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INORGANIC CHEMISTRY DIVISION
COMMISSION ON ATOMIC WEIGHTS AND ISOTOPIC ABUNDANCES*

HISTORY OF THE RECOMMENDED ATOMIC-WEIGHT VALUES FROM 1882 TO 1997: A COMPARISION OF DIFFERENCES FROM CURRENT VALUES TO THE ESTIMATED UNCERTAINTIES OF EARLIER VALUES

(Technical Report)

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History of the recommended atomic-weight values from 1882 to 1997: A comparision of differences from current values to the estimated uncertainties of earlier values (Technical Report)

Abstract—International commissions and national committees for atomic weights (mean relative atomic masses) have recommended regularly updated, best values for these atomic weights as applicable to terrestrial sources of the chemical elements. Presented here is a historically complete listing starting with the values in F. W. Clarke's 1882 recalculation, followed by the recommended values in the annual reports of the American Chemical Society's Atomic Weights Commission. From 1903, an International Commission published such reports and its values (scaled to an atomic weight of 16 for oxygen) are here used in preference to those of national committees of Britain, Germany, Spain, Switzerland, and the U.S.A. We have, however, made scaling adjustments from $A_r(^{16}O)$ to $A_r(^{12}C)$ where not negligible. From 1920, this International Commission constituted itself under the International Union of Pure and Applied Chemistry (IUPAC). Since then, IUPAC has published reports (mostly biennially) listing the recommended atomic weights, which are reproduced here. Since 1979, these values have been called the "standard atomic weights" and, since 1969, all values have been published with their estimated uncertainties. Few of the earlier values were published with uncertainties. Nevertheless, we assessed such uncertainties on the basis of our understanding of the likely contemporary judgement of the values' reliability. While neglecting remaining uncertainties of 1997 values, we derive "differences" and a retrospective index of reliability of atomic-weight values in relation to assessments of uncertainties at the time of their publication. A striking improvement in reliability appears to have been achieved since the commissions have imposed upon themselves the rule of recording estimated uncertainties from all recognized sources of error.

COMMENT

At frequent intervals (biennially in recent times), the International Union of Pure and Applied Chemistry (IUPAC) publishes revised tables of recommended atomic-weight values, A_r(E), for chemical element E. Recent editions of tables include uncertainties, $U[A_r(E)]$, and refer to the tabulated A_r(E) values as "standard atomic weights" applicable reliably to normal terrestrial sources. The latest such IUPAC table is based on a reevaluation in 1997 (ref. 1). In the table submitted here (Table 1), we list all recommended values since 1882, but exclude radioactive elements without stable isotopes (or radio-isotopes with half-lives comparable to the age of the earth). The values are shown in atomic-number order (column 1), with the currently recognized chemical symbol of element E (column 2), and current IUPAC recommended element name (column 3). A year, column 4, is given only when the Commission recommended for the element a new atomic-weight value, A_r(E), (column 5) or its uncertainty, $U[A_r(E)]$[1] (column 6; ref. 2). These values remain valid until the year of another change. No entry made for any element in a year implies that the last earlier entry is still current and that any later determinations have not lead the Commission to change the relevant recommended values. It is the stated policy of the Commission to refrain from such a change unless that change would result in a significant improvement in value or its uncertainty.

[1]In accordance with IUPAC's atomic weights Commission's statements, we have used for the uncertainty symbol a capital "*U*" as recommended in the ISO Guide to the expression of uncertainty in measurement (ref. 2) to indicate an expanded uncertainty. Although the Commission has declined to specify the degree of expansion, *i.e.* the recommended *K* value, we believe it is expected to correspond to at least two standard deviations.

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997

[Z is the atomic number. E is the symbol of the chemical element. A_r(E) is the recommended atomic-weight value adjusted, where appropriate, to the ^{12}C = 12 scale. $U[A_r(E)]$ is that year's estimated uncertainty in the standard atomic-weight value. $D[A_r(E)]$ is our estimate of the error in the standard atomic-weight value and is the difference of that year's A_r(E) from the latest standard A_r(E) value.]

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$D[A_r(E)]/U[A_r(E)]$
1	H	Hydrogen	1882	1.00	0.1	-0.0079	-0.079
			1894	1.008	0.003	0.00006	0.02
			1931	1.0078	0.0003	-0.00014	-0.47
			1938	1.0081	0.0003	0.00016	0.53
			1940	1.0080	0.0003	0.00006	0.2
			1961	1.00797	0.00001	0.00003	3
			1969	1.0080	0.0003	0.00006	0.2
			1971	1.0079	0.0001	-0.00004	-0.4
			1981	1.00794	0.00007		
2	He	Helium	1902	3.96	0.03	-0.042	-1.4
			1903	4.0	0.3	-0.0026	-0.009
			1911	3.99	0.03	-0.013	-0.42
			1916	4.00	0.03	-0.0026	-0.087
			1931	4.002	0.003	-0.0006	-0.20
			1938	4.003	0.003	0.00040	0.13
			1961	4.0026	0.0003	-0.000002	-0.007
			1969	4.00260	0.00001	-0.000002	-0.2
			1983	4.002602	0.000002		
3	Li	Lithium	1882	7.02	0.1	0.079	0.79
			1896	7.03	0.03	0.089	3.0
			1909	7.00	0.03	0.059	2.0
			1911	6.94	0.03	-0.001	-0.033
			1925	6.940	0.003	-0.001	-0.33
			1961	6.939	0.003	-0.002	-0.67
			1969	6.941	0.003	0	0
			1983	6.941	0.002		
4	Be	Beryllium	1882	9.11	0.1	0.098	0.98
			1894	9	3	-0.012	-0.004
			1896	9.08	0.03	0.068	2.3
			1900	9.1	0.3	0.088	0.29
			1925	9.02	0.03	0.0078	0.26
			1949	9.010	0.003	-0.0022	-0.73
			1961	9.0122	0.0003	0.000018	0.06
			1969	9.01218	0.00001	-0.000002	-0.2
			1985	9.012182	0.000003		
5	B	Boron	1882	10.97	0.1	0.16	1.6
			1894	11	3	0.19	0.063
			1896	10.95	0.03	0.14	4.6
			1900	11.0	0.3	0.19	0.63
			1919	10.9	0.3	0.089	0.30
			1925	10.82	0.03	0.009	0.3
			1961	10.811	0.003	0	0
			1969	10.81	0.01	-0.001	-0.1
			1983	10.811	0.005	0	0
			1995	10.811	0.007		
6	C	Carbon	1882	12.00	0.1	-0.011	-0.11
			1894	12	3	-0.011	-0.004
			1896	12.01	0.03	-0.0007	-0.023
			1898	12.00	0.03	-0.011	-0.36
			1916	12.005	0.003	-0.0057	-1.9
			1925	12.000	0.003	-0.011	-3.6

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$D[A_r(E)]/U[A_r(E)]$
6	C	Carbon	1931	12.00	0.03	-0.011	-0.36
			1937	12.01	0.03	-0.0007	-0.023
			1938	12.010	0.003	-0.0007	-0.23
			1953	12.007	0.003	-0.0037	-1.23
			1961	12.01115	0.00005	0.00045	9
			1969	12.011	0.001	0.0003	0.3
			1995	12.0107	0.0008		
7	N	Nitrogen	1882	14.03	0.1	0.023	0.23
			1895	14.05	0.03	0.043	1.4
			1896	14.04	0.03	0.033	1.1
			1907	14.01	0.03	0.0033	0.11
			1919	14.008	0.003	0.0013	0.42
			1961	14.0067	0.0003	-0.00004	-0.13
			1969	14.0067	0.0001	-0.00004	-0.4
			1985	14.00674	0.00007		
8	O	Oxygen	1882	16.00	0.1	0.0006	0.006
			1894	16.000	0.003	0.0006	0.2
			1931	16.0000		0.0006	0
			1951	16		0.0006	0
			1961	15.9994	0.0001	0	0
			1969	15.9994	0.0003		
9	F	Fluorine	1882	19.03	0.1	0.032	0.32
			1894	19	3	0.0016	0.001
			1896	19.03	0.03	0.032	1.1
			1897	19.06	0.03	0.062	2.1
			1900	19.05	0.03	0.052	1.7
			1903	19.0	0.3	0.0016	0.005
			1925	19.00	0.03	0.0016	0.053
			1961	18.9984	0.0003	-0.0000032	-0.011
			1969	18.9984	0.0001	-0.0000032	-0.032
			1971	18.99840	0.00001	-0.0000032	-0.32
			1975	18.998403	0.000001	-0.0000002	-0.2
			1985	18.9984032	0.0000009	0	0
			1995	18.9984032	0.0000005		
10	Ne	Neon	1904	20.0	0.3	-0.18	-0.60
			1909	20.2	0.3	0.020	0.077
			1928	20.183	0.003	0.0033	1.1
			1967	20.179	0.003	-0.0007	-0.23
			1979	20.179	0.001	-0.0007	-0.7
			1985	20.1797	0.0006		
11	Na	Sodium	1882	23.05	0.1	0.060	0.60
		(Natrium)	1909	23.00	0.03	0.010	0.34
			1925	22.997	0.003	0.0072	2.4
			1953	22.984	0.003	-0.0058	-1.9
			1961	22.9898	0.0003	0.00003	0.1
			1969	22.9898	0.0001	0.00003	0.3
			1971	22.98977	0.00001	0	0
			1985	22.989768	0.000006	-0.000002	-0.33
			1995	22.989770	0.000002		
12	Mg	Magnesium	1882	24.01	0.1	-0.30	-3.0
			1894	24.3	0.3	-0.005	-0.017
			1896	24.29	0.03	-0.015	-0.5
			1897	24.28	0.03	-0.025	-0.83
			1900	24.3	0.3	-0.005	-0.017
			1903	24.36	0.03	0.055	1.8

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
12	Mg	Magnesium	1909	24.32	0.03	0.015	0.5
			1961	24.312	0.003	0.007	2.3
			1967	24.305	0.003	0	0
			1969	24.305	0.001	0	0
			1985	24.3050	0.0006		
13	Al	Aluminium (Aluminum)	1882	27.08	0.1	0.098	0.98
			1894	27	3	0.018	0.006
			1896	27.11	0.03	0.13	4.3
			1900	27.1	0.3	0.12	0.40
			1922	27.0	0.3	0.018	0.062
			1925	26.97	0.03	-0.012	-0.38
			1951	26.98	0.03	-0.0015	-0.051
			1961	26.9815	0.0003	-0.00004	-0.13
			1969	26.9815	0.0001	-0.00004	-0.38
			1971	26.98154	0.00001	0.000002	0.2
			1985	26.981539	0.000005	0.000001	0.2
			1995	26.981538	0.000002		
14	Si	Silicon	1882	28.26	0.1	0.17	1.7
			1894	28.4	0.3	0.31	1.1
			1909	28.3	0.3	0.21	0.72
			1922	28.1	0.3	0.014	0.048
			1925	28.06	0.03	-0.026	-0.85
			1951	28.09	0.03	0.0045	0.15
			1961	28.086	0.001	0.0005	0.5
			1969	28.086	0.003	0.0005	0.17
			1975	28.0855	0.0003		
15	P	Phosphorus	1882	31.03	0.1	0.056	0.56
			1894	31	3	0.026	0.009
			1896	31.02	0.03	0.046	1.5
			1900	31.0	0.3	0.026	0.087
			1911	31.04	0.03	0.066	2.2
			1925	31.027	0.003	0.053	18
			1931	31.02	0.03	0.046	1.5
			1939	30.98	0.03	0.0062	0.21
			1951	30.965	0.003	-0.0088	-2.9
			1961	30.9738	0.0003	0.000039	0.13
			1969	30.9738	0.0001	0.000039	0.39
			1971	30.97376	0.00001	-0.000001	-0.1
			1985	30.973762	0.000004	0.000001	0.25
			1995	30.973761	0.000002		
16	S	Sulfur	1882	32.06	0.1	-0.006	-0.06
			1896	32.07	0.03	0.004	0.13
			1903	32.06	0.03	-0.006	-0.2
			1909	32.07	0.03	0.004	0.13
			1916	32.06	0.03	-0.006	-0.2
			1925	32.064	0.003	-0.002	-0.67
			1931	32.06	0.03	-0.006	-0.2
			1947	32.056	0.003	-0.01	-3.3
			1961	32.064	0.003	-0.002	-0.67
			1969	32.06	0.01	-0.006	-0.6
			1983	32.066	0.006		
17	Cl	Chlorine	1882	35.45	0.1	-0.0027	-0.027
			1909	35.46	0.03	0.0073	0.24
			1925	35.457	0.003	0.0043	1.4
			1961	35.453	0.001	0.0003	0.3
			1985	35.4527	0.0009		

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$D[A_r(E)]/U[A_r(E)]$
18	Ar	Argon	1902	39.96	0.03	0.012	0.4
			1903	39.9	0.3	-0.048	-0.16
			1911	39.88	0.03	-0.068	-2.3
			1919	39.9	0.3	-0.048	-0.16
			1925	39.91	0.03	-0.038	-1.3
			1931	39.944	0.003	-0.004	-1.3
			1961	39.948	0.003	0	0
			1969	39.948	0.003	0	0
			1979	39.948	0.001		
19	K	Potassium (Kalium)	1882	39.11	0.1	0.012	0.12
			1903	39.15	0.03	0.052	1.7
			1909	39.10	0.03	0.0017	0.057
			1925	39.096	0.003	-0.0023	-0.77
			1929	39.10	0.03	0.0017	0.057
			1934	39.096	0.003	-0.0023	-0.77
			1951	39.10	0.03	0.0017	0.057
			1961	39.102	0.003	0.0037	1.2
			1969	39.102	0.003	0.0037	1.2
			1971	39.098	0.003	-0.0003	-0.1
			1975	39.0983	0.0003	0	0
			1979	39.0983	0.0001		
20	Ca	Calcium	1882	40.08	0.1	0.002	0.02
			1894	40	3	-0.078	-0.026
			1896	40.08	0.03	0.002	0.067
			1897	40.07	0.03	-0.008	-0.27
			1900	40.1	0.3	0.022	0.073
			1909	40.09	0.03	0.012	0.4
			1912	40.07	0.03	-0.008	-0.27
			1931	40.08	0.03	0.002	0.067
			1969	40.08	0.01	0.002	0.2
			1983	40.078	0.004		
21	Sc	Scandium	1882	44.08	0.1	-0.88	-8.8
			1894	44.0	0.3	-0.96	-3.2
			1897	44.12	0.03	-0.84	-28
			1900	44.1	0.3	-0.86	-2.9
			1921	45.10	0.03	0.14	4.8
			1951	44.96	0.03	0.0041	0.14
			1961	44.956	0.003	0.00009	0.03
			1969	44.9559	0.0001	-0.00001	-0.1
			1983	44.95591	0.00001	0	0
			1985	44.955910	0.000009	0	0
			1995	44.955910	0.000008		
22	Ti	Titanium	1882	49.96	0.1	2.1	21
			1894	48	3	0.13	0.044
			1896	48.15	0.03	0.28	9.4
			1903	48.1	0.3	0.23	0.77
			1927	47.90	0.03	0.033	1.1
			1969	47.90	0.03	0.033	1.1
			1979	47.88	0.03	0.013	0.43
			1993	47.867	0.001		
23	V	Vanadium	1882	51.37	0.1	0.43	4.3
			1894	51.4	0.3	0.46	1.5
			1896	51.38	0.03	0.44	15
			1900	51.4	0.3	0.46	1.5
			1903	51.2	0.3	0.26	0.86
			1911	51.06	0.03	0.12	4.0

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
23	V	Vanadium	1912	51.0	0.3	0.058	0.20
			1925	50.96	0.03	0.018	0.62
			1931	50.95	0.03	0.0085	0.28
			1961	50.942	0.003	0.0005	0.17
			1969	50.9414	0.0003	-0.0001	-0.33
			1977	50.9415	0.0001		
24	Cr	Chromium	1882	52.13	0.1	0.14	1.3
			1894	52.1	0.3	0.10	0.35
			1896	52.14	0.03	0.14	4.8
			1900	52.1	0.3	0.10	0.35
			1910	52.0	0.3	0.0039	0.013
			1925	52.01	0.03	0.014	0.46
			1961	51.996	0.001	-0.0001	-0.1
			1967	51.996	0.003	-0.0001	-0.033
			1969	51.996	0.001	-0.0001	-0.1
			1983	51.9961	0.0006		
25	Mn	Manganese	1882	54.03	0.1	-0.91	-9.1
			1894	55	3	0.062	0.021
			1896	54.99	0.03	0.052	1.7
			1900	55.0	0.3	0.069	0.21
			1909	54.93	0.03	-0.0080	-0.27
			1953	54.94	0.03	0.0020	0.065
			1961	54.9380	0.0003	-0.00005	-0.16
			1969	54.9380	0.0001	-0.00005	-0.49
			1985	54.93805	0.00001	0.000001	0.1
			1995	54.938049	0.000009		
26	Fe	Iron	1882	56.04	0.1	0.20	2.0
			1894	56	3	0.16	0.052
			1896	56.02	0.03	0.18	5.8
			1900	56.0	0.3	0.16	0.52
			1901	55.9	0.3	0.055	0.18
			1909	55.85	0.03	0.005	0.17
			1912	55.84	0.03	-0.005	-0.17
			1940	55.85	0.03	0.005	0.17
			1961	55.847	0.003	0.002	0.67
			1969	55.847	0.003	0.002	0.67
			1993	55.845	0.002		
27	Co	Cobalt	1882	59.02	0.1	0.087	0.87
			1894	59	3	0.067	0.022
			1895	59.5	0.3	0.57	1.9
			1896	58.95	0.03	0.017	0.56
			1897	58.93	0.03	-0.0032	-0.11
			1898	58.99	0.03	0.057	1.9
			1900	59.0	0.3	0.067	0.22
			1909	58.97	0.03	0.037	1.2
			1925	58.94	0.03	0.0068	0.23
			1961	58.9332	0.0003	0	0
			1969	58.9332	0.0001	0	0
			1985	58.93320	0.00001	0	0
			1995	58.933200	0.000009		
28	Ni	Nickel	1892	58.06	0.03	-0.63	-21
			1894	58.7	0.3	0.0066	0.022
			1896	58.69	0.03	-0.0034	-0.11
			1900	58.7	0.3	0.0066	0.022
			1909	58.68	0.03	-0.013	-0.45
			1925	58.69	0.03	-0.0034	-0.11

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
28	Ni	Nickel	1955	58.71	0.03	0.017	0.55
			1969	58.71	0.03	0.017	0.55
			1973	58.70	0.01	0.0066	0.66
			1979	58.69	0.01	-0.0034	-0.34
			1989	58.6934	0.0002		
29	Cu	Copper	1882	63.32	0.1	-0.23	-2.3
			1894	63.6	0.3	0.054	0.18
			1909	63.57	0.03	0.024	0.8
			1947	63.54	0.03	-0.006	-0.2
			1965	63.546	0.001	0	0
			1969	63.546	0.003		
30	Zn	Zinc	1882	65.05	0.1	-0.34	-3.4
			1894	65.3	0.3	-0.09	-0.3
			1896	65.41	0.03	0.02	0.67
			1900	65.4	0.3	0.01	0.033
			1909	65.7	0.3	0.31	1.0
			1910	65.37	0.03	-0.02	-0.67
			1925	65.38	0.03	-0.01	-0.33
			1961	65.37	0.03	-0.02	-0.67
			1969	65.37	0.03	-0.02	-0.67
			1971	65.38	0.01	-0.01	-1
			1983	65.39	0.02		
31	Ga	Gallium	1882	68.96	0.1	-0.76	-7.6
			1894	69.0	0.3	-0.72	-2.4
			1897	69.91	0.03	0.19	6.2
			1900	70.0	0.3	0.28	0.92
			1909	69.9	0.3	0.18	0.59
			1919	70.1	0.3	0.38	1.3
			1923	69.72	0.03	-0.003	-0.1
			1969	69.72	0.01	-0.003	-0.3
			1983	69.723	0.004	0	0
			1987	69.723	0.001		
32	Ge	Germanium	1894	72.3	0.3	-0.31	-1.0
			1897	72.48	0.03	-0.13	-4.3
			1900	72.5	0.3	-0.11	-0.37
			1925	72.60	0.03	-0.01	-0.33
			1961	72.59	0.03	-0.02	-0.67
			1969	72.59	0.03	-0.02	-0.67
			1985	72.61	0.02		
33	As	Arsenic	1882	75.09	0.1	0.17	1.7
			1894	75.0	0.3	0.078	0.26
			1896	75.09	0.03	0.17	5.6
			1897	75.01	0.03	0.088	2.9
			1900	75.0	0.3	0.078	0.26
			1910	74.96	0.03	0.038	1.3
			1931	74.93	0.03	0.0084	0.28
			1934	74.91	0.03	-0.012	-0.39
			1961	74.9216	0.0003	0	0
			1969	74.9216	0.0001	0	0
			1985	74.92159	0.00002	-0.00001	-0.5
			1995	74.92160	0.00002		
34	Se	Selenium	1882	78.98	0.1	0.02	0.2
			1894	79.0	0.3	0.04	0.13
			1897	79.02	0.03	0.06	2
			1899	79.17	0.03	0.21	7
			1900	79.2	0.3	0.24	0.8

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
34	Se	Selenium	1934	78.96	0.03	0	0
			1969	78.96	0.03		
35	Br	Bromine	1882	79.95	0.1	0.046	0.46
			1903	79.96	0.03	0.056	1.9
			1909	79.92	0.03	0.016	0.53
			1925	79.916	0.003	0.012	4
			1961	79.909	0.002	0.005	2.5
			1965	79.904	0.001		
36	Kr	Krypton	1902	81.76	0.03	-2.0	-68
			1903	81.8	0.3	-2	-6.7
			1910	83.0	0.3	-0.8	-2.7
			1911	82.92	0.03	-0.88	-29
			1925	82.9	0.3	-0.9	-3
			1932	83.7	0.3	-0.1	-0.33
			1951	83.80	0.03	0	0
			1969	83.80	0.01		
37	Rb	Rubidium	1882	85.53	0.1	0.062	0.62
			1894	85.5	0.3	0.032	0.11
			1896	85.43	0.03	-0.038	-1.3
			1900	85.4	0.3	-0.068	-0.23
			1905	85.5	0.3	0.032	0.11
			1909	85.45	0.03	-0.018	-0.59
			1925	85.44	0.03	-0.028	-0.93
			1937	85.48	0.03	0.012	0.41
			1961	85.47	0.03	0.0022	0.073
			1969	85.4678	0.0003		
38	Sr	Strontium	1882	87.58	0.1	-0.04	-0.4
			1894	87.6	0.3	-0.02	-0.067
			1895	87.66	0.03	0.04	1.3
			1896	87.61	0.03	-0.01	-0.33
			1900	87.6	0.3	-0.02	-0.067
			1909	87.62	0.03	0	0
			1911	87.63	0.03	0.01	0.33
			1961	87.62	0.03	0	0
			1969	87.62	0.01		
39	Y	Yttrium	1882	90.02	0.1	1.1	11
			1894	89.1	0.3	0.19	0.65
			1896	88.95	0.03	0.044	1.5
			1897	89.02	0.03	0.11	3.8
			1900	89.0	0.3	0.094	0.31
			1916	88.7	0.3	-0.21	-0.69
			1919	89.33	0.03	0.42	14
			1925	88.9	0.3	-0.0058	-0.02
			1928	88.92	0.03	0.014	0.47
			1961	88.905	0.003	-0.00085	-0.28
			1969	88.9059	0.0001	0.00005	0.5
			1985	88.90585	0.00002		
40	Zr	Zirconium	1882	89.57	0.1	-1.6	-17
			1894	90.6	0.3	-0.62	-2.1
			1897	90.4	0.3	-0.82	-2.7
			1902	90.6	0.3	-0.62	-2.1
			1925	91	3	-0.22	-0.075
			1927	91.22	0.03	-0.004	-0.13
			1969	91.22	0.01	-0.004	-0.4
			1983	91.224	0.002		
41	Nb	Niobium	1882	94.03	0.1	1.1	11

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r$(E)]	$D[A_r$(E)]	$D[A_r$(E)] / $U[A_r$(E)]
41	Nb	Niobium	1894	94.0	0.1	1.1	3.6
			1897	93.73	0.3	0.82	27
			1900	93.7	0.03	0.79	2.6
			1903	94	0.3	1.1	0.36
			1909	93.5	0.3	0.59	2.0
			1917	93.1	0.3	0.19	0.64
			1931	93.3	0.3	0.39	1.3
			1935	92.91	0.03	0.0036	0.12
			1961	92.906	0.003	-0.00038	-0.13
			1969	92.9064	0.0001	0.00002	0.2
			1985	92.90638	0.00002		
42	Mo	Molybdenum	1882	95.75	0.1	-0.19	-1.9
			1894	96	3	0.06	0.02
			1896	95.98	0.03	0.04	1.3
			1897	95.99	0.03	0.05	1.7
			1900	96.0	0.3	0.06	0.2
			1938	95.95	0.03	0.01	0.33
			1961	95.94	0.03	0	0
			1969	95.94	0.03	0	0
			1975	95.94	0.01		
44	Ru	Ruthenium	1882	104.46	0.1	3.4	34
			1894	101.6	0.3	0.53	1.8
			1896	101.68	0.03	0.61	20
			1900	101.7	0.3	0.63	2.1
			1953	101.1	0.3	0.03	0.1
			1961	101.07	0.03	0	0
			1969	101.07	0.03	0	0
			1983	101.07	0.02		
45	Rh	Rhodium	1882	104.29	0.1	1.4	14
			1894	103	3	0.094	0.032
			1896	103.01	0.03	0.10	3.5
			1900	103.0	0.3	0.094	0.32
			1909	102.9	0.3	-0.0055	-0.018
			1925	102.91	0.03	0.0045	0.15
			1961	102.905	0.003	-0.0005	-0.17
			1969	102.9055	0.0001	0	0
			1985	102.90550	0.00003	0	0
			1995	102.90550	0.00002		
46	Pd	Palladium	1882	105.98	0.1	-0.44	-4.4
			1894	106.6	0.3	0.18	0.6
			1895	106.5	0.3	0.08	0.27
			1896	106.36	0.03	-0.06	-2
			1900	107.0	0.3	0.58	1.9
			1903	106.5	0.3	0.08	0.27
			1909	106.7	0.3	0.28	0.93
			1955	106.4	0.3	-0.02	-0.067
			1969	106.4	0.1	-0.02	-0.2
			1979	106.42	0.01		
47	Ag	Silver	1882	107.92	0.1	0.052	0.52
			1903	107.93	0.03	0.062	2.1
			1909	107.88	0.03	0.012	0.39
			1925	107.880	0.003	0.012	3.9
			1961	107.870	0.003	0.0018	0.6
			1965	107.868	0.001	-0.0002	-0.2
			1981	107.8682	0.0003	0	0
			1985	107.8682	0.0002		

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
48	Cd	Cadmium	1882	112.09	0.1	-0.32	-3.2
			1894	112	3	-0.41	-0.14
			1896	111.93	0.03	-0.48	-16
			1897	111.95	0.03	-0.46	-15
			1899	112.38	0.03	-0.031	-1.0
			1900	112.4	0.3	-0.011	-0.037
			1909	112.40	0.03	-0.011	-0.37
			1925	112.41	0.03	-0.001	-0.033
			1961	112.40	0.03	-0.011	-0.37
			1969	112.40	0.01	-0.011	-1.1
			1975	112.41	0.01	-0.001	-0.1
			1985	112.411	0.008		
49	In	Indium	1882	113.66	0.1	-1.2	-12
			1894	113.7	0.3	-1.1	-3.7
			1897	113.85	0.03	-0.97	-32
			1900	114	3	-0.82	-0.27
			1905	115	3	0.18	0.061
			1909	114.8	0.3	-0.018	-0.06
			1934	114.76	0.03	-0.058	-1.9
			1955	114.78	0.03	-0.038	-1.3
			1969	114.82	0.01	0.002	0.2
			1991	114.818	0.003		
50	Sn	Tin	1882	117.97	0.1	-0.74	-7.4
			1894	119	3	0.29	0.097
			1896	119.05	0.03	0.34	11
			1900	119.0	0.3	0.29	0.97
			1916	118.70	0.03	-0.01	-0.33
			1961	118.69	0.03	-0.02	-0.67
			1969	118.69	0.03	-0.02	-0.67
			1983	118.710	0.007		
51	Sb	Antimony	1882	120.23	0.1	-1.5	-15
		(Stibium)	1894	120	3	-1.8	-0.59
			1896	120.43	0.03	-1.3	-44
			1900	120.4	0.3	-1.4	-4.5
			1903	120.2	0.3	-1.6	-5.2
			1925	121.77	0.03	0.01	0.33
			1926	121.76	0.03	0	0
			1961	121.75	0.03	-0.01	-0.33
			1969	121.75	0.03	-0.01	-0.33
			1989	121.757	0.003	-0.003	-1
			1993	121.760	0.001		
52	Te	Tellurium	1882	128.25	0.1	0.65	6.5
			1894	125	3	-2.6	-0.87
			1896	127	3	-0.6	-0.2
			1897	127.49	0.03	-0.11	-3.7
			1900	127.5	0.3	-0.1	-0.33
			1902	127.7	0.3	0.1	0.33
			1903	127.6	0.3	0	0
			1909	127.5	0.3	-0.1	-0.33
			1934	127.61	0.03	0.01	0.33
			1961	127.60	0.03	0	0
			1969	127.60	0.03		
53	I	Iodine	1882	126.85	0.1	-0.054	-0.54
			1905	126.97	0.03	0.066	2.2
			1909	126.92	0.03	0.016	0.52
			1925	126.932	0.003	0.028	9.2

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
53	I	Iodine	1933	126.92	0.03	0.016	0.52
			1951	126.87	0.03	-0.034	-1.1
			1961	126.9044	0.0003	-0.00007	-0.23
			1969	126.9045	0.0001	0.00003	0.3
			1985	126.90447	0.00003		
54	Xe	Xenon	1902	128	3	-3.3	-1.1
			1910	130.7	0.3	-0.59	-2.0
			1911	130.2	0.3	-1.1	-3.6
			1932	131.3	0.3	0.01	0.033
			1955	131.30	0.03	0.01	0.33
			1969	131.30	0.01	0.01	1
			1979	131.29	0.03	0	0
			1985	131.29	0.02		
55	Cs	Caesium (Cesium)	1882	132.92	0.1	0.015	0.15
			1894	132.9	0.3	-0.0054	-0.018
			1896	132.89	0.03	-0.015	-0.52
			1900	132.9	0.3	-0.0054	-0.018
			1903	133.0	0.3	0.095	0.32
			1904	132.9	0.3	-0.0054	-0.018
			1909	132.81	0.03	-0.095	-3.2
			1934	132.91	0.03	0.0046	0.15
			1961	132.905	0.003	-0.00045	-0.15
			1969	132.9055	0.0001	0.00005	0.5
			1971	132.9054	0.0001	-0.00005	-0.5
			1985	132.90543	0.00005	-0.00002	-0.4
			1995	132.90545	0.00002		
56	Ba	Barium	1882	137.01	0.1	-0.32	-3.2
			1894	137.43	0.03	0.10	3.4
			1900	137.40	0.03	0.073	2.4
			1909	137.37	0.03	0.043	1.4
			1929	137.36	0.03	0.033	1.1
			1961	137.34	0.03	0.013	0.43
			1969	137.34	0.03	0.013	0.43
			1975	137.33	0.01	0.003	0.3
			1985	137.327	0.007		
57	La	Lanthanum	1882	138.84	0.1	-0.066	-0.66
			1894	138.2	0.3	-0.71	-2.4
			1896	138.6	0.3	-0.31	-1.0
			1897	138.64	0.03	-0.27	-8.8
			1900	138.6	0.3	-0.31	-1.0
			1903	138.9	0.3	-0.0055	-0.018
			1909	139.0	0.3	0.094	0.32
			1925	138.90	0.03	-0.0055	-0.18
			1933	138.92	0.03	0.014	0.48
			1961	138.91	0.03	0.0045	0.15
			1969	138.9055	0.0003	0	0
			1985	138.9055	0.0002		
58	Ce	Cerium	1882	140.75	0.1	0.63	6.3
			1894	140.25	0.03	0.13	4.5
			1898	139.35	0.03	-0.77	-26
			1900	139	3	-1.1	-0.37
			1903	140	3	-0.12	-0.039
			1904	140.25	0.03	0.13	4.47
			1929	140.13	0.03	0.014	0.47
			1961	140.12	0.03	0.004	0.13
			1969	140.12	0.01	0.004	0.4

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
58	Ce	Cerium	1985	140.115	0.004	-0.001	-0.25
			1995	140.116	0.001		
59	Pr	Praseodymium	1894	143.5	0.3	2.6	8.6
			1897	143.60	0.03	2.7	90
			1900	140.5	0.3	-0.41	-1.4
			1909	140.6	0.3	-0.31	-1.0
			1916	140.9	0.3	-0.0076	-0.026
			1925	140.92	0.03	0.012	0.41
			1961	140.907	0.003	-0.00065	-0.22
			1969	140.9077	0.0001	0.00005	0.5
			1985	140.90765	0.00003	0	0
			1995	140.90765	0.00002		
60	Nd	Neodymium	1894	140.5	0.3	-3.7	-12
			1897	140.80	0.03	-3.4	-115
			1899	143.6	0.3	-0.64	-2.1
			1909	144.3	0.3	0.06	0.2
			1925	144.27	0.03	0.03	1
			1961	144.24	0.03	0	0
			1969	144.24	0.03		
62	Sm	Samarium	1894	150.0	0.3	-0.36	-1.2
			1897	150.26	0.03	-0.1	-3.3
			1900	150.3	0.3	-0.06	-0.2
			1903	150	3	-0.36	-0.12
			1905	150.3	0.3	-0.06	-0.2
			1909	150.4	0.3	0.04	0.13
			1925	150.43	0.03	0.07	2.3
			1955	150.30	0.03	-0.06	-2
			1969	150.4	0.1	0.04	0.4
			1979	150.36	0.03		
63	Eu	Europium	1907	152.0	0.3	0.036	0.12
			1961	151.96	0.03	-0.004	-0.13
			1969	151.96	0.01	-0.004	-0.4
			1985	151.965	0.009	0.001	0.11
			1995	151.964	0.001		
64	Gd	Gadolinium	1894	156.1	0.3	-1.2	-3.8
			1897	156.76	0.03	-0.49	-16
			1900	157.0	0.3	-0.25	-0.83
			1902	156.4	0.3	-0.85	-2.8
			1903	156	3	-1.25	-0.42
			1909	157.3	0.3	0.05	0.17
			1925	157.26	0.03	0.01	0.33
			1931	157.3	0.3	0.05	0.17
			1937	156.9	0.3	-0.35	-1.2
			1955	157.21	0.03	-0.04	-1.3
			1961	157.25	0.03	0	0
			1969	157.25	0.03		
65	Tb	Terbium	1894	160	3	1.1	0.36
			1907	159.2	0.3	0.27	0.92
			1953	158.88	0.03	-0.045	-1.5
			1961	158.924	0.003	-0.0013	-0.45
			1969	158.9254	0.0001	0.00006	0.6
			1985	158.92534	0.00003	0	0
			1995	158.92534	0.00002		
66	Dy	Dysprosium	1908	162.5	0.3	0	0
			1925	162.52	0.03	0.02	0.67
			1930	162.46	0.03	-0.04	-1.3

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
66	Dy	Dysprosium	1955	162.46	0.03	-0.04	-1.3
			1961	162.50	0.03	0	0
			1969	162.50	0.03		
67	Ho	Holmium	1913	163.5	0.3	-1.4	-4.8
			1941	164.94	0.03	0.0097	0.32
			1961	164.930	0.003	-0.00032	-0.11
			1969	164.9303	0.0001	-0.00002	-0.2
			1971	164.9304	0.0001	0.00008	0.8
			1985	164.93032	0.00003	0	0
			1995	164.93032	0.00002		
68	Er	Erbium	1882	166.27	0.1	-0.99	-9.9
			1894	166.3	0.3	-0.96	-3.2
			1897	166.32	0.03	-0.94	-31
			1900	166.0	0.3	-1.3	-4.2
			1909	167.4	0.3	0.14	0.47
			1912	167.7	0.3	0.44	1.5
			1931	167.64	0.03	0.38	13
			1934	165.20	0.03	-2.1	-69
			1935	167.84	0.03	0.58	19
			1938	167.2	0.3	-0.06	-0.2
			1955	167.22	0.03	-0.04	-1.3
			1961	167.26	0.03	0	0
			1969	167.26	0.03		
69	Tm	Thulium	1894	170.7	0.3	1.7	5.9
			1903	171	3	2.1	0.69
			1909	168.5	0.3	-0.43	-1.4
			1922	169.9	0.3	0.97	3.2
			1925	169.4	0.3	0.47	1.6
			1953	168.89	0.03	-0.044	-1.4
			1961	168.934	0.003	-0.00021	-0.07
			1969	168.9342	0.0001	-0.00001	-0.1
			1985	168.93421	0.00003	0	0
			1995	168.93421	0.00002		
70	Yb	Ytterbium	1882	173.16	0.1	0.12	1.2
			1894	173.0	0.3	-0.04	-0.13
			1897	173.19	0.03	0.15	5
			1900	173.2	0.3	0.16	0.53
			1903	173	3	-0.04	-0.013
			1909	172.0	0.3	-1.0	-3.5
			1916	173.5	0.3	0.46	1.5
			1925	173.6	0.3	0.56	1.9
			1931	173.5	0.3	0.46	1.5
			1934	173.04	0.03	0	0
			1969	173.04	0.03		
71	Lu	Lutetium	1909	174.0	0.3	-0.97	-3.2
			1916	175.0	0.3	0.033	0.11
			1940	174.99	0.03	0.023	0.77
			1961	174.97	0.03	0.003	0.1
			1969	174.97	0.01	0.003	0.3
			1977	174.967	0.003	0	0
			1981	174.967	0.001		
72	Hf	Hafnium	1931	178.6	0.3	0.11	0.37
			1955	178.50	0.03	0.01	0.33
			1961	178.49	0.03	0	0
			1969	178.49	0.03	0	0
			1985	178.49	0.02		

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
73	Ta	Tantalum	1882	182.56	0.1	1.6	16
			1894	182.6	0.3	1.7	5.5
			1897	182.84	0.03	1.9	63
			1900	182.8	0.3	1.9	6.2
			1903	183	3	2.1	0.68
			1907	181.0	0.3	0.052	0.17
			1910	181.5	0.3	0.55	1.8
			1931	181.4	0.3	0.45	1.5
			1936	180.88	0.03	-0.068	-2.3
			1953	180.89	0.03	-0.058	-1.9
			1961	180.948	0.003	0.0001	0.033
			1969	180.9479	0.0003	0	0
			1979	180.9479	0.0001		
74	W	Tungsten	1882	184.03	0.1	0.19	1.9
		(Wolfram)	1894	184	3	0.16	0.053
			1895	184.9	0.3	1.1	3.5
			1896	184.84	0.03	1	33
			1897	184.83	0.03	0.99	33
			1900	184.0	0.3	0.16	0.53
			1938	183.92	0.03	0.08	2.7
			1955	183.80	0.03	-0.04	-1.3
			1961	183.85	0.03	0.01	0.33
			1969	183.85	0.03	0.01	0.33
			1991	183.84	0.01		
75	Re	Rhenium	1931	186.31	0.03	0.10	3.4
			1955	186.16	0.03	-0.04	-1.3
			1961	186.2	0.3	-0.007	-0.023
			1969	186.2	0.1	-0.007	-0.07
			1973	186.207	0.001		
76	Os	Osmium	1882	198.95	0.1	8.7	87
			1894	190.8	0.3	0.57	1.9
			1896	190.99	0.03	0.76	25
			1900	191.0	0.3	0.77	2.6
			1909	190.9	0.3	0.67	2.2
			1925	190.8	0.3	0.57	1.9
			1934	191.5	0.3	1.2	4.2
			1938	190.2	0.3	-0.03	-0.1
			1969	190.2	0.1	-0.03	-0.3
			1991	190.23	0.03		
77	Ir	Iridium	1882	193.09	0.1	0.87	8.7
			1894	193.1	0.3	0.88	2.9
			1896	193.12	0.03	0.90	30
			1900	193.1	0.3	0.88	2.9
			1903	193.0	0.3	0.78	2.6
			1909	193.1	0.3	0.88	2.9
			1953	192.2	0.3	-0.017	-0.057
			1969	192.22	0.03	0.003	0.1
			1993	192.217	0.003		
78	Pt	Platinum	1882	194.87	0.1	-0.21	-2.1
			1894	195	3	-0.078	-0.026
			1896	194.89	0.03	-0.19	-6.3
			1900	194.9	0.3	-0.18	-0.59
			1903	194.8	0.3	-0.28	-0.93
			1909	195.0	0.3	-0.078	-0.26
			1911	195.2	0.3	0.12	0.41
			1925	195.23	0.03	0.15	5.1

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
78	Pt	Platinum	1955	195.03	0.03	-0.048	-1.6
			1969	195.09	0.03	0.012	0.4
			1979	195.08	0.03	0.002	0.067
			1995	195.078	0.002		
79	Au	Gold	1882	196.61	0.1	-0.36	-3.6
			1894	197.3	0.3	0.33	1.1
			1896	197.24	0.03	0.27	9.1
			1897	197.23	0.03	0.26	8.8
			1900	197.2	0.3	0.23	0.78
			1953	197.0	0.3	0.033	0.11
			1961	196.967	0.003	0.00045	0.15
			1969	196.9665	0.0001	-0.00005	-0.5
			1985	196.96654	0.00003	-0.00001	-0.33
			1995	196.96655	0.00002		
80	Hg	Mercury	1882	200.17	0.1	-0.42	-4.2
			1894	200.0	0.3	-0.59	-2.0
			1912	200.6	0.3	0.01	0.033
			1925	200.61	0.03	0.02	0.67
			1961	200.59	0.03	0	0
			1969	200.59	0.03	0	0
			1989	200.59	0.02		
81	Tl	Thallium	1882	204.18	0.1	-0.20	-2.0
			1896	204.15	0.03	-0.23	-7.8
			1903	204.1	0.3	-0.28	-0.94
			1909	204.0	0.3	-0.38	-1.3
			1925	204.39	0.03	0.0067	0.22
			1961	204.37	0.03	-0.013	-0.44
			1969	204.37	0.03	-0.013	-0.44
			1979	204.383	0.001	-0.0003	-0.3
			1985	204.3833	0.0002		
82	Pb	Lead	1882	206.95	0.1	-0.25	-2.5
			1896	206.92	0.03	-0.28	-9.3
			1903	206.9	0.3	-0.3	-1
			1909	207.10	0.03	-0.1	-3.3
			1916	207.20	0.03	0	0
			1931	207.22	0.03	0.02	0.67
			1937	207.21	0.03	0.01	0.33
			1961	207.19	0.03	-0.01	-0.33
			1969	207.2	0.1		
83	Bi	Bismuth	1882	208.00	0.1	-0.98	-9.8
			1894	208.9	0.3	-0.08	-0.27
			1895	208	3	-0.98	-0.33
			1896	208.11	0.03	-0.87	-29
			1900	208.1	0.3	-0.88	-2.9
			1903	208.5	0.3	-0.48	-1.6
			1907	208.0	0.3	-0.98	-3.7
			1922	209.0	0.3	0.020	0.065
			1925	209.00	0.03	0.020	0.65
			1961	208.980	0.003	-0.00038	-0.13
			1969	208.9806	0.0001	0.00022	2.2
			1971	208.9804	0.0001	0.00002	0.2
			1985	208.98037	0.00003	-0.00001	-0.33
			1995	208.98038	0.00002		
90	Th	Thorium	1882	233.95	0.1	1.9	19
			1894	232.6	0.3	0.56	1.9
			1896	232.63	0.03	0.59	20

TABLE 1. Compilation and retrospective evaluation of the IUPAC-recommended (standard) atomic-weight A_r(E) values from 1882 to 1997 (contd.)

Z	E	Name	Year	A_r(E)	$U[A_r(E)]$	$D[A_r(E)]$	$\frac{D[A_r(E)]}{U[A_r(E)]}$
90	Th	Thorium	1900	232.6	0.3	0.56	1.9
			1903	232.5	0.3	0.46	1.5
			1909	232.42	0.03	0.38	13
			1911	232.4	0.3	0.36	1.2
			1919	232.15	0.03	0.11	3.7
			1931	232.12	0.03	0.082	2.7
			1953	231.98	0.03	-0.058	-1.9
			1961	232.038	0.003	-0.0001	-0.033
			1969	232.0381	0.0001		
91	Pa	Protactinium	1937	231	3	-0.036	-0.012
			1969	231.0359	0.0001	0.00002	0.2
			1985	231.03588	0.00002		
92	U	Uranium	1882	239.03	0.1	1.0	10
			1894	239.6	0.3	1.6	5.2
			1896	239.59	0.03	1.6	52
			1900	239.6	0.3	1.6	5.2
			1903	238.5	0.3	0.47	1.6
			1916	238.2	0.3	0.17	0.57
			1925	238.17	0.03	0.14	4.7
			1931	238.14	0.03	0.11	3.7
			1937	238.07	0.03	0.041	1.4
			1961	238.03	0.03	0.0011	0.037
			1969	238.029	0.001	0.0001	0.1
			1979	238.0289	0.0001		

Mononuclidic elements have highly accurate A_r(E) values that depend only on the numeric value of the atomic mass of the nuclide. Recommended nuclidic mass values are published in tables (ref. 3) with sponsorship by the International Union of Pure and Applied Physics.

The element symbol and name for some elements have changed during the last century, as has the spelling of elements authorized by international commissions. These changes are summarized in Table 2. It may be noted that in the International Commission report of 1906 it was mentioned that Urbain and Auer had independently proved that the "old" ytterbium was a mixture of two elements, for the second of which Urbain had suggested, and the Commission approved, lutecium. To avoid confusion, the optional name, neoytterbium, for the other element was recommended. A symbol appears not to have been proposed. The optional name neoytterbium was not abandoned until 1925.

Table of the values in history

The values for A_r(E) in our table for years prior to the founding in 1920 of IUPAC are those in International Critical Tables (ICT) (ref. 4) assembled by G. P. Baxter, based on the International Atomic Weights Commission values A_r(E) since that Commission's first substantive report in 1903 (ref. 5). The Commission membership of F. W. Clarke (U.S.A.), W. Ostwald (Germany), T. E. Thorpe (Great Britain), and G. Urbain (France) was designed to be small. It remained the same up to World War I, but the reports during the war years were no longer signed by Ostwald.

Early values. Many early determinations and lists of atomic weights were quoted both as scaled to hydrogen (1) and to oxygen (16). Since, for most elements, the latter scale related more directly to the chemical determinations employed, and thus did not depend on the uncertainty of the $A_r(O)/A_r(H)$ ratio, the oxygen scale was generally preferred, and are used here without adjustment. The correction factor for converting atomic weights from the old chemical $A_r(^{16}O) = 16$ scale to the new $A_r(^{12}C) = 12$ scale is 0.9999625 and would be negligible. For a few early physical determinations of atomic weights based on $A_r(^{16}O) = 16$, the correction factor is 0.99968218 and could not be neglected for 18 values in our table, namely: for Be in 1949, C (1953), Na (1953), P (1951), S (1947), In (1955), I (1951), Sm (1955), Gd (1955), Tb (1953), Dy (1955), Er (1955), Tm (1953), Ta (1953), W (1955), Re (1955), Pt

TABLE 2. List of International Commission Names of Elements Selected by the *Journal of the American Chemical Society* and Dates of Changes in the Commission Reports[a]

Years	Al[b]	Be	Cs[c]	Cb[d]	Dy	Eu	Gl[e]	Hf	Ho	Lu[f]	Nb	Re	S[g]	W[h]	Remarks[i]
1903/6	um		ae	✓			✓						ph	tu	A, Yt
1907	um		ae	✓		✓	✓						ph	tu	A, Sa, Yt
1908	um		ae	✓		✓	✓						ph	tu	A, Sa
1909	um		ae	✓	✓	✓	✓			c			ph	tu	A, Sa
1910	um		ae	✓	✓	✓	✓			c			ph	tu	A, Sa, Yt
1912[j]	ium		ae	✓	✓	✓	✓			c			ph	tu	A, Sa, Yt
1913/7[j]	ium		ae	✓	✓	✓	✓		✓	c			f	tu	A, Sa, Yt
	W	O	R	L	D		W	A	R		I				
1920	um		ae	✓	✓	✓	✓		✓	c			f	tu	A, Sa, Yt
1921/2	um		e	✓	✓	✓	✓		✓	c			f	tu	A, Sa, Yt
1925	um	✓	e	✓	✓	✓			✓	c			f	tu	A
1931/41	um	✓	e	✓	✓	✓		✓	✓	c		✓	f	tu	A
	W	O	R	L	D		W	A	R		II				
1947	um	✓	e	✓	✓	✓		✓	✓	c		✓	f	tu	A
1949	um	✓	e		✓	✓		✓	✓	t	✓	✓	f	wo	A
1951/5	um	✓	e		✓	✓		✓	✓	t	✓	✓	f	tu	A
1961	um	✓	e		✓	✓		✓	✓	t	✓	✓	f	tu	

[a] Until 1961 the Commission published reports in *Comptes Rendus IUPAC*. Owing to that journal's limited circulation, the reports were reprinted in most countries' principal chemical publications, *e.g.* by *Journal of the American Chemical Society*, to which we here refer. After 1967 IUPAC published in *Pure and Applied Chemistry* which has wider circulation and is in English, so that national journals tended to abandon the practice of reprinting the Commission reports regularly. For the elements of Table 1, the only remaining departures from current nomenclature were:

i. in 1967, "cesium" for Cs was used;
ii. several changes in option or preference for calling element of symbol W (wolfram or tungsten);
iii. since 1977, the optional names of "stibium", "natrium", and "kalium" for Sb, Na, and K, respectively, were so recognized; and
iv. since 1993, the optional English names of aluminum and cesium for Al and Cs, respectively, were so recognized.

[b] "um" indicates that the name of aluminum was used and "ium" indicates that the name of aluminium was used.

[c] "ae" indicates that the spelling caesium was used and "e" indicates that the spelling cesium was used.

[d] Niobium was preferred in Europe, whereas columbium was used in the United States.

[e] Glucinum (symbol Gl) was commonly used for the element that is now universally known as beryllium.

[f] "c" indicates that the spelling lutecium was used and "t" indicates that the spelling lutetium was used.

[g] "ph" indicates that the spelling sulphur was used and "f" indicates that the spelling sulfur was used.

[h] Note that the element's symbol was always W; "tu" indicates that the element was named tungsten; "wo" indicates that the element was named wolfram.

[i] "A" for argon, in the year's reports indicated; Sa for samarium, and Yt for yttrium.

[j] Published in prior year. This practice seemed desirable since many commercial and scientific documents referenced the Commission-recommended atomic weights. The delay, however, in recognizing reliable new results led to the attempt after 1925 of publishing reports in the year indicated. This aim was not often achieved.

(1955), and Th (1953). The adjustments made to these 18 values were very small compared with the changes and uncertainties of the atomic-weight values as discussed herein.

Prior to 1903, Baxter quotes the values from the American Chemical Society's Atomic Weights Committee which he himself chaired after 1912. That Committee was chaired by F. W. Clarke between 1894 and 1912, when it made significant changes (ref. 6) from Clarke's own 1882 recalculation of the atomic-weight values (ref. 7). The values in that 1882 calculation represented significant improvements in methods of A_r(E) determination and their critical analysis. These values are quoted as the starting values by Baxter in the ICT collection (ref. 4) and also in the table presented here (Table 1).

For the remaining years before 1903, the reports of the American Committee on Atomic Weights differed from the subsequent 1903 International Committee reports in the omission of chemical symbols in the atomic-weight tables. Only the full chemical names were listed. Helium and argon, though listed from 1882, were not given A_r values in the American reports until 1901, the year in which neon, krypton, and xenon first appeared in the tables but also without values (refs. 5 & 8).

Minor questions of interpretation. Where Baxter's ICT 1925 values disagree slightly with the IUPAC Commission's 1925 report (ref. 9), we have chosen to select the latter, interpreting the ICT values to be applicable until, but not including, 1925. There are very small discrepancies (usually only in the inclusion or exclusion of a final zero) between the ICT values and some national reprintings of the International Atomic Weights Commission's A_r(E) values. For our table, we have adopted the ICT values. Baxter also had to make some interpretive decisions on the applicable year of a report. The so-called 1920/21 international report (ref. 10), for example, was first published in July 1920 (in Britain) and in September 1920 (in the U.S.A.), whereas a slightly differing international report for 1921 was issued later (ref. 11).

We are not concerned with a few more important differences between A_r(E) values in the American and independent German Commission on Atomic Weights (ref. 12) as well as those in the short-lived British (ref. 13), Spanish (ref. 14) and Swiss (ref. 15) committees. Following Baxter's lead, only the internationally recommended values are given in our table after 1903.

Estimated uncertainties. In recent years, the IUPAC Atomic-Weight Tables have given uncertainty estimates to all A_r(E) values, but prior to 1969 the majority of the values did not carry a quoted uncertainty. Where not recorded, we have entered such expanded uncertainty values based on general statements of the reliability to be expected from recommended values. Any such assignment of uncertainties is necessarily open to doubt. From statements made by those who performed earlier atomic-weight measurements, we have the impression that the published data were intended to be truncated to such an extent that these scientists felt confident to the last given digit. Our initial fear was that we were overestimating the intended, but unstated uncertainties, by uniformly giving $U[A_r(E)]$ equal 3 in the last quoted digit. The only exception we have made is for estimates of Clarke's original 1882 A_r(E) values, which we estimated to ± 0.10 because Clarke explained (ref. 7) that he had quoted all A_r(E) values to two decimals even though he thought they were not all reliable to that accuracy. Readers may find one or two $U[A_r(E)]$ values of very early A_r(E) values grossly excessive, such as $A_r(C) = 12 \pm 3$, until it is remembered that the author did not give any decimal figures because he had considerable doubt of the carbon valency of 4 rather than 2 based on CO, cyanates, and lingering doubts on benzene.

As the reader will see in Table 1, the assigned uncertainties, in the light of the analysis presented here, were in fact underestimated. Is it not typical of all experimental scientists that, unaware of unknown error sources and unable to assess the effects of unlikely but large sources, their uncertainties tend to be too low?

Deviations from 1997 values and reliability index. Deviations $D[A_r(E)]$ are given in column 7. They are the differences of the given year's $A_r(E)$ from the latest (1997) standard $A_r(E)$ value, here assumed to be equal to ideal "error-free" values for judging the reliability of earlier recommended values. The 1997 values are the commissions's current best knowledge of the atomic weights and represent the closest available approach to the hypothetical "error-free" values. The deviations from the 1997 values, therefore, yield estimated errors for the earlier values. With probably very few exceptions, and certainly for the 19 mononuclidic elements, these current $A_r(E)$ values are surely much nearer their hypothetical error-free values. $D[A_r(E)]$ yields especially reliable estimates of errors for early $A_r(E)$ values when they were based mostly on chemical, as opposed to physical (now mass-spectrometric) determinations. The quotient $D[A_r(E)]/U[A_r(E)]$ in column 8 is a retrospective measure of the reliability of the originally recommended value judged by its own assigned uncertainty (ref. 16). The bias is determined by subtracting the mean $D[A_r(E)]/U[A_r(E)]$ value from all other of these fractional values. The mean value of 0.31756 in column 8 is quite small relative to many individual values and represents a general bias of all values, which we subtracted from all values for judging retrospectively the reliability of individual atomic-weight values. For that purpose we calculated a "reliability index" of atomic-weight values, d, in relation to their uncertainty estimations or assignments (ref. 16), such that:

$$d = (n-1)^{-1/2} \cdot \Sigma \{[D[A_r(E)]]^2/[U[A_r(E)]]^2\}^{1/2},$$

where n is the number of values of $D[A_r(E)]/U[A_r(E)]$. A well-evaluated data set should have $d < 1$. The value of d calculated for all the data on which the reliability could be assessed is large, namely 9.63. That value is calculated from n = 718, which equals the total number of entries, 802, diminished by the last quoted values of each of the 84 elements listed.

There is a positive bias of the values in column 8 of Table 1, the ratios of differences from present-day values divided by the original uncertainty. The algebraic sum of all values, which ideally should be zero, is +227.696. The mean value of the bias is +227.696/(718-1) = +0.31356. This is a fraction of the initial uncertainty that is by no means negligible. The corresponding figures for the values between 1969 and 1997 are 0.606 and 0.606/(194-68-1) = 0.004848, and are very much smaller. We wonder whether data prior to 1969 might suffer from unsuspected contamination in atomic-weight determinations.

For values since 1969 (n = 111), we find $d = 0.45$, indicating a desirable high degree of reliability of IUPAC's evaluation of more recent $A_r(E)$ values. It must be remembered that by neglecting the remaining and unknown errors in the 1997 values, we have biased the reliability index in favor of the assessment of recent changes in $A_r(E)$ values. Nevertheless, it is remarkable that the $d = 0.45$ value for the reliability of recently recommended $A_r(E)$ values agrees with that in reference (ref. 16) in which the reliability was assessed by a different retrospective method. That method, though inferior to the method used in this paper, was free from the bias due to the remaining uncertainties in the current $A_r(E)$ values.

CONCLUSION

We have assembled more than a century's historic record of internationally recognized atomic-weight values and their uncertainties. Comparison of older with current best values leads to a retrospective analysis of this carefully evaluated data set. The self-discipline by the relevant IUPAC Commission of estimating uncertainties since 1969 appears to have contributed to improved reliability, by about an order of magnitude, as quantified by a previously proposed numerical index measure. This conclusion is convincing and not dependent on details of the analysis. For instance, one could weight each tabulated entry by the number of years of its validity, or one could discard all data within ten years of the present because they are too close to current values to provide adequate retrospection. The ultimate conclusion would remain unchanged.

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Erratum:

IUPAC Recommendations on Nomenclature and Symbols and Technical Reports from Commissions

Commission on Atomic Weights and Isotopic Abundances (T. B. Coplen and H. S. Peiser). History of the recommended atomic-weight values from 1882 to 1997: A comparison of differences from current values to the estimated uncertainties of earlier values (Technical report). *Pure & Applied Chemistry* 1998, **70**(1), 237–257.

Unfortunately a correction to the proof was not carried out before the article went to press. On page 256, a curly bracket was not moved to the left of the summation sign. The equation should then read as follows, and readers are asked to paste this new version over that which was orginally printed:

$d = (n-1)^{-1/2} \cdot \{\Sigma\, [D[A_r(E)]]^2/[U[A_r(E)]]^2\}^{1/2}$,

The publishers apologise for any confusion that may have arisen.