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Standard Atomic Weights Tables 2007 Abridged to Four and Five Significant Figures

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Abstract: In response to a recommendation to the Commission on Isotopic Abundances and Atomic Weights (CIAAW) that abridged versions of the Table on Standard Atomic Weights be prepared and published, this report has been prepared. A brief history is presented of such Atomic Weight tables that have been abridged to four significant figures and to five significant figures are noted. Tables of Standard Atomic Weight values abridged to four places and five places from the official 2007 Table of Atomic Weights approved by CIAAW are included.

I. Introduction

During the meeting of the Commission on Isotopic Abundances and Atomic Weights (CIAAW) held at the 43rd General Assembly of the International Union of Pure and Applied Chemistry (IUPAC) in Beijing, China, CIAAW made a recommendation that a Subcommittee of the Natural Assessment of Fundamental Understanding (SNAFU) be created to investigate a series of fundamental questions that have been of interest to the CIAAW for many years but which had never adequately been discussed in the past, due to the lack of time available at the earlier CIAAW meetings.

The SNAFU Task Group held meetings at the International Bureau of Weights and Measures (BIPM) in Sevres, France during July 18th to 20th 2007, prior to the CIAAW meetings in Pisa, Italy, which were held in conjunction with the 44th IUPAC General Assembly that was held in Torino, Italy. Among the various SNAFU recommendations to the CIAAW was that tables of Atomic Weight values abridged to four significant figures and to five significant figures should be prepared and should be published along with the full, unabridged IUPAC table in the 2007 report of the CIAAW.

II. Early History

During the first half century of its existence, the International Commission on Atomic Weights (ICAW) published just a single Table of Atomic Weight values in alphabetical order of the chemical element names. In their 1957 report[1], the ICAW began to provide two Tables of Atomic Weight values, the original table in the alphabetical order of the chemical element names and a second table, where the atomic weights were listed in the order of the atomic number of each chemical element.

In 1975, at the request of members of the IUPAC's "Committee for the Teaching of Chemistry" (CTC), the then ICAW chairman and its secretary, Norman N. Greenwood and H. Steffen Peiser, respectively, prepared a Table of Atomic Weight values, which was abridged to Four Significant Figures. The IUPAC-CTC disseminated this table[2] in their "International Newsletter on Chemical Education" No. 2, dated June 1975. It was stated that this Table was not expected to undergo any significant change in the values in the future.

Even though the Atomic Weights Commission had agreed to provide help to the CTC in the preparation of this Table, the Commission felt strongly that it was not advisable to incorporate this abridged table into the formal ICAW report.

Greenwood and Peiser also wished to prepare and publish a Table of Atomic Weights to Five Significant Figures. However, the Commission thought that it was inappropriate at that time to initiate the preparation of such a Table. It should be noted that at the time, there were only ten elements in the full Table (other than the mono-nuclidic elements), which had values that were known to more than five significant figures.

In 1981, again at the request of the CTC, the Commission prepared another Table of the Atomic Weight values abridged to four significant figures. Greenwood and Peiser were assigned the task of preparing this Table. It was approved[3] by the ICAW in 1983 and was given to the CTC for their dissemination. As in the case of the 1975 Table, it was again stated that this Table was not expected to undergo any significant change in values in the future.

Also in 1981, the first Atomic Weights Table, abridged to five significant figures, was produced[4]. In the official, unabridged 1981Table, there were 16 elements listed to four figures, 31 elements listed to five figures and only 14 elements (excluding mononuclidic elements) had six or more figures. Another Atomic Weights Table, which was abridged to five significant figures, was produced and published in the official 1993 report[5].

III. 4-Place Standard Atomic Weights Tables

The Table of Atomic Weights to Four Significant Figures did not include the full list of the usual footnotes and annotations to the Commission's Table. However, there was a note attached for seven elements that the values may differ from the atomic weights listed for these elements in some naturally occurring samples because of a variation in relative abundance of the isotopes.

Among the notes to the Table, there was a reference to the full table in the ICAW report and the fact that this full table is revised every two years. However, the comment was added that it is unlikely that the values quoted to four significant figures will be altered by any of the revisions in the full table.

Table of Standard Atomic Weights 2007 Abridged to Four Significant Figures

Atomic Number	Chemical Name	Chemical Symbol	Atomic Weight
1	Hydrogen	H	1.008
2	Helium	He	4.003
3	Lithium	Li	6.941 (2) #
4	Beryllium	Be	9.012
5	Boron	B	11.81 #
6	Carbon	C	12.01
7	Nitrogen	N	14.01
8	Oxygen	O	16.00
9	Fluorine	F	19.00
10	Neon	Ne	20.18
11	Sodium	Na	22.99
12	Magnesium	Mg	24.31
13	Aluminium	Al	26.98
14	Silicon	Si	28.09
15	Phosphorus	P	30.97
16	Sulfur	S	32.07 #
17	Chlorine	Cl	35.45
18	Argon	Ar	39.95
19	Potassium	K	39.10
20	Calcium	Ca	40.08 #
21	Scandium	Sc	44.96
22	Titanium	Ti	47.87
23	Vanadium	V	50.94
24	Chromium	Cr	52.00
25	Manganese	Mn	54.94
26	Iron	Fe	55.85
27	Cobalt	Co	58.93
28	Nickel	Ni	58.69
29	Copper	Cu	63.55
30	Zinc	Zn	65.38 (2)
31	Gallium	Ga	69.72
32	Germanium	Ge	72.64
33	Arsenic	As	74.92
34	Selenium	Se	78.96 (3)
35	Bromine	Br	79.90
36	Krypton	Kr	83.80 #
37	Rubidium	Rb	85.47 #
38	Strontium	Sr	87.62 #
39	Yttrium	Y	88.91
40	Zirconium	Zr	91.22 #

Abridged 4-Place Standard Atomic Weights Table 2007 (Continued)

Atomic Number	Element Name	Element Symbol	Atomic Weight
41	Niobium	Nb	92.91
42	Molybdenum	Mo	95.96 (2) #
43	Technetium	Tc	
44	Ruthenium	Ru	101.1 #
45	Rhodium	Rh	102.9
46	Palladium	Pd	106.4 #
47	Silver	Ag	107.9 #
48	Cadmium	Cd	112.4 #
49	Indium	In	114.8
50	Tin	Sn	118.7 #
51	Antimony	Sb	121.8 #
52	Tellurium	Te	127.6 #
53	Iodine	I	126.9
54	Xenon	Xe	131.3 #
55	Caesium	Cs	132.9
56	Barium	Ba	137.3
57	Lanthanum	La	138.9
58	Cerium	Ce	140.1 #
59	Praseodymium	Pr	140.9
60	Neodymium	Nd	144.2 #
61	Promethium	Pm	
62	Samarium	Sm	150.4 #
63	Europium	Eu	152.0 #
64	Gadolinium	Gd	157.3 #
65	Terbium	Tb	158.9
66	Dysprosium	Dy	162.5 #
67	Holmium	Ho	164.9
68	Erbium	Er	167.3 #
69	Thulium	Tm	168.9
70	Ytterbium	Yb	173.1 #
71	Lutetium	Lu	175.0
72	Hafnium	Hf	178.5
73	Tantalum	Ta	180.9
74	Tungsten	W	183.9
75	Rhenium	Re	186.2
76	Osmium	Os	190.2
77	Iridium	Ir	192.2
78	Platinum	Pt	195.1
79	Gold	Au	197.0
80	Mercury	Hg	200.6

Abridged 4-Place Standard Atomic Weights Table 2007 (Continued)

Atomic Number	Element Name	Element Symbol	Atomic Weight
81	Thallium	Tl	204.4
82	Lead	Pb	207.2 #
83	Bismuth	Bi	209.0
84	Polonium	Po	
85	Astatine	At	
86	Radon	Rn	
87	Francium	Fr	
88	Radium	Ra	
89	Actinium	Ac	
90	Thorium	Th	232.0
91	Protactinium	Pa	231.0
92	Uranium	U	238.0 #
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	
103	Lawrencium	Lr	
104	Rutherfordium	Rf	
105	Dubnium	Db	
106	Seaborgium	Sg	
107	Bohrium	Bh	
108	Hassium	Hs	
109	Meitnerium	Mt	
110	Darmstadtium	Ds	
111	Roentgenium	Rg	
112	*		
113	*		
114	*		
115	*		
116	*		
118	*		

Notes applicable to the Table of Atomic Weights abridged to four significant figures:
Since 1961, the internationally accepted values have been scaled relative to the isotope $^{12}C = 12$, exactly. Atomic weights are dimensionless quantities.

22 elements have only one nuclide that occurs in nature and is either stable or very long-lived. The atomic weights of these elements have been determined very precisely, often to better than a fraction of one part in a million. However, most elements have more than one naturally occurring isotope and the variation in nature of the relative abundance of these isotopes limits the precision with which the atomic weight of an element can be quoted. For such elements, the atomic weight is not a “constant of nature” but is best regarded as a property of the particular sample of that element being studied.

It is also possible to separate the isotopes artificially. The atomic weight values given in the Table do not apply to artificially separated isotopes and other samples that have been submitted to processes that appreciably change the isotopic composition of the elements.

In addition, many elements, including all those of atomic number greater than that of bismuth, are radioactive with isotopes, which transform into other elements in the course of time. The atomic weight of a given sample of such an element depends on the relative rate at which its various isotopes decay and sometimes also on the radiogenic origin of the particular sample. For such elements, it is not possible to quote an approximate atomic weight, which is generally applicable even to four significant figures, so the column for the atomic weight is left blank.

The meanings of the symbols given in the Table are as follows:

* Chemical elements above atomic number 111 have been reported in the peer-reviewed, scientific literature but have not yet been vetted and named by IUPAC.

Values so marked may differ from the atomic weights of the relevant elements in some naturally occurring samples because of a variation in the relative isotopic abundance of the isotopes.

IV. 5-Place Standard Atomic Weights Tables

It has been noted that the detail and the number of significant figures found in the full Atomic Weights Table exceed the needs and the interests of most users, who are more concerned with the length of time during which a given table has validity to the precision limit of their interests.

It was noted that the abridged table was published with the reasonable hope that not even one of the quoted values will need to be changed because of every biennial revision of the unabridged table, although the quoted uncertainties may be altered. It was stated that any change in an abridged value will probably be by only one unit in the final significant figure or by the addition of a fifth significant figure, where only four appear in the table presented at the time. Such constancy in these values is desirable for textbooks and numerical tables derived from atomic weight data.

Table of Standard Atomic Weights 2007 to Abridged to Five Significant Figures

Atomic Number	Element Name	Element Symbol	Atomic Weight	Annotations
1	Hydrogen	H	1.0079	g m
2	Helium	He	4.0026	
3	Lithium	Li	6.941 (2) #	g m r
4	Beryllium	Be	9.0122	
5	Born	B	10.811 (7)	g m r
6	Carbon	C	12.011	g r
7	Nitrogen	N	14.007	
8	Oxygen	O	15.999	
9	Fluorine	F	18.998	
10	Neon	Ne	20.180	m
11	Sodium	Na	22.990	
12	Magnesium	Mg	24.305	
13	Aluminium	Al	26.982	
14	Silicon	Si	28.086	
15	Phosphorus	P	30.974	
16	Sulfur	S	32.065 (5)	g r
17	Chlorine	Cl	35.453 (2)	m
18	Argon	Ar	39.948	g r
19	Potassium	K	39.098	g
20	Calcium	Ca	40.078 (4)	g
21	Scandium	Sc	44.956	
22	Titanium	Ti	47.867	
23	Vanadium	V	50.942	
24	Chromium	Cr	51.996	
25	Manganese	Mn	54.938	
26	Iron	Fe	55.845 (2)	
27	Cobalt	Co	58.933	
28	Nickel	Ni	58.693	
29	Copper	Cu	63.546 (3)	r
30	Zinc	Zn	65.38 (2)	
31	Gallium	Ga	69.723	
32	Germanium	Ge	72.64	
33	Arsenic	Ar	74.922	
34	Selenium	Se	78.96 (3)	
35	Bromine	Br	79.904	
36	Krypton	Kr	83.798 (2)	g m
37	Rubidium	Rb	85.468	
38	Strontium	St	87.62	g r
39	Yttrium	Y	88.906	
40	Zirconium	Zr	91.224 (2)	g

Abridged 5-Place Standard Atomic Weights Table 2007 (Continued)

Atomic Number	Element Name	Element Symbol	Atomic Weight	Annotations
41	Niobium	Nb	92.906	
42	Molybdenum	Mo	95.96 (2)	g
43	Technetium	Tc		
44	Ruthenium	Ru	101.07 (2)	g
45	Rhodium	Rh	102.91	
46	Palladium	Pd	106.42	g
47	Silver	Ag	107.87	
48	Cadmium	Cd	112.41	
49	Indium	In	114.82	
50	Tin	Sn	118.71	
51	Antimony	Sb	121.76	g
52	Tellurium	Te	127.60 (3)	g
53	Iodine	I	126.90	
54	Xenon	Xe	131.29	g m
55	Caesium	Cs	132.91	
56	Barium	Ba	137.33	
57	Lanthanum	La	138.91	
58	Cerium	Ce	140.12	g
59	Praseodymium	Pr	140.91	
60	Neodymium	Nd	144.24	g
61	Promethium	Pm		
62	Samarium	Sm	150.36 (2)	g
63	Europium	Eu	151.96	g
64	Gadolinium	Gd	157.25 (3)	g
65	Terbium	Tb	158.93	
66	Dysprosium	Dy	162.50	g
67	Holmium	Ho	164.93	
68	Erbium	Er	167.26	g
69	Thulium	Tm	168.93	
70	Ytterbium	Yb	173.05	g
71	Lutetium	Lu	174.97	g
72	Hafnium	Hf	178.49 (2)	
73	Tantalum	Ta	180.95	
74	Tungsten	W	183.84	
75	Rhenium	Re	186.21	
76	Osmium	Os	190.23 (3)	g
77	Iridium	Ir	192.22	
78	Platinum	Pt	195.08	
79	Gold	Au	196.97	
80	Mercury	Hg	200.59 (2)	

Abridged 5-Place Standard Atomic Weight Table 2007 (Continued)

Atomic Number	Element Name	Element Symbol	Atomic Weight	Annotations
81	Thallium	Tl	204.38	
82	Lead	Pb	207.2	g r
83	Bismuth	Bi	208.98	
84	Polonium	Po		
85	Astatine	At		
86	Radon	Rn		
87	Francium	Fr		
88	Radium	Ra		
89	Actinium	Ac		
90	Thorium	Th	232.04	g
91	Protactinium	Pa	231.04	
92	Uranium	U	238.03	g m
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		
103	Lawrencium	Lr		
104	Rutherfordium	Rf		
105	Dubnium	Db		
106	Seaborgium	Sg		
107	Bohrium	Bh		
108	Hassium	Hs		
109	Meitnerium	Mt		
110	Darmstadtium	Ds		
111	Roentgenium	Rg		
112	*			
113	*			
114	*			
115	*			
116	*			
118	*			

* - Chemical elements above atomic number 111 have been reported in the peer-reviewed scientific literature and have not yet been vetted and named by IUPAC

Annotations in the table:

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

r – range in isotopic composition in normal terrestrial materials limits the precision in the tabulated value of the atomic weight.

m – modified isotopic compositions may be found in commercially available material causing deviations of the atomic weight value from that given in the Table because the material has been subjected to an undisclosed or inadvertent isotopic separation.

- commercially available lithium materials have atomic weight values that range between 6.939 and 6.996; if a more accurate value is required, it must be determined for the specific material.

Preamble to the table:

Atomic weights, scaled to the relative atomic mass, A_r (^{12}C) = 12, are here quoted to five significant figures unless the dependable accuracy is more limited by either the combined uncertainties of the best published atomic weight determinations, or by the variability of isotopic composition in normal terrestrial occurrences (the latter applies to the elements annotated r). The last significant figure of each tabulated value is considered reliable to ±1 except when a larger single digit uncertainty is inserted in parentheses following the atomic weight. Neither the highest nor the lowest actual atomic weight of any normal sample is thought likely to differ from the tabulated values by more than one assigned uncertainty. However, the tabulated values do not apply either to samples of highly exceptional isotopic composition arising from most unusual geological occurrences (for elements annotated g) or to those whose isotopic composition has been artificially altered. Such might even be found in commerce without disclosure of that modification (for elements annotated m). Elements with no stable isotope do not have an atomic weight and such entries have a blank in the atomic weight column. However, three such elements (Th, Pa and U) do have a characteristic terrestrial isotopic composition and for these an atomic weight value is tabulated. For more detailed information, users should refer to the full IUPAC Table of Standard Atomic Weights.

V. Discussion and Conclusions

It was noted above that a statement was made in the CTC Table of 1975, abridged to four significant figures, that the table was not expected to undergo any significant change in values in the future. In fact, compared to the CTC Table, abridged to four significant figures, that was published in 1975, there were actually two changes in the value of the

atomic weight and one change in the atomic weight uncertainty in the CTC table that was published in 1983.

For the period between the 1983 table and the present 2007 table of atomic weight values abridged to four significant figures, there have been a total of seven changes. There have been changes in the values of atomic weights for five chemical elements and there have been changes in the uncertainty of the atomic weight value for two elements.

In slightly more than thirty years, there have been ten changes in the 4-place table of the atomic weights or one every three years on the average. These ten changes have involved eight different chemical elements, since titanium changed value twice and molybdenum changed its value once and its uncertainty once.

If we examine the polynuclidic elements, i.e., those elements, which are neither mono-nuclidic nor radioactive, there are a total of 61 elements. In the 1975 Table, there were actually 18 elements of those 61 elements, or approximately 30% of the total, which were only known to four significant figures in the unabridged table at that time. Since that time, there have actually been changes in the value or in the uncertainty of the atomic weight to four significant figures for 8 of the 61 remaining elements, or changes for about 13% of the elements presented. The expectation both in 1975 and in 1983 that no significant changes in the 4-place table would occur in the future has fallen victim to reality. In the past, the Commission members thought that this Table would be essentially constant with time but the table will obviously need to be continually reviewed at each biennial meeting of the Commission. The number of changes with time will probably decrease in the future, since of the total of 18 elements, which were only known to four significant figures in the 1975 table, there are only 7 elements in the 2007 unabridged table of atomic weights.

During the time period between the first published Atomic Weights table, abridged to five significant figures, in 1981 and the next published table in 1993, there were 21 changes that occurred in the values between these two 5-place tables. Of the differences, 15 corresponded to a change in the atomic weight value and 6 of these differences were changes in the atomic weight uncertainty. It was mentioned earlier that at the time of publication of the 1981 Table, the full, unabridged Atomic Weight table has 16 elements, which were listed to four significant figures and another 31 elements, which were listed to five significant figures. The remaining 14 elements in the table were listed to six or more significant figures. At the time of the 1993 full, unabridged table, there were 8 elements, which were only known to four significant figures and another 26 elements, which were known to five significant figures and the remaining 27 elements were listed to six or more significant figures. In the full, unabridged 2007 Atomic weights Table, there are 7 elements that are listed to four significant figures and 21 elements that are listed to five significant figures. Once again, the remaining 33 elements were listed to six or more significant figures.

For the tables abridged to five significant figures, there were a total of another 14 changes between the 1993 table and the 2007 table. Of these differences, six corresponded to a

change in the atomic weight value, while eight of them corresponded to a change in the atomic weight uncertainty. Thus between the 1981 Table abridged to five significant figures and the 2007 table, there were a total of thirty-five changes in a total of thirty elements. Sulfur, zinc and germanium changed atomic weight values twice and the uncertainty in the atomic weight value for xenon changed twice. In the case of boron, there was one change in the value and one change in the uncertainty of the atomic weight.

Over the period of twenty-six years, since the first abridged table of atomic weight values to five significant figures, a total of thirty of the sixty-one non-radioactive, polynuclidic chemical elements have changed either in value or in uncertainty. This would correspond to approximately half of all of these elements. The early estimate by the Commission that the table should be checked approximately every decade to look for changes completely underestimated the number of changes that have occurred.

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