of ±0.003 to the recommended atomic weight, 55.847.

27   Cobalt: ^{59}Co   Atomic Weight 58.9332

The atomic weight of this element has been stated as 58.94 since the 1925 Table, based upon a chemical determination by Baxter and Dorcas (B22) (1924). The ratio has been recalculated.

		Observed ratio	Atomic weight
Comparison of CoCl$_2$ with silver (B22) (1924)	CoCl$_2$/2Ag	0.601859	58.939

The recommended atomic weight for the present table is the rounded mass, 58.9332, from EKMW (1960).

28   Nickel: ^{58}Ni, ^{60}Ni,   Atomic Weight 58.71
^{61}Ni, ^{62}Ni, ^{64}Ni

In the 1955 Table an earlier chemical value of 58.69 was replaced by 58.71 which was based upon isotopic abundance measurements by White and Cameron (W5) (1948), and masses determined by Collins, Nier and Johnson (C4) (1952). With the same abundances and with masses from EKMW (1960) the calculated atomic weight is 58.71. The reliability of the abundance measurements does not justify an additional significant figure.

Recalculation of the chemical determinations from which the earlier chemical value was derived suggests that they be included in this report because they may be useful in studying the reliability of isotopic abundance measurements for elements that have numerous isotopes. One of the objects of the experimental work was to compare the atomic weights of meteoritic nickel with that of terrestrial origin. The following results are for terrestrial nickel.

		Observed ratio	Atomic weight
Comparison of NiCl$_2$ with silver (B19) (1923)	NiCl$_2$/ 2Ag	0.600731	58.696
Comparison of NiCl$_2$ with AgCl (B19) (1923)	NiCl$_2$/ 2AgCl	0.452118	58.692
Comparison of NiBr$_2$ with silver (B28) (1929)	NiBr$_2$/ 2Ag	1.012829	58.690
Comparison of NiBr$_2$ with AgBr (B28) (1929)	NiBr$_2$/ 2AgBr	0.581819	58.689
		Average	58.692

29   Copper: ^{63}Cu, ^{65}Cu   Atomic Weight 63.54

In 1947 the atomic weight of copper was changed from 63.57 to 63.54 based upon the chemical determinations by Hönigschmid and Johannsen (H55) (1944) and Ruer and Bode (R12) (1924). The chemical ratios have been recalculated.

		Observed ratio	Atomic weight
Comparison of CuCl with Ag (H55) (1944)	CuCl/Ag	0.917675	63.537
Comparison of CuCl with AgCl (H55) (1944)	CuCl/AgCl	0.690673	63.536
Reduction of CuO to Cu (R12) (1924)	CuO/Cu	1.25181	63.538

The abundances determined by Hess, Inghram and Hayden (H7) (1948) with masses from EKMW (1960) give a calculated atomic weight of 63.547, while those reported by White and Cameron (W5) (1948) give 63.550. The Commission recommended 63.54 for the atomic weight of copper.

30   Zinc: ^{64}Zn, ^{66}Zn,   Atomic Weight 65.37
^{67}Zn, ^{68}Zn, ^{70}Zn

The chemical ratios upon which 65.38 as the atomic weight of zinc has been based since 1925 were recalculated, together with more recent measurements.

		Observed ratio	Atomic weight
Comparison of ZnCl₂ with Ag (H53) (1941)	ZnCl₂/ 2Ag	0.631681	65.373
Comparison of ZnCl₂ with AgCl (H53) (1941)	ZnCl₂/ 2AgCl	0.475426	65.373
Electrolytic reduction of ZnBr₂ to Zn (in mercury) (B13) (1916)	ZnBr₂/ Zn	3.444605	65.376
Same reaction, ZnCl₂ (B16) (1921)	ZnCl₂/ Zn	2.084684	65.370

The isotopic abundances measured by Hess, Inghram and Hayden (H7) (1948) and by Leland and Nier (L1) (1948) are in excellent agreement. The averaged % abundances, ^{64}Zn = 48.89; ^{66}Zn = 27.81; ^{67}Zn = 4.11; ^{68}Zn = 18.57; and ^{70}Zn = 0.62, with masses from EKMW (1960), give a calculated atomic weight of 65.387. The Commission recommended retaining the chemically determined value of 65.37 for the atomic weight.

31   Gallium: ^{69}Ga, ^{71}Ga   Atomic Weight 69.72

The atomic weight of gallium was changed to 69.72 in 1923, based upon the chemical ratio determination by Richards and Craig (R11) (1923). Recalculation of that ratio and of a later one gave the following:

		Observed ratio	Atomic weight
Comparison of chloride with silver (R11) (1923)	GaCl₃/3Ag	0.544097	69.716
Conversion of metal to oxide (L7) (1935)	2Ga/Ga₂O₃	0.74396	69.733

Gallium samples of terrestrial and of meteoritic origin were compared by Inghram, Hess, Brown and Goldberg (I4) (1948). The ^{69}Ga/^{71}Ga ratio was 1.510 for terrestrial and 1.509 for meteoritic samples. With % abundances of ^{69}Ga = 60.16; ^{71}Ga = 39.84 and masses from EKMW (1960), the calculated atomic weight is 69.72, in good agreement with the chemically determined value. The Commission recommended 69.72 for the present table.

32   Germanium: ^{70}Ge,   Atomic Weight 72.59 ^{72}Ge, ^{73}Ge, ^{74}Ge, ^{76}Ge

The atomic weight of germanium has appeared as 72.60 since 1925. The ratios upon which this value was based have been recalculated together with more recent data.

		Observed ratio	Atomic weight
Comparison of chloride with silver (B21) (1924)	GeCl₄/ 4Ag	0.496928	72.602
Comparison of chloride with AgCl (B21) (1924)	GeCl₄/ 4AgCl	0.374010	72.605
Comparison of bromide with silver (B23) (1925)	GeBr₄/ 4Ag	0.909016	72.586
Comparison of bromide with AgBr (B23) (1925)	GeBr₄/ 4AgBr	0.522195	72.593
Comparison of chloride with silver (H44) (1936)	GeCl₄/ 4Ag	0.496893	72.587
Comparison of chloride with AgCl (H44) (1936)	GeCl₄/ 4AgCl	0.373977	72.586

Comparison of bromide with silver (H39) (1935)	GeBr₄/ 4Ag	0.909000	72.579
Comparison of bromide with AgBr (H39) (1935)	GeBr₄/ 4AgBr	0.522175	72.578

                Average   72.590

Five determinations of the isotopic composition of germanium are quoted in NDT (1959). The determination by Reynolds (R4) (1953) appears most likely to be free of systematic errors and, with masses from EKMW (1960), the calculated atomic weight is 72.630. The results reported by Graham, Macnamara, Crocker and MacFarlane (G3) (1951) on five of six terrestrial samples examined give a calculated atomic weight of 72.634. The sixth sample gives an atomic weight differing by 0.004 from the others. Graham, et al., and Reynolds examined fractionally distilled germanium halides and observed no isotope separation in the purification of the compounds. The isotopic composition determined by Inghram, Hayden and Hess (I6) (1948) gives a calculated atomic weight of 72.629. If all five determinations are averaged, assuming equal reliability, the calculated atomic weight is 72.628.

Thus, chemical ratio determinations give an atomic weight of 72.59 and physical measurements 72.63. The Commission recommended inclusion of the chemical value, 72.59, in the present table.

33   Arsenic: ^{75}As   Atomic Weight 74.9216

The atomic weight, 74.91, which has appeared previously was introduced in the 1934 Table and was based upon the ratios AsCl₃/3Ag and AsBr₃/3Ag determined by Baxter, Shaefer, Dorcas and Scripture (B33) (1933). For the present table the recommended value is 74.9216 from EKMW (1960).

34   Selenium: ^{74}Se, ^{76}Se,   Atomic Weight 78.96 ^{77}Se, ^{78}Se, ^{80}Se, ^{82}Se

The atomic weight of 78.96 was introduced in the 1934 Table based upon the work of Hönigschmid and Kapfenberger (H32) (1933). Recalculation of their ratio and the ratios obtained more recently by Hönigschmid and Görnhardt (H56) (1944) gave the following:

		Observed ratio	Atomic weight
Synthesis of silver selenide (H32) (1933)	2Ag/ Ag₂Se	0.732081	78.954
Comparison of SeOCl₂ with Ag (H56) (1944)	SeOCl₂/ 2Ag	0.768794	78.954
Comparison of SeOCl₂ with AgCl (H56) (1944)	SeOCl₂/ 2AgCl	0.578624	78.955

The isotopic abundances reported by White and Cameron (W5) (1948) with masses from EKMW (1960) give a calculated atomic weight of 78.99. The determination by Hibbs (H9) (1949) gives an atomic weight of 78.97. The Commission recommended 78.96 for inclusion in the present table.

35   Bromine: ^{79}Br, ^{81}Br   Atomic Weight 79.909   ± 0.002

The atomic weight of bromine has been unchanged at 79.916 since 1925. The change to 79.909 is a direct result of the new atomic weight

for silver. The assigned uncertainty arises from that in the value for silver. Cameron and Lippert (C2) (1955) compared bromines of several different origins and found no differences in isotopic composition within the precision of the measurements. With their % abundances of ^{79}Br = 50.537 and ^{81}Br = 49.463 and masses from EKMW (1960), the calculated atomic weight is 79.907.

36   Krypton: ^{78}Kr, ^{80}Kr,   Atomic Weight 83.80
         ^{82}Kr, ^{83}Kr, ^{84}Kr, ^{86}Kr

In 1951 the atomic weight of krypton was based upon measurements of the abundances of the isotopes by Nier (N7) (1950) and masses measured by Nier. Recalculation with the same abundances and with masses from EKMW (1960) gave an atomic weight of 83.80, recommended for the present table.

37   Rubidium: ^{85}Rb,   Atomic Weight 85.47
         ^{87}Rb

The previous atomic weight of 85.48 was introduced in the 1937 Table, based upon the ratios RbCl/Ag and of RbBr/Ag and RbBr/AgBr measured by Archibald, Hooley and Phillips (A4) (1936), and Archibald and Hooley (A3) (1936). Recalculation of these ratios yields 85.473 for the atomic weight. The ^{85}Rb = 72.15% and ^{87}Rb = 27.85% measured by Nier (N7) (1950), with masses from EKMW (1960), give a calculated atomic weight of 85.468. The Commission recommended 85.47 for the present table.

38   Strontium: ^{84}Sr, ^{86}Sr, Atomic Weight 87.62
         ^{87}Sr, ^{88}Sr

The atomic weight of strontium has been recommended as 87.63 since 1911, based upon chemical ratios measured by Thorpe and Francis (T3) (1910) and by Richards (R8) (1905). Recalculation of the ratios yields 87.63 for the atomic weight. The isotopic abundances determined by Nier (N4) (1938) with masses from EKMW (1960) give a calculated atomic weight of 87.616. The average of the four determinations cited in NDT (1959); ^{84}Sr = 0.560%, ^{86}Sr = 9.870%, ^{87}Sr = 7.035%, ^{88}Sr = 82.535% also yields 87.616 for the calculated atomic weight. The Commission recommended 87.62 for inclusion in the present table.

39   Yttrium: ^{89}Y Atomic Weight 88.905

Since 1928 the atomic weight of yttrium has been 88.92, based upon chemical ratios measured by Hönigschmid and H. Frh. Auer von Welsbach (H22) (1927). Collins, Rourke and White (C5) (1957) and Hess (H5) (1956) have searched for other stable nuclides of yttrium and have set upper limits for their existence of 0.0005% or less from mass 85 to 95. For the present table the recommended value, 88.905, is from EKMW (1960).

40   Zirconium: ^{90}Zr, ^{91}Zr, Atomic Weight 91.22
         ^{92}Zr, ^{94}Zr, ^{96}Zr

The atomic weight of zirconium, 91.22, based upon chemical ratios, has been unchanged since 1927. The ratios have been recalculated.

		Observed ratio	Atomic weight
Comparison of bromide with Ag (H21) (1924)	ZrBr₄/ 4Ag	0.952244	91.24
Comparison of bromide with AgBr (H21) (1924)	ZrBr₄/ 4AgBr	0.547021	91.24

The investigators corrected the observed values by −0.03 for the presence of hafnium in the sample. The recalculated values, thus corrected, give 91.21. From the isotopic composition determined by White and Cameron (W5) (1948) and with masses from EKMW (1960), an atomic weight of 91.22 is calculated. The Commission recommended the adoption of this value.

41   Niobium: ^{93}Nb Atomic Weight 92.906

The previous atomic weight, 92.91, has been based since 1935 upon the chemical ratio of NbCl₅/ 5Ag measured by Hönigschmid and Wintersberger (H37) (1934). Recalculation yields 92.904. White, Collins and Rourke (W4) (1956) have set upper limits of 0.0001% to 0.0002% for the possible existence of other stable nuclides at masses 89 to 98. For the present table, the mass 92.906 is taken from EKMW (1960).

42   Molybdenum: ^{92}Mo, Atomic Weight 95.94
         ^{94}Mo, ^{95}Mo, ^{96}Mo, ^{97}Mo,
         ^{98}Mo, ^{100}Mo

The atomic weight of molybdenum has been stated as 95.95 since the publication of the 1938 Table. The chemical ratio measured by Hönigschmid and Wittmann (H42) (1936) upon which this was based has been recalculated.

		Observed ratio	Atomic weight
Comparison of MoCl₅ with silver (H42) (1936)	MoCl₅/ 5Ag	0.506552	95.944

The isotopic abundance measurements of Williams and Yuster (W8) (1946) with masses from EKMW (1960), give a calculated atomic weight of 95.90. The abundances reported by Hibbs (H9) (1949) give 95.94. The Commission recommended that the chemical basis for the assignment of the value be retained and that 95.94 be used in the present table.

44   Ruthenium: ^{96}Ru,   Atomic Weight 101.07
         ^{98}Ru, ^{99}Ru, ^{100}Ru,
         ^{101}Ru, ^{102}Ru, ^{104}Ru

In the 1953 revision of the table, the atomic weight of ruthenium, 101.1, was based upon the abundance measurements by Friedman and Irsa (F3) (1953), and masses measured by Geiger, Hogg, Duckworth and Dewdney (G1) (1953). With the average of the % abundances reported by Friedman and Irsa, Baldock (B3) (1954) and White, Collins and Rourke (W4) (1956): ^{96}Ru = 5.51; ^{98}Ru = 1.87; ^{99}Ru = 12.72; ^{100}Ru = 12.62; ^{101}Ru = 17.07; ^{102}Ru = 31.63; ^{104}Ru = 18.58; and with masses from EKMW (1960), the calculated atomic weight is 101.07. [Masses for ^{100}Ru and ^{101}Ru were taken as 99.9055 and 100.9046 by interpolation between ^{99}Ru and ^{102}Ru, since they did not appear in EKMW (1960).]

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The revised value of 101.07 was recommended for the present table.

45 Rhodium: ^{103}Rh Atomic Weight 102.905

The atomic weight of rhodium has appeared as 102.91 since 1925. It was based upon the chemical ratio of $Rh(NH_3)_5Br_3/Rh$ and of $Rh(NH_3)_5Cl_3/Rh$ measured by Renz (R2) (1909) and Dittmar (D1) (1909), respectively. The recalculated values are 102.904 and 102.914. For the present table, the recommended value, 102.905, is from EKMW (1960).

46 Palladium: ^{102}Pd, Atomic Weight 106.4
^{104}Pd, ^{105}Pd, ^{106}Pd,
^{108}Pd, ^{110}Pd

The value 106.4 has appeared since 1955 based upon the isotopic abundances of Sites, Consolazio and Baldock (S7) (1953), and masses determined by Halsted (H1) (1952). With masses from EKMW (1960), the recalculated atomic weight is 106.4, which is recommended for the present table.

47 Silver: ^{107}Ag, ^{109}Ag Atomic Weight 107.870 ± 0.003

The basis for the assignment of the atomic weight has been discussed in detail on pages 4178–4179.

48 Cadmium: ^{106}Cd, Atomic Weight 112.40
^{108}Cd, ^{110}Cd, ^{111}Cd,
^{112}Cd, ^{113}Cd, ^{114}Cd, ^{116}Cd

The change from the previous value of 112.41, in use since 1925, to 112.40, in the present table, has been based upon recalculation of the following chemical determinations:

		Observed ratio	Atomic weight
Comparison of chloride with silver (H45) (1936)	CdCl$_2$/ 2Ag	0.849661	112.400
Comparison of bromide with silver (H45) (1936)	CdBr$_2$/ 2Ag	1.26175	112.392
Comparison of bromide with AgBr (H45) (1936)	CdBr$_2$/ 2AgBr	0.724832	112.398
Electrolytic reduction of CdCl$_2$ to Cd (B11) (1915) (in mercury)	CdCl$_2$/ Cd	1.630814	112.404
Electrolytic reduction of CdBr$_2$ to Cd (B13) (1916) (in mercury)	CdBr$_2$/ Cd	2.421938	112.394
Electrolytic reduction of CdCl$_2$ to Cd (B13) (1916) (in mercury)	CdCl$_2$/ Cd	1.630838	112.400
Electrolytic reduction of CdSO$_4$ to Cd (B17) (1921) (in mercury)	Cd/SO$_4$	1.17019	112.410
	Average		112.400

The isotopic abundances of Leland and Nier (L1) (1948) with masses from EKMW (1960), give a calculated atomic weight of 112.42. The more recent determination by Palmer (P1) (1958) gives 112.43.

49 Indium: ^{113}In, ^{115}In Atomic Weight 114.82

The value 114.82 was introduced in the 1955 Table, based upon the isotopic abundances meas- ured by White and Cameron (W5) (1948) and masses measured by Halsted (H1) (1952). The isotopic abundances by White and Cameron and by White, Collins and Rourke (W4) (1956) were averaged to give ^{113}In = 4.28% and ^{115}In = 95.72%, which with masses from EKMW (1960) give a calculated atomic weight of 114.82, which is recommended for the present table.

50 Tin: ^{112}Sn, ^{114}Sn, Atomic Weight 118.69
^{115}Sn, ^{116}Sn, ^{117}Sn,
^{118}Sn, ^{119}Sn, ^{120}Sn,
^{122}Sn, ^{124}Sn

The value for tin has been 118.70 since 1925. The chemical ratios upon which this value was based have been recalculated.

		Observed ratio	Atomic weight
Electrolytic reduction of SnCl$_4$ to Sn (B15) (1920) (in mercury)	SnCl$_4$/Sn	2.194802	118.691
Comparison of SnCl$_4$ with silver (B45) (1915)	SnCl$_4$/4Ag	0.603742	118.691
Comparison of SnBr$_4$ with silver (B43) (1920)	SnBr$_4$/4Ag	1.015863	118.689

Four mass spectrometric determinations of the isotopic composition are reported in NDT (1959). The average of these abundances with masses from EKMW (1960) give a calculated atomic weight of 118.73, which is significantly higher than that from the chemical ratios. The Commission recommended 118.69 for inclusion in the present table.

51 Antimony: ^{121}Sb, Atomic Weight 121.75
^{123}Sb

The atomic weight of antimony, 121.76, has been essentially unchanged since 1925. The chemical ratios upon which it was based have been recalculated.

		Observed ratio	Atomic weight
Comparison of SbCl$_3$ with silver (H20) (1924)	SbCl$_3$/ 3Ag	0.70488	121.747
Comparison of SbCl$_3$ with AgCl (H20) (1924)	SbCl$_3$/ 3AgCl	0.53053	121.752
Comparison of SbBr$_3$ with silver (H20) (1924)	SbBr$_3$/ 3Ag	1.11699	121.742
Comparison of SbBr$_3$ with AgBr (H20) (1924)	SbBr$_3$/ 3AgBr	0.64167	121.749
Comparison of SbCl$_3$ with silver (W2) (1924)	SbCl$_3$/ 3Ag	0.704864	121.742
Comparison of SbBr$_3$ with AgBr (K3) (1927)	SbBr$_3$/ 3AgBr	0.641659	121.743
Comparison of SbBr$_3$ with silver (W7) (1921)	SbBr$_3$/ 3Ag	1.117074	121.769
Comparison of SbBr$_3$ with AgBr (W7) (1921)	SbBr$_3$/ 3AgBr	0.641682	121.756
	Average		121.750

The isotopic abundances of White and Cameron (W5) (1948) with masses from EKMW (1960) give a calculated atomic weight of 121.76. The Commission recommended 121.75 for inclusion in the present table.

52   Tellurium: ^{120}Te,   Atomic Weight 127.60
^{122}Te, ^{123}Te, ^{124}Te,
^{125}Te, ^{126}Te, ^{128}Te, ^{130}Te

The previous value for the atomic weight of tellurium, 127.61, appeared first in the 1934 Table. It was based upon chemical ratios which have been recalculated, together with the results of a more recent investigation.

		Observed ratio	Atomic weight
Comparison of TeBr$_4$ with silver (H35) (1933)	TeBr$_4$/ 4Ag	1.03649	127.589
Comparison of TeBr$_4$ with AgBr (H35) (1933)	TeBr$_4$/ 4AgBr	0.595426	127.598
Synthesis of Ag$_2$Te (H36) (1933)	Ag$_2$Te/ 2Ag	1.59145	127.599
Comparison of TeCl$_4$ with silver (H38) (1935)	TeCl$_4$/ 4Ag	0.624425	127.615
Comparison of TeCl$_4$ with AgCl (H38) (1935)	TeCl$_4$/ 4AgCl	0.469960	127.612
		Average	127.603

The average of the isotopic abundances of White and Cameron (W5) (1948) and of Williams and Yuster (W8) (1946) with masses from EKMW (1960), give a calculated atomic weight of 127.63. The Commission recommended 127.60 for inclusion in the present table.

53   Iodine: ^{127}I   Atomic Weight 126.9044

The previous value for iodine, 126.91, was adopted by the Commission in 1951, based upon then unpublished mass measurements by Nier. It replaced a value of 126.92 which had been obtained from chemical ratios. The value, 126.9044, recommended for the present table is the mass from EKMW (1960).

54   Xenon: ^{124}Xe,   Atomic Weight 131.30
^{126}Xe, ^{128}Xe, ^{129}Xe,
^{130}Xe, ^{131}Xe, ^{132}Xe,
^{134}Xe, ^{136}Xe

In 1955 the Commission recommended the atomic weight of 131.30 for xenon, basing it upon the isotopic composition measured by Nier (N7) (1950) and the masses reported by Halsted (H1) (1952). With the same abundances and the masses from EKMW (1960), the calculated atomic weight is 131.29. The Commission recommended 131.30 for the present table, based on an earlier calculation which was slightly in error.

55   Cesium: ^{133}Cs   Atomic Weight 132.905

The value of 132.91 has appeared since 1934 based upon the CsCl/Ag ratio determined by Baxter and Thomas (B31) (1933). Baxter and Harrington (B40) (1940) redetermined the ratio and found 132.912 which, when recalculated, yields 132.901. White, Collins and Rourke (W4) (1956) have set very low values for the possible existence of other stable nuclides of cesium. The Commission recommended the mass 132.905, from EKMW (1960), for the present table.

56   Barium: ^{130}Ba,   Atomic Weight 137.34
^{132}Ba, ^{134}Ba, ^{135}Ba,
^{136}Ba, ^{137}Ba, ^{138}Ba

The atomic weight of barium had been unchanged at 137.36 since 1929. The ratios upon which it was based have been recalculated.

		Observed ratio	Atomic weight
Conversion of Ba(ClO$_4$)$_2$ to BaCl$_2$ (H26) (1929)	BaCl$_2$/ 4O$_2$	1.627095	137.354
Comparison of BaCl$_2$ with silver (H26) (1929)	BaCl$_2$/ 2Ag	0.965273	137.342
Comparison of BaCl$_2$ with AgCl (H26) (1929)	BaCl$_2$/ 2AgCl	0.726509	137.345
		Average	137.347

The isotopic abundances measured by Nier (N4) (1938) with masses from EKMW (1960) give a calculated atomic weight of 137.33. Abundances reported by Thode (T2) (1958) with the same masses give 137.34. The Commission recommended 137.34 for inclusion in the present table.

57   Lanthanum: ^{138}La,   Atomic Weight 138.91
^{139}La

The atomic weight of lanthanum has been taken as 138.92 since 1933, based upon an average of the chemical ratios determined by Baxter and Behrens (B30) (1932) and Baxter, Tani and Chapin (B18) (1921). Recalculation of these results gives 138.913 and 138.900. With the % isotopic composition ^{138}La = 0.089 and ^{139}La = 99.911, reported by Inghram, Hayden and Hess (I1) (1947) and by White, Collins and Rourke (W4) (1956) and masses from EKMW (1960), the calculated atomic weight is 138.905. The Commission recommended 138.91 for the present table.

58   Cerium: ^{136}Ce,   Atomic Weight 140.12
^{138}Ce, ^{140}Ce, ^{142}Ce

The value 140.13 which has appeared in the tables since 1929 was based upon the ratios CeCl$_3$/3Ag and CeCl$_3$/3AgCl determined by Hönigschmid and Holch (H25) (1929). Recalculation of these ratios yields 140.114. The isotopic abundances determined by Inghram, Hayden and Hess (I1) (1947) and by Hibbs (H9) (1949), with masses from EKMW (1960), give a calculated atomic weight of 140.12. The Commission recommended this value for inclusion in the present table.

59   Praseodymium: Atomic Weight 140.907
^{141}Pr

The atomic weight of praseodymium has been taken as 140.92 since 1925. It was based upon the chemical ratios PrCl$_3$/3Ag and PrCl$_3$/3AgCl, measured by Baxter and Stewart (B10) (1915) which, when recalculated, yield 140.913. The atomic weight of 140.907 recommended for the present table is the mass from EKMW (1960). Very low limits for the existence of other stable nuclides of this element were set by Collins, Rourke and White (C5) (1957).

60   Neodymium: ^{142}Nd, Atomic Weight 144.24
^{143}Nd, ^{144}Nd, ^{145}Nd,
^{146}Nd, ^{148}Nd, ^{150}Nd

The atomic weight of neodymium has been taken as 144.27 since 1925, based upon chemical ratios determined by Baxter and Chapin (B8) (1911)

and Baxter, Whitcomb, Stewart and Chapin (B14) (1916). For the present table, the Commission recommended the value 144.24, based upon masses from EKMW (1960) and % isotopic abundances of ^{142}Nd = 27.11; ^{143}Nd = 12.17; ^{144}Nd = 23.85; ^{145}Nd = 8.30; ^{146}Nd = 17.22; ^{148}Nd = 5.73; and ^{150}Nd = 5.62, which are the averages of the abundances measured by Inghram, Hess and Hayden (I5) (1948) and by Walker and Thode (W1) (1953).

62   Samarium: ^{144}Sm,   Atomic Weight 150.35
        ^{147}Sm, ^{148}Sm, ^{149}Sm,
        ^{150}Sm, ^{152}Sm, ^{154}Sm

In 1955 the value 150.35 for the atomic weight was based upon isotopic abundance measurements by Inghram, Hayden and Hess (I6) (1948) and masses reported by Hogg and Duckworth (H11) (1954). The unweighted averages of five isotopic abundance measurements cited in NDT (1959) with masses from BJN (1960) give a calculated atomic weight of 150.37. The latest abundance measurement by Aitken, Littler, Lockett and Palmer (A1) (1957) gives 150.38. The Commission recommended that 150.35 be retained in the present table.

This element deserves further study, both because of the disparity among the several isotopic abundance determinations and because the chemical determinations of Stewart and James (S10) (1917), Owens, Balke and Kremers (O1) (1920) and Hönigschmid and Hirschbold-Wittner (H52) (1941) all yield higher values, ranging from 150.36 to 150.43.

63   Europium: ^{151}Eu,   Atomic Weight 151.96
        ^{153}Eu

The value 152.0 had been unchanged since 1909 and was based upon chemical ratios determined by Jantsch (J1) (1908). More recent determinations of the ratio EuCl$_2$/2Ag by Baxter and Tuemmler (B36) (1938), and of the same ratio, as well as EuCl$_2$/2AgCl, by Kapfenberger (K1) (1938) yielded 151.95 and 151.89, respectively. The abundances measured by Hess (H6) (1948) and by Collins, Rourke and White (C5) (1957) were averaged, giving ^{151}Eu = 47.82 and ^{153}Eu = 52.18 which, with masses from BJN (1960) give a calculated atomic weight of 151.96 which the Commission recommended for the present table.

64   Gadolinium: ^{152}Gd,   Atomic Weight 157.25
        ^{154}Gd, ^{155}Gd, ^{156}Gd,
        ^{157}Gd, ^{158}Gd, ^{160}Gd

The former value, 157.26, was adopted in 1955 and was based upon isotopic abundance measurements by Hess (H6) (1948) and Leland (L4) (1950) and masses measured by Hogg and Duckworth (H11) (1954). With the same abundances and with masses from BJN (1960) the calculated atomic weight is 157.25, which the Commission recommended for the present table.

65   Terbium: ^{159}Tb   Atomic Weight 158.924

The value for this element was revised in 1953 to 158.93 on the basis of the mass interpolated from the packing fraction curve. Very low abun-

dance limits have been set for the existence of other stable nuclides of the element by Collins, Rourke and White (C5) (1957). The Commission recommended the new value of 158.924 based on the mass of ^{159}Tb from EKMW (1960).

66   Dysprosium: ^{156}Dy,   Atomic Weight 162.50
        ^{158}Dy, ^{160}Dy, ^{161}Dy,
        ^{162}Dy, ^{163}Dy, ^{164}Dy

The atomic weight of dysprosium, 162.51, adopted in 1955, was based upon abundance measurements by Inghram, Hayden and Hess (I7) (1949) and masses measured by Hogg and Duckworth (H11) (1954). With the same abundances and masses from BJN (1960), the recommended atomic weight is 162.50.

67   Holmium: ^{165}Ho   Atomic Weight 164.930

The atomic weight of this element has been taken as 164.94 since 1941. It was based upon the ratio HoCl$_3$/3Ag measured by Hönigschmid and Hirschbold-Wittner (H50) (1940). Recalculation yields 164.928. Low upper limits for the existence of other stable nuclides of this element have been set by Collins, Rourke and White (C5) (1957). The Commission recommended the atomic weight of 164.930 from BJN (1960).

68   Erbium: ^{162}Er,   Atomic Weight 167.26
        ^{164}Er, ^{166}Er, ^{167}Er,
        ^{168}Er, ^{170}Er

The previous value, 167.27, was adopted in 1955. It was based upon isotopic measurements by Hayden, Hess and Inghram (H3) (1950) and masses measured by Hogg and Duckworth (H11) (1954). With masses from BJN (1960) the same isotopic abundances, as well as those measured by Leland (L4) (1950), give a calculated atomic weight of 167.26 which is recommended for the present table.

The results of a chemical determination by Hönigschmid and Wittner (H46) (1937), which yielded 167.24, cannot be regarded as trustworthy because of uncertainties in the corrections applied for the presence of other rare earths and yttrium.

69   Thulium: ^{169}Tm   Atomic Weight 168.934

In 1953 the Commission derived 168.94 as the atomic weight of this element from its position on the packing fraction curve. For the present table the mass 168.934, measured by BJN (1960), was recommended.

70   Ytterbium: ^{168}Yb,   Atomic Weight 173.04
        ^{170}Yb, ^{171}Yb, ^{172}Yb,
        ^{173}Yb, ^{174}Yb, ^{176}Yb

The atomic weight of ytterbium has been taken as 173.04 since 1934. This value was based upon measurements by Hönigschmid and Striebel (H33) (1933), which yield 173.03 when recalculated. A later determination, by Hönigschmid and Hirschbold-Wittner (H51) (1941), for which more thoroughly purified and evaluated material appears to have been used, yields 173.09 on recalculation. With masses from BJN (1960) and the average of the % abundances measured by Hayden, Hess and Inghram (H2) (1949) and by Leland (L4) (1950):

^{168}Yb = 0.135; ^{170}Yb = 3.03; ^{171}Yb = 14.31; ^{172}Yb = 21.82; ^{173}Yb = 16.135; ^{174}Yb = 31.84; and ^{176}Yb = 12.73, the calculated atomic weight is 173.04. The Commission has recommended this value for the present table.

71   Lutetium: ^{175}Lu,   Atomic Weight 174.97
      ^{176}Lu

The value 174.99 was accepted by the Commission for inclusion in the 1940 Table, based upon chemical ratios determined by Hönigschmid and Wittner (H47) (1939) and isotopic abundances measured by Mattauch and Lichtblau (M2) (1939). Recalculation of the chemical measurements yields 174.97. The abundances determined by Hayden, Hess and Inghram (H3) (1950) and Collins, Rourke and White (C5) (1957), when averaged, give ^{175}Lu = 97.41% and ^{176}Lu = 2.59%. With masses from BJN (1960), an atomic weight of 174.97 is calculated. This value is recommended for the present table.

72   Hafnium: ^{174}Hf,   Atomic Weight 178.49
      ^{176}Hf, ^{177}Hf, ^{178}Hf,
      ^{179}Hf, ^{180}Hf

In the 1955 Table the value of 178.50 was introduced, based upon abundances measured by Hibbs (H9) (1949) and masses determined by Hogg and Duckworth (H11) (1954). For the present table the % abundances of Hibbs (H9) (1949) and of Reynolds (R4) (1953) and White, Collins and Rourke (W4) (1956) have been averaged: ^{174}Hf = 0.18; ^{176}Hf = 5.20; ^{177}Hf = 18.50; ^{178}Hf = 27.13; ^{179}Hf = 13.75; and ^{180}Hf = 35.24, and with masses from BJN (1960) give a calculated atomic weight of 178.49.

73   Tantalum: ^{180}Ta,   Atomic Weight 180.948
      ^{181}Ta

In 1953 the chemically determined value for tantalum was replaced by 180.95, derived from the position of the element on the packing fraction curve. At that time the element was thought to consist of the single nuclide ^{181}Ta. White, Collins and Rourke (W3) (1955) have reported the existence of stable ^{180}Ta. The abundance of ^{180}Ta is 0.0120% by averaging the results of White, Collins and Rourke (W4) (1956) and Palmer (P1) (1958), and with masses from BJN (1960), the calculated atomic weight is 180.948, which is recommended for the present table.

74   Tungsten: ^{180}W,   Atomic Weight 183.85
      ^{182}W, ^{183}W, ^{184}W, ^{186}W

In 1955 the atomic weight of tungsten, 183.86, was accepted based upon abundance measurements by Williams and Yuster (W8) (1946) and masses measured by Duckworth, Johnson, Preston and Woodcock (D2) (1950); Duckworth, Kegley, Olson and Stanford (D5) (1951); and Geiger, Hogg, Duckworth and Dewdney (G1) (1953). The unweighted average of % abundances measured by Williams and Yuster (W8) (1946), Mattauch and Scheld (M4) (1948), White and Cameron (W5) (1948) and Hibbs (H9) (1949) are: ^{180}W = 0.14; ^{182}W = 26.29; ^{183}W = 14.31; ^{184}W = 30.66; and ^{186}W = 28.60. With masses from BJN (1960)

the calculated atomic weight is 183.85, recommended for the present table.

In view of the general reliability of measurements by Hönigschmid and his associates, the work of Hönigschmid and Menn (H43) (1936) on the ratio WCl$_6$/6Ag should not be neglected in future consideration of this element. Recalculation of the measurement yields 183.91.

75   Rhenium: ^{185}Re,   Atomic Weight 186.2
      ^{187}Re

In 1955 the atomic weight of rhenium was taken as 186.22, based upon abundances measured by White and Cameron (W5) (1948) and masses estimated from the packing fraction curve. From the same abundances and masses of BJN (1960), the Commission recommended the more conservative value, 186.2, for the present table.

76   Osmium: ^{184}Os,   Atomic Weight 190.2
      ^{186}Os, ^{187}Os, ^{188}Os,
      ^{189}Os, ^{190}Os, ^{192}Os

In 1938 the atomic weight of osmium was changed to 190.2, based upon the isotopic composition reported by Nier (N2) (1937) and a packing fraction of -1×10^{-4}. There has been no other measurement of the isotopic composition. Recalculation with Nier's abundances and masses from BJN (1960) gives 190.2, which is recommended for the present table.

77   Iridium: ^{191}Ir, ^{193}Ir   Atomic Weight 192.2

The value of 192.2 was chosen for the 1953 Table based upon abundances measured by Sampson and Bleakney (S1) (1936), and masses estimated from the packing fraction curve. The only more recent measurement of the isotopic composition is that of Baldock (B3) (1954). With his abundances and masses from BJN (1960) the calculated atomic weight is 192.22. The Commission recommended retaining 192.2 as the value.

78   Platinum: ^{190}Pt,   Atomic Weight 195.09
      ^{192}Pt, ^{194}Pt, ^{195}Pt,
      ^{196}Pt, ^{198}Pt

In 1955 the value of 195.09 was adopted, based upon isotopic abundance measurements by Inghram, Hess and Hayden (I2) (1947) and by Leland (L3) (1949) and masses measured by Duckworth, Woodcock and Preston (D4) (1950); by Duckworth, Johnson, Preston and Woodcock (D2) (1950); and by Hogg and Duckworth (H11) (1954). The average of the abundances of Inghram, Hess and Hayden (I2) (1947) and of White, Collins and Rourke (W4) (1956) with masses from BJN (1960), give a calculated value of 195.09. The Commission recommended retention of this value in the present table.

79   Gold: ^{197}Au   Atomic Weight 196.967

The rounded value, 197.0, estimated from the packing fraction curve was adopted for the 1953 Table. For the present table the mass 196.967 is taken from BJN (1960).

80   Mercury: ^{196}Hg,   Atomic Weight 200.59
      ^{198}Hg, ^{199}Hg, ^{200}Hg,
      ^{201}Hg, ^{202}Hg, ^{204}Hg

TABLE OF RELATIVE ATOMIC WEIGHTS 1961

Based on the Atomic Mass of $^{12}C = 12$

The values for atomic weights given in the table apply to elements as they exist in nature, without artificial alteration of their isotopic composition, and, further, to natural mixtures that do not include isotopes of radiogenic origin.

Alphabetical Order

Name	Symbol	Atomic number	Atomic weight	Name	Symbol	Atomic number	Atomic weight
Actinium	Ac	89	....	Osmium	Os	76	190.2
Aluminum	Al	13	26.9815	Oxygen	O	8	15.9994[a]
Americium	Am	95	....	Palladium	Pd	46	106.4
Antimony	Sb	51	121.75	Phosphorus	P	15	30.9738
Argon	Ar	18	39.948	Platinum	Pt	78	195.09
Arsenic	As	33	74.9216	Plutonium	Pu	94	....
Astatine	At	85	....	Polonium	Po	84	....
Barium	Ba	56	137.34	Potassium	K	19	39.102
Berkelium	Bk	97	....	Praseodymium	Pr	59	140.907
Beryllium	Be	4	9.0122	Promethium	Pm	61	....
Bismuth	Bi	83	208.980	Protactinium	Pa	91	....
Boron	B	5	10.811[a]	Radium	Ra	88	....
Bromine	Br	35	79.909[b]	Radon	Rn	86	....
Cadmium	Cd	48	112.40	Rhenium	Re	75	186.2
Calcium	Ca	20	40.08	Rhodium	Rh	45	102.905
Californium	Cf	98	....	Rubidium	Rb	37	85.47
Carbon	C	6	12.01115[a]	Ruthenium	Ru	44	101.07
Cerium	Ce	58	140.12	Samarium	Sm	62	150.35
Cesium	Cs	55	132.905	Scandium	Sc	21	44.956
Chlorine	Cl	17	35.453[b]	Selenium	Se	34	78.96
Chromium	Cr	24	51.996[b]	Silicon	Si	14	28.086[a]
Cobalt	Co	27	58.9332	Silver	Ag	47	107.870[b]
Copper	Cu	29	63.54	Sodium	Na	11	22.9898
Curium	Cm	96	....	Strontium	Sr	38	87.62
Dysprosium	Dy	66	162.50	Sulfur	S	16	32.064[a]
Einsteinium	Es	99	....	Tantalum	Ta	73	180.948
Erbium	Er	68	167.26	Technetium	Tc	43	....
Europium	Eu	63	151.96	Tellurium	Te	52	127.60
Fermium	Fm	100	....	Terbium	Tb	65	158.924
Fluorine	F	9	18.9984	Thallium	Tl	81	204.37
Francium	Fr	87	....	Thorium	Th	90	232.038
Gadolinium	Gd	64	157.25	Thulium	Tm	69	168.934
Gallium	Ga	31	69.72	Tin	Sn	50	118.69
Germanium	Ge	32	72.59	Titanium	Ti	22	47.90
Gold	Au	79	196.967	Tungsten	W	74	183.85
Hafnium	Hf	72	178.49	Uranium	U	92	238.03
Helium	He	2	4.0026	Vanadium	V	23	50.942
Holmium	Ho	67	164.930	Xenon	Xe	54	131.30
Hydrogen	H	1	1.00797[a]	Ytterbium	Yb	70	173.04
Indium	In	49	114.82	Yttrium	Y	39	88.905
Iodine	I	53	126.9044	Zinc	Zn	30	65.37
Iridium	Ir	77	192.2	Zirconium	Zr	40	91.22
Iron	Fe	26	55.847[b]				
Krypton	Kr	36	83.80				
Lanthanum	La	57	138.91				
Lead	Pb	82	207.19				
Lithium	Li	3	6.939				
Lutetium	Lu	71	174.97				
Magnesium	Mg	12	24.312				
Manganese	Mn	25	54.9380				
Mendelevium	Md	101	....				
Mercury	Hg	80	200.59				
Molybdenum	Mo	42	95.94				
Neodymium	Nd	60	144.24				
Neon	Ne	10	20.183				
Neptunium	Np	93	....				
Nickel	Ni	28	58.71				
Niobium	Nb	41	92.906				
Nitrogen	N	7	14.0067				
Nobelium	No	102	....				

[a] Atomic weights so designated are known to be variable because of natural variations in isotopic composition. The observed ranges are:

Hydrogen	±0.00001
Boron	±0.003
Carbon	±0.00005
Oxygen	±0.0001
Silicon	±0.001
Sulfur	±0.003

[b] Atomic weights so designated are believed to have the following experimental uncertainties:

Chlorine	±0.001
Chromium	±0.001
Iron	±0.003
Bromine	±0.002
Silver	±0.003

TABLE OF RELATIVE ATOMIC WEIGHTS 1961

Based on the Atomic Mass of $^{12}C = 12$

The values for atomic weights given in the table apply to elements as they exist in nature, without artificial alteration of their isotopic composition, and, further, to natural mixtures that do not include isotopes of radiogenic origin.

Order of Atomic Number

Atomic number	Name	Symbol	Atomic weight	Atomic number	Name	Symbol	Atomic weight
1	Hydrogen	H	1.00797[a]	61	Promethium	Pm	....
2	Helium	He	4.0026	62	Samarium	Sm	150.35
3	Lithium	Li	6.939	63	Europium	Eu	151.96
4	Beryllium	Be	9.0122	64	Gadolinium	Gd	157.25
5	Boron	B	10.811[a]	65	Terbium	Tb	158.924
6	Carbon	C	12.01115[a]	66	Dysprosium	Dy	162.50
7	Nitrogen	N	14.0067	67	Holmium	Ho	164.930
8	Oxygen	O	15.9994[a]	68	Erbium	Er	167.26
9	Fluorine	F	18.9984	69	Thulium	Tm	168.934
10	Neon	Ne	20.183	70	Ytterbium	Yb	173.04
11	Sodium	Na	22.9898	71	Lutetium	Lu	174.97
12	Magnesium	Mg	24.312	72	Hafnium	Hf	178.49
13	Aluminum	Al	26.9815	73	Tantalum	Ta	180.948
14	Silicon	Si	28.086[a]	74	Tungsten	W	183.85
15	Phosphorus	P	30.9738	75	Rhenium	Re	186.2
16	Sulfur	S	32.064[a]	76	Osmium	Os	190.2
17	Chlorine	Cl	35.453[b]	77	Iridium	Ir	192.2
18	Argon	Ar	39.948	78	Platinum	Pt	195.09
19	Potassium	K	39.102	79	Gold	Au	196.967
20	Calcium	Ca	40.08	80	Mercury	Hg	200.59
21	Scandium	Sc	44.956	81	Thallium	Tl	204.37
22	Titanium	Ti	47.90	82	Lead	Pb	207.19
23	Vanadium	V	50.942	83	Bismuth	Bi	208.980
24	Chromium	Cr	51.996[b]	84	Polonium	Po	....
25	Manganese	Mn	54.9380	85	Astatine	At	....
26	Iron	Fe	55.847[b]	86	Radon	Rn	....
27	Cobalt	Co	58.9332	87	Francium	Fr	....
28	Nickel	Ni	58.71	88	Radium	Ra	....
29	Copper	Cu	63.54	89	Actinium	Ac	....
30	Zinc	Zn	65.37	90	Thorium	Th	232.038
31	Gallium	Ga	69.72	91	Protactinium	Pa	....
32	Germanium	Ge	72.59	92	Uranium	U	238.03
33	Arsenic	As	74.9216	93	Neptunium	Np	....
34	Selenium	Se	78.96	94	Plutonium	Pu	....
35	Bromine	Br	79.909[b]	95	Americium	Am	....
36	Krypton	Kr	83.80	96	Curium	Cm	....
37	Rubidium	Rb	85.47	97	Berkelium	Bk	....
38	Strontium	Sr	87.62	98	Californium	Cf	....
39	Yttrium	Y	88.905	99	Einsteinium	Es	....
40	Zirconium	Zr	91.22	100	Fermium	Fm	....
41	Niobium	Nb	92.906	101	Mendelevium	Md	....
42	Molybdenum	Mo	95.94	102	Nobelium	No	....
43	Technetium	Tc	....				
44	Ruthenium	Ru	101.07				
45	Rhodium	Rh	102.905				
46	Palladium	Pd	106.4				
47	Silver	Ag	107.870[b]				
48	Cadmium	Cd	112.40				
49	Indium	In	114.82				
50	Tin	Sn	118.69				
51	Antimony	Sb	121.75				
52	Tellurium	Te	127.60				
53	Iodine	I	126.9044				
54	Xenon	Xe	131.30				
55	Cesium	Cs	132.905				
56	Barium	Ba	137.34				
57	Lanthanum	La	138.91				
58	Cerium	Ce	140.12				
59	Praseodymium	Pr	140.907				
60	Neodymium	Nd	144.24				

[a] Atomic weights so designated are known to be variable because of natural variations in isotopic composition. The observed ranges are:

Hydrogen	±0.00001
Boron	±0.003
Carbon	±0.00005
Oxygen	±0.0001
Silicon	±0.001
Sulfur	±0.003

[b] Atomic weights so designated are believed to have the following experimental uncertainties:

Chlorine	±0.001
Chromium	±0.001
Iron	±0.003
Bromine	±0.002
Silver	±0.003

THE RADIOACTIVE ELEMENTS 1961
Alphabetical Order

Name	Symbol	Atomic number	Isotope	Half-life		Mode of disintegration
Actinium	Ac	89	227	21	years	β-, α
Americium	Am	95	243	7.8×10^3	years	α
Astatine	At	85	210	8.3	hours	α
Berkelium	Bk	97	247	ca. 10^4	years	α
Californium	Cf	98	249	360	years	α
Curium	Cm	96	247	$>4 \times 10^7$	years	α
Einsteinium	Es	99	254	ca. 320	days	α
Fermium	Fm	100	253	3	days	α
Francium	Fr	87	223	22	minutes	β-
Mendelevium	Md	101	256	ca. 1.5	hours	electron capture
Neptunium	Np	93	237	2.1×10^6	years	α
Nobelium	No	102		ca. 10	minutes	α
Plutonium	Pu	94	242	3.8×10^5	years	α
Polonium	Po	84	210*	138	days	α
Promethium	Pm	61	147*	2.6	years	β-
Protactinium	Pa	91	231	3.4×10^4	years	α
Radium	Ra	88	226	1622	years	α
Radon	Rn	86	222	3.8	days	α
Technetium	Tc	43	99*	2.1×10^5	years	β-
Thorium	Th	90	232	1.4×10^{10}	years	α
Uranium	U	92	238	4.5×10^9	years	α

This table lists selected isotopes of the chemical elements, whether occurring in nature or known only through synthesis, that are commonly classed as radioactive. The listed isotope may be either the one of longest known half-life, or, for those marked with an asterisk, a better known one.

THE RADIOACTIVE ELEMENTS 1961
Order of Atomic Number

Atomic number	Name	Symbol	Isotope	Half-life		Mode of disintegration
43	Technetium	Tc	99*	2.1×10^5	years	β-
61	Promethium	Pm	147*	2.6	years	β-
84	Polonium	Po	210*	138	days	α
85	Astatine	At	210	8.3	hours	α
86	Radon	Rn	222	3.8	days	α
87	Francium	Fr	223	22	minutes	β-
88	Radium	Ra	226	1622	years	α
89	Actinium	Ac	227	21	years	β-, α
90	Thorium	Th	232	1.4×10^{10}	years	α
91	Protactinium	Pa	231	3.4×10^4	years	α
92	Uranium	U	238	4.5×10^9	years	α
93	Neptunium	Np	237	2.1×10^6	years	α
94	Plutonium	Pu	242	3.8×10^5	years	α
95	Americium	Am	243	7.8×10^3	years	α
96	Curium	Cm	247	$>4 \times 10^7$	years	α
97	Berkelium	Bk	247	ca. 10^4	years	α
98	Californium	Cf	249	360	years	α
99	Einsteinium	Es	254	ca. 320	days	α
100	Fermium	Fm	253	3	days	α
101	Mendelevium	Md	256	ca. 1.5	hours	electron capture
102	Nobelium	No		ca. 10	minutes	a

This table lists selected isotopes of the chemical elements, whether occurring in nature or known only through synthesis, that are commonly classed as radioactive. The listed isotope may be either the one of longest known half-life or, for those marked with an asterisk, a better known one.

The atomic weight of mercury, 200.61, has been unchanged since 1925. The chemical ratios upon which it has been based were recalculated.

		Observed ratio	Atomic weight
Comparison of $HgCl_2$ with silver (H19) (1923)	$HgCl_2$/2Ag	1.25847	200.596
Comparison of $HgBr_2$ with silver (H19) (1923)	$HgBr_2$/2Ag	1.67056	200.589

The masses of BJN (1960) with the isotopic abundances of Nier (N8) (1950) give a calculated atomic weight of 200.61. The Commission recommended the value 200.59 for inclusion in the present table.

81 Thallium: ^{203}Tl, ^{205}Tl Atomic Weight 204.37

The atomic weight of thallium has been stated as 204.39 since 1925. The chemical ratios have been recalculated.

		Observed ratio	Atomic weight
Comparison of TlCl with silver (H16) (1922)	TlCl/Ag	2.22324	204.368
Comparison of TlCl with AgCl (H16) (1922)	TlCl/AgCl	1.67332	204.372
Comparison of TlBr with silver (H27) (1930)	TlBr/Ag	2.63539	204.371
		Average	204.370

The isotopic abundances determined by White and Cameron (W5) (1948) and by Hibbs (H9) (1949) with masses from BJN (1960), give a calculated atomic weight of 204.38. The Commission recommended the value 204.37 for the present table.

82   Lead: ^{204}Pb,   Atomic Weight 207.19
      ^{206}Pb, ^{207}Pb, ^{208}Pb

The atomic weight of lead has been taken as 207.21 since 1937. The chemical determinations have been recalculated.

		Observed ratio	Atomic weight
Comparison of PbCl$_2$ with silver (B32) (1933)	PbCl$_2$/2Ag	1.28905	207.194
Comparison of PbCl$_2$ with silver (B35) (1937)	PbCl$_2$/2Ag	1.28906	207.196
Comparison of PbCl$_2$ with silver (H34) (1933)	PbCl$_2$/2Ag	1.28903	207.189

The isotopic composition of "common" lead is variable because it has been affected by contributions of radiogenic lead. The Commission recommended using 207.19 as the value for the present table, since it was felt that it quite well represented the lead most likely to be encountered in normal laboratory work.

The atomic weights of leads of widely differing isotopic composition should be calculated from the composition and the masses of the individual species. The masses from EKMW (1960) are:

^{204}Pb	203.9749	^{207}Pb	206.9759
^{206}Pb	205.9762	^{208}Pb	207.9766

83   Bismuth: ^{209}Bi   Atomic Weight 208.980

The atomic weight of bismuth has been stated as 209.00 since 1925, based upon chemical ratios determined by Hönigschmid (H13) (1917), and by Hönigschmid and Birckenbach (H14) (1921).

Recalculation of those ratios yields 208.976. For the present table the mass from EKMW (1960), 208.980. is recommended by the Commission.

90   Thorium: ^{232}Th   Atomic Weight 232.038

The atomic weight 232.05 of this element was based, in 1953, upon the mass measured by Stanford, Duckworth, Hogg and Geiger (S11) (1952). For the present table the Commission recommended the mass from EKMW (1960), 232.038.

92   Uranium: ^{234}U,   Atomic Weight 238.03
      ^{235}U, ^{238}U

The atomic weight of uranium was changed to 238.07 in 1937, based upon measurements of the ratio UCl$_4$/4Ag by Hönigschmid and Wittner (H41) (1936). Recalculation yields 238.05. Natural uranium contains 0.0056% ^{234}U, as measured by White, Collins and Rourke (W4) (1956). The ^{235}U abundance has been carefully determined by mass spectrometric comparison to gravimetric standards prepared from separated ^{235}U and ^{238}U of very high chemical and isotopic purity. The accepted abundance of ^{235}U in natural uranium is 0.7205%, determined by Boardman and Meservey and quoted by Greene, Kienberger and Meservey (G5) (1955). With these abundances and masses from EKMW (1960), the calculated atomic weight is 238.03, which the Commission recommended for the present table.

A variation of 0.1% of the ^{235}U content in certain ores has been reported by Smith (S8) (1961) and by Senftle, Stieff, Cuttitta and Kuroda (S4) (1957). Others also have observed variations of this magnitude. This causes a range of ±0.0024 in the atomic weight and is not significant for the recommended value.

The atomic weight of other than naturally occurring uranium must be calculated from the isotopic composition and masses. The masses from EKMW (1960) are listed for such use. The uncertainty does not exceed ±1 in the last decimal place.

^{233}U	233.0395	^{236}U	236.0457
^{234}U	234.0409	^{237}U	237.0486
^{235}U	235.0439	^{238}U	238.0508

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