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Report on Atomic Weights for 1956–1957

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The International Commission on Atomic Weights met in Paris in July 1957, during the 19th Conference of the International Union of Pure and Applied Chemistry. At this meeting it was agreed that no changes would be recommended in the values for atomic weights approved by the International Union in 1955.[1] This action was taken in view of the possibility that the efforts being made by the Commission to achieve unification of the chemical scale of atomic weights with the scale of nuclidic masses used by physicists might necessitate a general revision of the table within a few years. Changes in atomic weights recommended by the Commission in 1949, 1951, 1953 and 1955[2] have resolved most of the previously existing discrepancies between atomic weights derived from chemical ratios or gas-density measurements and those derived from mass spectrometry or nuclear reaction data.[1] Remaining differences are, in almost all instances, within the limits of uncertainty inherent in the respective techniques. However, there are four anisotopic elements for which values derived from physical measurements are regarded by the Commission as more accurate than the values given in the 1955 table. It will be noted that the differences, as given in the following table, are small.

	Values from physical measurements	1955 value
Arsenic	74.92	74.91
Yttrium	88.91	88.92
Praseodymium	140.91	140.92
Bismuth	208.99	209.00

Nevertheless they should be taken into account in chemical work of the highest accuracy.

In 1949 the Commission adopted the practice of including in the table of atomic weights the mass numbers of selected isotopes of those radioactive elements that are either too short-lived or of too variable isotopic composition to justify the assignment of atomic weights. In the table these mass numbers were bracketed to distinguish them from atomic weights. In 1957 the Commission decided to discontinue this practice on the ground that the kind of information supplied by mass numbers is inconsistent with the primary purpose of a table of atomic weights, which is to provide accurate values of these constants for use in chemical calculations. In keeping with this change of policy the table appended to this report also omits mass numbers for the radioactive elements, whether naturally-occurring or synthetic. Exceptions are made for naturally-occurring uranium and thorium and for certain other elements that are only very slightly radioactive.

The Commission adopted in 1957 the new practice of listing the radioactive elements in an auxiliary table and of indicating for each of these elements the mass number of a selected isotope. In most instances, the designated isotope is the one of longest known half-life. In the belief that it may be useful to some readers such a table is also appended to this report.

In its report to the International Union[3] the Commission adopted still another innovation. That was to provide the tables of atomic weights and of the radioactive elements in two arrangements—in the conventional alphabetical order and in the order of atomic numbers. Because of the obvious advantages of the atomic-number arrangement for certain uses, both arrangements of the

(1) E. Wichers, THIS JOURNAL, **78**, 3235 (1956).

(2) E. Wichers, *ibid.*, **72**, 1431 (1950); **74**, 2447 (1952); **76**, 2033 (1954); **78**, 3235 (1956).

(3) *Compt. rend.*, XIXth Conference, Int. Union Pure Appl. Chem., 139 (1957).

TABLE OF ATOMIC WEIGHTS
1957
(ALPHABETICAL ORDER)

	Symbol	Atomic no.	Atomic wt.
Actinium	Ac	89	...
Aluminum	Al	13	26.98
Americium	Am	95	...
Antimony	Sb	51	121.76
Argon	Ar	18	39.944
Arsenic	As	33	74.91
Astatine	At	85	...
Barium	Ba	56	137.36
Berkelium	Bk	97	...
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	...
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
Copper	Cu	29	63.54
Curium	Cm	96	...
Dysprosium	Dy	66	162.51
Einsteinium	Es	99	...
Erbium	Er	68	167.27
Europium	Eu	63	152.0
Fermium	Fm	100	...
Fluorine	F	9	19.00
Francium	Fr	87	...
Gadolinium	Gd	64	157.26
Gallium	Ga	31	69.72
Germanium	Ge	32	72.60
Gold	Au	79	197.0
Hafnium	Hf	72	178.50
Helium	He	2	4.003
Holmium	Ho	67	164.94
Hydrogen	H	1	1.0080
Indium	In	49	114.82
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
Mendelevium	Md	101	...
Mercury	Hg	80	200.61
Molybdenum	Mo	42	95.95
Neodymium	Nd	60	144.27
Neon	Ne	10	20.183
Neptunium	Np	93	...
Nickel	Ni	28	58.71
Niobium	Nb	41	92.91
Nitrogen	N	7	14.008
Nobelium	No	102	...
Osmium	Os	76	190.2
Oxygen	O	8	16
Palladium	Pd	46	106.4
Phosphorus	P	15	30.975
Platinum	Pt	78	195.09
Plutonium	Pu	94	...
Polonium	Po	84	...
Potassium	K	19	39.100
Praseodymium	Pr	59	140.92
Promethium	Pm	61	...
Protactinium	Pa	91	...
Radium	Ra	88	...
Radon	Rn	86	...
Rhenium	Re	75	186.22
Rhodium	Rh	45	102.91
Rubidium	Rb	37	85.48
Ruthenium	Ru	44	101.1
Samarium	Sm	62	150.35
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	32.006[a]
Tantalum	Ta	73	180.95
Technetium	Tc	43	...
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	183.86
Uranium	U	92	238.07
Vanadium	V	23	50.95
Xenon	Xe	54	131.30
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.92
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22

[a] 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.

table of atomic weights are appended to this report. The alphabetical arrangement of the table of radioactive elements is omitted.

During the 1957 Conference of the International Union the Commission on Inorganic Nomenclature adopted changes in the symbols of argon (Ar) and mendelevium (Md). The Commission also recognized the discovery of elements Nos. 99, 100 and 102 and adopted the names proposed by the discoverers. They are, respectively, einsteinium (Es), fermium (Fm) and nobelium (No).

Unification of the Scales.—The Commission at its meeting in Paris reviewed the attitudes taken by chemists and physicists toward the problem of achieving a unified scale. For a discussion of the problem see the report to the American Chemical Society for 1954–1955.[1] No evidence was reported of a favorable opinion toward the adoption of a scale based on 1 as the assigned mass of hydrogen-1 or 4 as the mass of helium-4. There was some opinion favorable to a scale based on 19 as the assigned mass of fluorine-19, but there was also some

TABLE OF ATOMIC WEIGHTS
1957
(ORDER OF ATOMIC NUMBER)

Atomic no.	Name	Symbol	Atomic wt.
1	Hydrogen	H	1.0080
2	Helium	He	4.003
3	Lithium	Li	6.940
4	Beryllium	Be	9.013
5	Boron	B	10.82
6	Carbon	C	12.001
7	Nitrogen	N	14.008
8	Oxygen	O	16
9	Fluorine	F	19.00
10	Neon	Ne	20.183
11	Sodium	Na	22.991
12	Magnesium	Mg	24.32
13	Aluminum	Al	26.98
14	Silicon	Si	28.09
15	Phosphorus	P	30.975
16	Sulfur	S	32.066[a]
17	Chlorine	Cl	35.457
18	Argon	Ar	39.944
19	Potassium	K	39.100
20	Calcium	Ca	40.08
21	Scandium	Sc	44.96
22	Titanium	Ti	47.90
23	Vanadium	V	50.95
24	Chromium	Cr	52.01
25	Manganese	Mn	54.95
26	Iron	Fe	55.85
27	Cobalt	Co	58.94
28	Nickel	Ni	58.71
29	Copper	Cu	63.54
30	Zinc	Zn	65.38
31	Gallium	Ga	69.72
32	Germanium	Ge	72.60
33	Arsenic	As	74.91
34	Selenium	Se	78.96
35	Bromine	Br	79.916
36	Krypton	Kr	83.80
37	Rubidium	Rb	85.48
38	Strontium	Sr	87.63
39	Yttrium	Y	88.92
40	Zirconium	Zr	91.22
41	Niobium	Nb	92.91
42	Molybdenum	Mo	95.95
43	Technetium	Tc	...
44	Ruthenium	Ru	101.1
45	Rhodium	Rh	102.91
46	Palladium	Pd	106.4
47	Silver	Ag	107.880
48	Cadmium	Cd	112.41
49	Indium	In	114.82
50	Tin	Sn	118.70
51	Antimony	Sb	121.76
52	Tellurium	Te	127.61
53	Iodine	I	126.91
54	Xenon	Xe	131.30
55	Cesium	Cs	132.91
56	Barium	Ba	137.36
57	Lanthanum	La	138.92
58	Cerium	Ce	140.13
59	Praseodymium	Pr	140.92
60	Neodymium	Nd	144.27
61	Promethium	Pm	...
62	Samarium	Sm	150.35
63	Europium	Eu	152.0
64	Gadolinium	Gd	157.26
65	Terbium	Tb	158.93
66	Dysprosium	Dy	162.51
67	Holmium	Ho	164.94
68	Erbium	Er	167.27
69	Thulium	Tm	168.94
70	Ytterbium	Yb	173.04
71	Lutetium	Lu	174.99
72	Hafnium	Hf	178.50
73	Tantalum	Ta	180.95
74	Tungsten	W	183.86
75	Rhenium	Re	186.22
76	Osmium	Os	190.2
77	Iridium	Ir	192.2
78	Platinum	Pt	195.09
79	Gold	Au	197.0
80	Mercury	Hg	200.61
81	Thallium	Tl	204.39
82	Lead	Pb	207.21
83	Bismuth	Bi	209.00
84	Polonium	Po	...
85	Astatine	At	...
86	Radon	Rn	...
87	Francium	Fr	...
88	Radium	Ra	...
89	Actinium	Ac	...
90	Thorium	Th	232.05
91	Protactinium	Pa	...
92	Uranium	U	238.07
93	Neptunium	Np	...
94	Plutonium	Pu	...
95	Americium	Am	...
96	Curium	Cm	...
97	Berkelium	Bk	...
98	Californium	Cf	...
99	Einsteinium	Es	...
100	Fermium	Fm	...
101	Mendelevium	Md	...
102	Nobelium	No	...

[a] 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.

very strong opposition to such a scale, especially on the part of physicists who are leaders in the field of nuclidic mass measurements. Taking this specific opposition into account, as well as a basic reluctance on the part of physicists generally to abandon the existing physical scale, the Commission concluded, in its formal report,[3] that further consideration of unification should be restricted to the adoption of one or the other of the two existing scales. If the chemical scale were to be the one retained, it would be modified to eliminate the existing ambiguity arising from the natural variation in the relative abundance of the oxygen isotopes. This could be accomplished, for example, by basing the scale on oxygen-16, which would be assigned a relative mass of 15.9956.

THE RADIOACTIVE ELEMENTS[a]
1957
(ORDER OF ATOMIC NUMBER)

At. no.	Name	Symbol	Isotope	Half-life		Disintegration
43	Technetium	Tc	99*	2.2×10^6	yr.	β^-
61	Promethium	Pm	147*	2.6	yr.	β^-
84	Polonium	Po	210*	140	days	α
85	Astatine	At	210	8.3	yr.	α
86	Radon	Rn	222	3.8	days	α
87	Francium	Fr	223	21	min.	β^-
88	Radium	Ra	226	1622	yr.	α
89	Actinium	Ac	227	22	yr.	β^-, α
90	Thorium	Th	232	1.4×10^{10}	yr.	α
91	Protactinium	Pa	231	3.4×10^4	yr.	α
92	Uranium	U	238	4.5×10^9	yr.	α
93	Neptunium	Np	237	2.2×10^6	yr.	α
94	Plutonium	Pu	242	3.8×10^5	yr.	α
95	Americium	Am	243	7.6×10^3	yr.	α
96	Curium	Cm	247	4×10^7	yr.	α
97	Berkelium	Bk	249*	290	days	β^-
98	Californium	Cf	251*	660	days	β^-
99	Einsteinium	Es	254	280	days	α
100	Fermium	Fm	253	4.5	days	α
101	Mendelevium	Md	256	0.5	hr.	Spontaneous fission
102	Nobelium	No	. .	*ca.* 10 min.		α

[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.

After the Commission had submitted its formal report there was an extensive exchange of correspondence, both among members of the Commission and among others interested in the problem. This correspondence led to the consideration of other alternatives for unification. Of these a scale based on the exact number 12 as the assigned mass of carbon-12 appears to offer the best promise of acceptance. It was suggested independently by A. Ölander and A. O. C. Nier and has been strongly supported by J. Mattauch. Since the mass of carbon-12 on the present chemical scale is only 42 parts in one million less than 12, the adoption of the "carbon-12 scale" would result in changing presently accepted atomic and molecular weights by an amount too small to be significant for most uses of these data. This argument was put forward also for the fluorine-19 scale, which would require a change of the same magnitude, but in the opposite direction. Both Nier and Mattauch recognize the importance of carbon-12 in mass spectrometry, in which it has been the most important secondary standard for the determination of nuclidic masses. Mattauch prepared a discussion of the carbon-12 scale and other alternatives that would have the same advantage of requiring only small changes in numbers based on the present chemical scale. This discussion was published as an addendum to the report of the International Commission.[3] Because it cannot well be paraphrased or condensed without loss of meaning, Mattauch's discussion is reproduced in full at the end of the present report.

To chemists a scale for which an isotope of carbon is the reference species may well seem a strange choice. Even the element carbon, in its natural mixture of isotopes, has never been attractive for stoichiometric comparisons. In fact, the atomic weight of carbon was one of the more elusive of such constants when only chemical ratios and gas-density measurements were available for its determination. Furthermore, carbon-12 of sufficient isotopic purity for determinations of chemical ratios or comparisons of gas-densities would be almost unobtainable. However, such objections can be countered with the argument that the mass of carbon-12 has been related, by physical measurements of more than adequate accuracy, to the masses of other species useful for chemical ratios.

In the opinion of this writer a unified scale based on 12 as the assigned exact mass of carbon-12 is the only one that physicists are likely to be willing to accept in place of the present physical scale. To many of them the alternative of adopting a (defined) equivalent of the chemical scale, with the resulting non-integral value (15.9956) for the mass of oxygen-16, is unacceptable. Although this attitude may not be logical it is nevertheless understandable.

As the result of his analysis of the problem, Mattauch[3] has come to the conclusion that a scale based on carbon-12 is inherently better than a scale based on oxygen-16. It remains to be seen whether physicists generally will concede that Mattauch's argument carries enough force to justify abandoning the present physical scale. However, chemists have shown a strong opposition to unification on the basis of the present physical scale. The opposition is based primarily on the confusion resulting from a change of nearly 3 parts in 10,000 in all molecular weights and molar quantities and the enormous task of revising published data.[4]

It thus appears unlikely that unification can be accomplished by retaining either of the existing scales. However, there is a good possibility that the carbon-12 scale will prove an acceptable replacement for both scales now in use. A decision to adopt the carbon-12 scale should not be made unless it can be expected to displace both of the oxygen scales within a reasonable time. To add a third scale would only cause more confusion. Further, the decision should not be made before there has been sufficient time for full consideration of the question and there is general confidence in the advantages to be gained from the change. If these conditions can be met, the change will be highly desirable.

(4) In a private communication K. S. Pitzer has expressed this objection in the following language:

"I would like to emphasize that it will not be feasible to abandon the present chemical scale unless the change in numerical values is limited to the level of a few thousandths of a per cent. I suppose there are hundreds of millions of recorded numerical entries in the chemical handbooks and literature which are based on the chemist's mole. Many of these are of relatively low accuracy, but I would estimate there are about a million recorded values which are given to a precision of a hundredth of a per cent. or thereabouts and which would have to be revised if we were to shift to the present physicist's scale of oxygen-16 = 16. The labor and confusion involved in a change of this magnitude is in my estimate much more serious than the inconvenience of retaining two parallel scales indefinitely."

WASHINGTON 25, D. C.