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Report of the Committee on Atomic Weights of the American Chemical Society

BY EDWARD WICHERS

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The Council of the International Union of Chemistry, at its meeting in Stockholm in July, 1953, accepted the recommendations of the International Commission on Atomic Weights concerning new values for the atomic weights of ten elements. The new values and the reasons for the changes are stated in the following paragraphs. In this discussion conversions to the chemical scale, of mass data reported on the physical scale, have been made with the divisor 1.000275, in accordance with the practice followed by the International Commission since 1940.

Carbon.—Former value, 12.010; new value, 12.011. The new value is based primarily on the masses of C^{12} and C^{13} calculated by Li, Whaling, Fowler and Lauritsen[1] from observations of energy changes accompanying nuclear reactions, and on the determination by Nier[2] of the relative abundances of the two isotopes. The masses found for the two isotopes are 12.0038 and 13.0075, and Nier's value for the abundance ratio C^{13}/C^{12} is 0.0112 for atmospheric carbon dioxide and 0.0115 for carbon in limestone, in good agreement with several other of the more recent determinations. The average mass (physical scale) for atmospheric carbon therefore is 12.0146, and the atomic weight, 12.0113. Corresponding values for carbon in limestone are 12.0149 and 12.0116. For the purposes of the Table of Atomic Weights the International Commission proposed 12.011. In work of sufficient refinement account should be taken of the actual isotopic composition of the carbon-bearing substance that is at hand.

It is noteworthy that the work of Baxter and Hale,[3] on the ratio $Na_2CO_3:I_2O_5$, yields 12.011 as the atomic weight of carbon if sodium is taken as 22.991, its new value, and iodine is taken as 126.91, the value adopted in 1951. At the time this work was done its significance was not appreciated because the atomic weights of sodium and iodine were both considered to be appreciably greater than now appears to be true.

Gold.—Former value, 197.2; new value, 197.0. The formerly used value is not based on recent, or very secure, chemical evidence, and is inconsistent with the value for this simple element estimated from the packing fraction curve, 197.03 ± 0.01. The rounded value 197.0 was proposed.

Iridium.—Former value, 193.1; new value 192.2. As in the case of gold, no recent chemical determinations have been made. The masses of the two isotopes, Ir^{191} and Ir^{193}, can be estimated from the packing fraction curve to be greater than integers by about 0.02. The relative abundances of the two were found by Sampson and Bleakney[4] to be 38.5 and 61.5%. The fact that this determination is not recent and has not been repeated made it advisable to recommend the rounded value of 192.2.

Manganese.—Former value, 54.93; new value, 54.94. The mass of this single nuclear species was recently found by Collins, Nier and Johnson[5] to be 54.9558. Conversion to the chemical scale yields 54.9407. The high precision of this work was considered to justify revision to 54.94.

Ruthenium.—Former value, 101.70; new value, 101.1. Until recently there had been only one measurement of the relative abundances of the seven isotopes of ruthenium since Aston's pioneer work. This was by Ewald,[6] whose observations yielded 101.04 for the atomic weight of the element, in marked disagreement with the value, 101.7, in the International Table. However, recent measurements of the abundances by Friedman and Irsa,[7] combined with mass calculations by Geiger, Hogg, Duckworth and Dewdney,[8] give the atomic weight as 101.10. It is noteworthy that

(1) C. W. Li, W. Whaling, W. A. Fowler and C. C. Lauritsen, *Phys. Rev.*, **83**, 512 (1951).

(2) A. O. Nier, *ibid.*, **77**, 789 (1950).

(3) G. P. Baxter and A. H. Hale, THIS JOURNAL, **56**, 615 (1934).

(4) M. B. Sampson and W. Bleakney, *Phys. Rev.*, **50**, 732 (1936).

(5) T. L. Collins, A. O. Nier and W. H. Johnson, Jr., *ibid.*, **86**, 408 (1952).

(6) H. Ewald, *Z. Physik*, **122**, 487 (1944).

(7) L. Friedman and A. P. Irsa, THIS JOURNAL, **75**, 5741 (1953).

(8) J. S. Geiger, B. G. Hogg, H. E. Duckworth and J. W. Dewdney, *Phys. Rev.*, **89**, 621 (1953).

the two values derived from mass spectrometry are in excellent agreement with that resulting from a chemical ratio determined by Gleu and Rehm[9] in 1937. Their value, 101.08, was not at that time accepted by the Commission. The close agreement of the results of these three investigations was taken to justify revision of the atomic weight of ruthenium to 101.1.

Sodium.—Former value, 22.997; new value, 22.991. The accepted atomic weight of this important element has remained unchanged since 1905, when the classical work of Richards and Wells[10] on the ratios of sodium chloride to silver and to silver chloride clearly disclosed the need of revising the value based on the earlier work of Stas. G. P. Baxter, in a private communication to the International Commission after his retirement from it, reported that his own observations had led him to believe that the official value was somewhat too high, but he apparently was not well enough satisfied to recommend a specific revision. There is now a considerable accumulation of evidence from mass spectrographic measurements and nuclear calculations. Since sodium is a simple element, no isotopic abundance measurements are involved. Henglein,[11] by mass spectrometric measurement, finds 22.9966 for the mass on the physical scale. Dr. K. Way, in a private communication, has shown that a consideration of the energies of a series of three reactions by which sodium can be converted to oxygen-16, ($Na^{23}(d,\alpha)Ne^{21}$; $Ne^{21}(d,\alpha)F^{19}$; $F^{19}(p,\alpha)O^{16}$), yields 22.9971. In addition, a combination of two reactions starting with Neon-22 yields 22.9972, and a series of three steps from aluminum to sodium gives 22.9968. Li,[12] from a similar calculation, finds 22.9971. The average of these five very concordant values is 22.9970, which becomes 22.9907 on the chemical scale. The Commission recommended 22.991. As noted previously under carbon, the ratio $Na_2CO_3:I_2O_5$, as determined by Baxter and Hale,[3] yields 22.991 for sodium if carbon is taken as 12.011 and iodine as 126.91.

Tantalum.—Former value, 180.88; new value, 180.95. Consideration of the position of this simple element on the packing fraction curve showed that the old value must be in errror and that it should be revised to 180.95.

Terbium.—Former value, 159.2; new value 158.93. No natural isotopes of this element have been detected. Although its mass has not been directly measured, consideration of the packing fraction curve showed that the old value must be too high and was believed to justify revision to 158.93.

Thorium.—Former value, 232.12; new value 232.05. The mass of this simple element was recently determined by Stanford, Duckworth, Hogg and Geiger,[13] and reported as 232.109. Conversion to the chemical scale gives 232.05, the value recommended.

(9) K. Gleu and K. Rehm, *Z. anorg. allgem. Chem.*, **235**, 352 (1937).

(10) T. W. Richards and R. C. Wells, Publ. Carnegie Inst. Washington, No. 28 (1905).

(11) A. Henglein, *Z. Naturforsch.*, **6a**, 745 (1951).

(12) C. W. Li, *Phys. Rev.*, **88**, 1038 (1952).

(13) G. S. Stanford, H. E. Duckworth, B. G. Hogg and J. S. Geiger, *ibid.*, **85**, 1039 (1952).

Thulium.—Former value, 169.4; new value 168.94. The situation with respect to thulium is like that for terbium. It is a simple element whose mass has not been directly measured but, when calculated from the position on the packing fraction curve, yields a value for the atomic weight that differs by 0.5 from the one hitherto used. The calculated mass is 168.99 and the atomic weight derived from it, which is now recommended, is 168.94.

It will be noted that while most of the changes are rather small, a few are large. These larger changes remove the remaining conspicuous discrepancies between the older values, chemically derived, and those based on mass spectrometry. Such differences as still remain between the International atomic weights and values based exclusively on physical determinations are relatively small and, for the most part, cannot be resolved on the basis of existing evidence. The relative facility with which the masses of single nuclear species can be measured or calculated, and the high accuracy of such determinations, have resulted in an almost complete cessation of work on the determination of atomic weights by means of chemical ratios. For the 22 simple elements (those having no natural isotopes) the evidence from mass spectrometry and from calculations based on the energies involved in nuclear transformations now outweighs that derived from stoichiometry. The situation is not quite the same for the other elements. Relative isotopic abundances are not, as yet, being measured with the accuracy obtained in the determination of individual masses. For this reason values for the atomic weights of isotopic elements that are derived from physical measurements have a greater degree of uncertainty than those for simple elements. Resolution of the remaining differences between chemically determined atomic weights and those derived from physical measurements must therefore, in most instances, await either new chemical work, for which there is not much prospect, or more accurate measurement of isotopic abundance ratios. Fortunately, few, if any, of the remaining differences are large enough to be significant for any but the most refined uses of atomic weights.

In the last previous detailed report of this Committee[14] there was a brief discussion of the inherent slight inexactness of the chemical scale of atomic weights resulting from the known slight variations in the isotopic composition of the element oxygen. This inexactness has been of no practical consequence because none of the atomic weights in the International Table, with the possible exception of silver, is given with sufficient precision to be affected by the variations thus far observed in the isotopic composition of natural oxygen. Furthermore, the International Commission has followed a uniform practice, ever since the existence of oxygen isotopes became known, in converting to the chemical scale data recorded in terms of the physical scale, which is based on 16 as the relative mass of the single species, O^{16}. Prior to 1940 the factor used for this purpose was 1.00027. From

(14) Edward Wichers, THIS JOURNAL, **74**, 2447 (1952).

INTERNATIONAL ATOMIC WEIGHTS

1953

	Symbol	Atomic Number	Atomic Weight[a]
Actinium	Ac	89	227
Aluminum	Al	13	26.98
Americium	Am	95	[243]
Antimony	Sb	51	121.76
Argon	A	18	39.944
Arsenic	As	33	74.91
Astatine	At	85	[210]
Barium	Ba	56	137.36
Berkelium	Bk	97	[245]
Beryllium	Be	4	9.013
Bismuth	Bi	83	209.00
Boron	B	5	10.82
Bromine	Br	35	79.916
Cadmium	Cd	48	112.41
Calcium	Ca	20	40.08
Californium	Cf	98	[248]
Carbon	C	6	12.011
Cerium	Ce	58	140.13
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.457
Chromium	Cr	24	52.01
Cobalt	Co	27	58.94
Columbium (see Niobium)			
Copper	Cu	29	63.54
Curium	Cm	96	[245]
Dysprosium	Dy	66	162.46
Erbium	Er	68	167.2
Europium	Eu	63	152.0
Fluorine	F	9	19.00
Francium	Fr	87	[223]
Gadolinium	Gd	64	156.9
Gallium	Ga	31	69.72
Germanium	Ge	32	72.60
Gold	Au	79	197.0
Hafnium	Hf	72	178.6
Helium	He	2	4.003
Holmium	Ho	67	164.94
Hydrogen	H	1	1.0080
Indium	In	49	114.76
Iodine	I	53	126.91
Iridium	Ir	77	192.2
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.92
Lead	Pb	82	207.21
Lithium	Li	3	6.940
Lutetium	Lu	71	174.99
Magnesium	Mg	12	24.32
Manganese	Mn	25	54.94
Mercury	Hg	80	200.61
Molybdenum	Mo	42	95.95
Neodymium	Nd	60	144.27
Neptunium	Np	93	[237]
Neon	Ne	10	20.183
Nickel	Ni	28	58.69
Niobium (Columbium)	Nb	41	92.91
Nitrogen	N	7	14.008
Osmium	Os	76	190.2
Oxygen	O	8	16
Palladium	Pd	46	106.7
Phosphorus	P	15	30.975
Platinum	Pt	78	195.23
Plutonium	Pu	94	[242]
Polonium	Po	84	210
Potassium	K	19	39.100
Praseodymium	Pr	59	140.92
Promethium	Pm	61	[145]
Protactinium	Pa	91	231
Radium	Ra	88	226.05
Radon	Rn	86	222
Rhenium	Re	75	186.31
Rhodium	Rh	45	102.91
Rubidium	Rb	37	85.48
Ruthenium	Ru	44	101.1
Samarium	Sm	62	150.43
Scandium	Sc	21	44.96
Selenium	Se	34	78.96
Silicon	Si	14	28.09
Silver	Ag	47	107.880
Sodium	Na	11	22.991
Strontium	Sr	38	87.63
Sulfur	S	16	32.066[b]
Tantalum	Ta	73	180.95
Technetium	Tc	43	[99]
Tellurium	Te	52	127.61
Terbium	Tb	65	158.93
Thallium	Tl	81	204.39
Thorium	Th	90	232.05
Thulium	Tm	69	168.94
Tin	Sn	50	118.70
Titanium	Ti	22	47.90
Tungsten	W	74	183.92
Uranium	U	92	238.07
Vanadium	V	23	50.95
Xenon	Xe	54	131.3
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.92
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

[a] A value given in brackets denotes the mass number of the isotope of longest known half-life. [b] Because of natural variations in the relative abundance of the isotopes of sulfur the atomic weight of this element has a range of ±0.003.

1940 on the more precise factor 1.000275 has been used. Since this factor does not correspond exactly to any known occurrence of natural oxygen, and is not based on an intentional averaging of the composition of natural oxygen, its continued use has provided an arbitrarily fixed relation between the chemical scale of atomic weights and the physical scale. It would be desirable to adopt a formal definition of the relation between the chemical and physical scales, and the International Commission has moved in this direction. Final agreement as to the wording of the definition was not reached in time for the Stockholm meeting, and the outcome therefore cannot be predicted with certainty. It is altogether likely, however, that when such a definition is adopted it will be based on oxygen of such isotopic composition that its atomic weight will be 1.000275 times that of O^{16}.

Analytical chemists now occasionally find it necessary to make stoichiometric calculations involving mixtures of hydrogen and deuterium of known isotopic composition differing significantly from natural hydrogen. In such calculations the recommended value, on the chemical scale, for the isotopic weight of H^1 is 1.0079 and of H^2 2.0142.

WASHINGTON 25, D. C.