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DIVISION OF INORGANIC CHEMISTRY
COMMISSION ON ATOMIC WEIGHTS

ATOMIC WEIGHTS OF THE ELEMENTS 1971

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DIVISION OF INORGANIC CHEMISTRY

COMMISSION ON ATOMIC WEIGHTS†

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CHANGES IN ATOMIC WEIGHT VALUES

In their *1969 Report*[1] the Commission on Atomic Weights made two important innovations: they indicated the estimated reliability of the quoted values by the mode of printing the last digit, and they added various references to seven footnotes in order further to elaborate or qualify the values given. The values then chosen have not been criticized. On the basis of work published or accepted for publication during the last two years the following changes are now recommended.

Changes in Atomic Weights

Chemical symbol	1969 atomic weight	1971 atomic weight
H	1.008_0	1.0079
F	18.9984	18.99840
Na	22.9898	22.98977
Al	26.9815	26.98154
P	30.9738	30.97376
K	39.10_2	39.09_8
Zn	65.3_7	65.38
Cs	132.9055	132.9054
Ho	164.9303	164.9304
Bi	208.9806	208.9804

Four of these ten new values have implied uncertainties one tenth of those of the 1969 values. Two of the new values have implied uncertainties one third of the 1969 values. Eight of the above changes are within the implied precision of the old values. Two are outside that range by one unit in the last decimal.

The change in the value for *hydrogen* derives from a complex problem. The most likely value relevant to a laboratory sample is 1.00797. Previously the Commission decided to round this off to 1.008_0, the final digit being subscript because the full range of normal hydrogen sources departs by more than

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0.0001 from the above value as a result of variations in isotopic abundance. In consequence of the skew distribution of abundances of deuterium in nature the value of 1.0079 encompasses all normal samples whereas the value 1.0080 does not. Added precision can therefore be incorporated by using the value 1.0079 rather than the former value of 1.008_0. Although as a rule the atomic weight values in the table should not be influenced by any variations in isotopic abundance caused by chemical processing, it is worth noting that sometimes hydrogen gas used in laboratories has been depleted of deuterium through electrolysis. The atomic weight of laboratory hydrogen is therefore at times close to 1.0079_0.

The change for *potassium* depends on a new analysis by G. Marinenko[2] of old chemical data by R. G. Bates and E. Wichers[3] which gives additional credence to atomic weight determinations for potassium by chemical methods. The Commission therefore feels that the presently used mass spectroscopic data should not be the only basis for the published atomic weight value. Unfortunately, the two sets of chemical and mass spectroscopic data, whilst being self-consistent within each set, show unexplained discrepancies between the two sets; for this reason the Commission has decided to use a mean value rather than the mass spectroscopic value alone. This reduces the atomic weight of potassium by one part in 10^4 to 39.09_8.

The new value for *zinc* depends on an accurate new coulometric determination by G. Marinenko and R. T. Foley[4]. Even on conservative estimates of uncertainties and unsuspected bias of the new technique an improvement in the precision of the atomic weight for zinc was possible; this is reflected in the new value of 65.38 in which the final digit is printed on line.

New nuclidic mass data assembled and assessed by A. H. Wapstra and N. B. Gove[5] have led to improved accuracy of recommended atomic weights of some mononuclidic elements (*fluorine*, *sodium*, *aluminium* and *phosphorus*). Based on the same work, the values for *caesium* and *holmium* were adjusted by one unit in the fourth decimal figure and the value for *bismuth* by two units in the fourth decimal figure.

The Commission points out that the precision with which the atomic weights of mononuclidic elements are quoted in the tables is less than the accuracy claimed for the mass-spectrometrically determined relative atomic masses. This is partly because the precision of relative mass measurements of individual nuclides is often greater than the precision with which it has been established experimentally that minute traces of other long-lived isotopes of that element are absent in naturally occurring samples.

New data on isotopic abundances in unusual geological locations have made it desirable to add the footnote g to the elements *lithium*[6], *magnesium*[7], and *calcium*[7].

Footnote b has been deleted from *neptunium*.

Information on the atomic weight of *technetium* is being withdrawn from the Table of Atomic Weights because the longer-lived isotope ^{97}Tc is becoming available in addition to the fission product ^{99}Tc. However, data for both isotopes are given in the Table of Relative Atomic Masses of Selected Isotopes.

The Commission has noted that the use of small digits to indicate an uncertainty higher than ± 1 in the last digit has led to difficulties in printing.

For this reason the Commission now recommends that subscript digits be used for this purpose.

THE RELATIVE PRECISION OF ATOMIC WEIGHT VALUES

The relative precision with which values of the atomic weights are quoted varies widely (see *Figure 1*). In some instances, low relative precision is a necessary consequence of the known variability of isotopic abundances in normal materials (e.g. lithium, boron, etc.). However, the figure also indicates deficiencies in the data on such elements as titanium, nickel, germanium, molybdenum, palladium, tin, rhenium, and osmium.

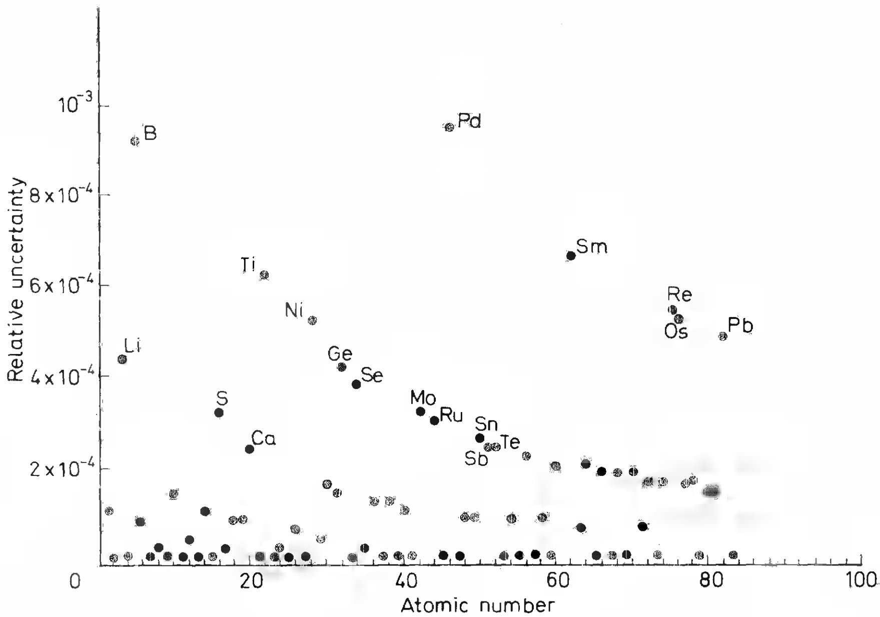

Figure 1. Relative uncertainty of the atomic weight values of the elements 1971.

In pointing to the low relative precision of data on these elements the Commission hopes to stimulate research and development work on the use of established and new techniques for redetermination of atomic weights. Calibrated isotopic abundance measurements are especially needed, and provision of standard reference materials of known isotopic abundance would also be found helpful. Renewed attempts might be made to distribute typical homogeneous materials known to be representative of the natural composition of specified elements.

SYMBOLS AND TERMINOLOGY

Simultaneously with the *1969 Report* of the Commission on Atomic Weights[1], the Commission on Symbols, Terminology and Units of the

TABLE OF ATOMIC WEIGHTS 1971

Scaled to the relative atomic mass, $A_r(^{12}C) = 12$

The values of $A_r(E)$ given here apply to elements as they exist in materials of terrestrial origin and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ± 1 in the last digit, or ± 3 if that digit is subscript.

Alphabetical Order in English

Name	Symbol	Atomic number	Atomic weight	Name	Symbol	Atomic number	Atomic weight
Actinium	Ac	89	—	Mercury	Hg	80	200.5_9
Aluminium	Al	13	26.98154[a]	Molybdenum	Mo	42	95.9_4
Americium	Am	95	—	Neodymium	Nd	60	144.2_4
Antimony	Sb	51	121.7_5	Neon	Ne	10	20.17_9[c]
Argon	Ar	18	39.94_8[b,c,d,g]	Neptunium	Np	93	237.0482[f]
Arsenic	As	33	74.9216[a]	Nickel	Ni	28	58.7_1
Astatine	At	85	—	Niobium	Nb	41	92.9064[a]
Barium	Ba	56	137.3_4	Nitrogen	N	7	14.0067[b,c]
Berkelium	Bk	97	—	Nobelium	No	102	—
Beryllium	Be	4	9.01218[a]	Osmium	Os	76	190.2
Bismuth	Bi	83	208.9804[a]	Oxygen	O	8	15.999_4[b,c,d]
Boron	B	5	10.81[c,d,e]	Palladium	Pd	46	106.4
Bromine	Br	35	79.904[c]	Phosphorus	P	15	30.97376[a]
Cadmium	Cd	48	112.40	Platinum	Pt	78	195.0_9
Caesium	Cs	55	132.9054[a]	Plutonium	Pu	94	—
Calcium	Ca	20	40.08[g]	Polonium	Po	84	—
Californium	Cf	98	—	Potassium	K	19	39.09_8
Carbon	C	6	12.011[b,d]	Praseodymium	Pr	59	140.9077[a]
Cerium	Cc	58	140.12	Promethium	Pm	61	—
Chlorine	Cl	17	35.453[c]	Protactinium	Pa	91	231.0359[f]
Chromium	Cr	24	51.996[c]	Radium	Ra	88	226.0254[f,g]
Cobalt	Co	27	58.9332[a]	Radon	Rn	86	—
Copper	Cu	29	63.54_6[c,d]	Rhenium	Re	75	186.2
Curium	Cm	96	—	Rhodium	Rh	45	102.9055[a]
Dysprosium	Dy	66	162.5_0	Rubidium	Rb	37	85.467_8[c]

Einsteinium	Es	99	—	Ruthenium	Ru	44	101.0_7
Erbium	Er	68	167.2_6	Samarium	Sm	62	150.4
Europium	Eu	63	151.96	Scandium	Sc	21	44.9559[a]
Fermium	Fm	100	—	Selenium	Se	34	78.9_6
Fluorine	F	9	18.99840[a]	Silicon	Si	14	28.08_6[d]
Francium	Fr	87	—	Silver	Ag	47	107.868[c]
Gadolinium	Gd	64	157.2_5	Sodium	Na	11	22.98977[a]
Gallium	Ga	31	69.72	Strontium	Sr	38	87.62[g]
Germanium	Ge	32	72.5_9	Sulfur	S	16	32.06[d]
Gold	Au	79	196.9665[a]	Tantalum	Ta	73	180.947_9[b]
Hafnium	Hf	72	178.4_9	Technetium	Tc	43	—
Helium	He	2	4.00260[b,c]	Tellurium	Te	52	127.6_0
Holmium	Ho	67	164.9304[a]	Terbium	Tb	65	158.9254[a]
Hydrogen	H	1	1.0079[b,d]	Thallium	Tl	81	204.3_7
Indium	In	49	114.82	Thorium	Th	90	232.0381[f]
Iodine	I	53	126.9045[a]	Thulium	Tm	69	168.9342[a]
Iridium	Ir	77	192.2_2	Tin	Sn	50	118.6_9
Iron	Fe	26	55.84_7	Titanium	Ti	22	47.9_0
Krypton	Kr	36	83.80	Tungsten	W	74	183.8_5
Lanthanum	La	57	138.905_5[b]	Uranium	U	92	238.029[b,c,e]
Lawrencium	Lr	103	—	Vanadium	V	23	50.941_4[b,c]
Lead	Pb	82	207.2[d,g]	Wolfram	W	74	183.8_5
Lithium	Li	3	6.94_1[c,d,e,g]	Xenon	Xe	54	131.30
Lutetium	Lu	71	174.97	Ytterbium	Yb	70	173.0_4
Magnesium	Mg	12	24.305[c,g]	Yttrium	Y	39	88.9059[a]
Manganese	Mn	25	54.9380[a]	Zinc	Zn	30	65.38
Mendelevium	Md	101	—	Zirconium	Zr	40	91.22

[a] Element with only one stable nuclide.
[b] Element with one predominant isotope (about 99 to 100 per cent abundance); errors in abundance determinations have a correspondingly small effect on the confidence in the value of A_r(E).
[c] Element for which the value of A_r(E) derives its reliability from calibrated measurements (i.e. from comparisons with synthetic mixtures of known isotopic composition).
[d] Element for which known variations in isotopic abundance in terrestrial material prevent a more precise atomic weight being given; A_r(E) values should be applicable to any 'normal' material.
[e] Element for which values of A_r may be found in commercially available products that differ from the tabulated value of A_r(E) because of inadvertent or undisclosed changes of isotopic composition.
[f] Element for which the value of A_r is that of the most commonly available long-lived nuclide.
[g] Element for which geological specimens are known in which the element has an anomalous isotopic composition.

TABLE OF ATOMIC WEIGHTS 1971

Scaled to the relative atomic mass, $A_r(^{12}C) = 12$

The values of $A_r(E)$ given here apply to elements as they exist in materials of terrestrial origin and to certain artificial elements. When used with due regard to the footnotes they are considered reliable to ± 1 in the last digit, or ± 3 if that digit is subscript.

Order of Atomic Number

Atomic number	Name	Symbol	Atomic weight	Atomic number	Name	Symbol	Atomic weight
1	Hydrogen	H	1.0079[b,d]	53	Iodine	I	126.9045[a]
2	Helium	He	4.00260[b,c]	54	Xenon	Xe	131.30
3	Lithium	Li	6.94_1[c,d,e,g]	55	Caesium	Cs	132.9054[a]
4	Beryllium	Be	9.01218[a]	56	Barium	Ba	137.3_4
5	Boron	B	10.81[c,d,e]	57	Lanthanum	La	138.905_5[b]
6	Carbon	C	12.011[b,d]	58	Cerium	Ce	140.12
7	Nitrogen	N	14.0067[b,c]	59	Praseodymium	Pr	140.9077[a]
8	Oxygen	O	15.999_4[b,c,d]	60	Neodymium	Nd	144.2_4
9	Fluorine	F	18.99840[a]	61	Promethium	Pm	—
10	Neon	Ne	20.17_9[c]	62	Samarium	Sm	150.4
11	Sodium	Na	22.98977[a]	63	Europium	Eu	151.96
12	Magnesium	Mg	24.305[c,g]	64	Gadolinium	Gd	157.2_5
13	Aluminium	Al	26.98154[a]	65	Terbium	Tb	158.9254[a]
14	Silicon	Si	28.08_6[d]	66	Dysprosium	Dy	162.5_0
15	Phosphorus	P	30.97376[a]	67	Holmium	Ho	164.9304[a]
16	Sulfur	S	32.06[d]	68	Erbium	Er	167.2_6
17	Chlorine	Cl	35.453[c]	69	Thulium	Tm	168.9342[a]
18	Argon	Ar	39.94_8[b,c,d,g]	70	Ytterbium	Yb	173.0_4
19	Potassium	K	39.09_8	71	Lutetium	Lu	174.97
20	Calcium	Ca	40.08[g]	72	Hafnium	Hf	178.4_9
21	Scandium	Sc	44.9559[a]	73	Tantalum	Ta	180.947_9[b]
22	Titanium	Ti	47.9_0	74	Wolfram (Tungsten)	W	183.8_5

23 Vanadium	V	50.941_4 [b,c]	75 Rhenium	Re	186.2
24 Chromium	Cr	51.996[c]	76 Osmium	Os	190.2
25 Manganese	Mn	54.9380[a]	77 Iridium	Ir	192.2_2
26 Iron	Fe	55.84_7	78 Platinum	Pt	195.0_9
27 Cobalt	Co	58.9332[a]	79 Gold	Au	196.9665[a]
28 Nickel	Ni	58.7_1	80 Mercury	Hg	200.5_9
29 Copper	Cu	63.54_6 [c,d]	81 Thallium	Tl	204.3_7
30 Zinc	Zn	65.38	82 Lead	Pb	207.2[d,g]
31 Gallium	Ga	69.72	83 Bismuth	Bi	208.9804[a]
32 Germanium	Ge	72.5_9	84 Polonium	Po	—
33 Arsenic	As	74.9216[a]	85 Astatine	At	—
34 Selenium	Se	78.9_6	86 Radon	Rn	—
35 Bromine	Br	79.904[c]	87 Francium	Fr	—
36 Krypton	Kr	83.80	88 Radium	Ra	226.0254[f,g]
37 Rubidium	Rb	85.467_8 [c]	89 Actinium	Ac	—
38 Strontium	Sr	87.62[g]	90 Thorium	Th	232.0381[f]
39 Yttrium	Y	88.9059[a]	91 Protactinium	Pa	231.0359[f]
40 Zirconium	Zr	91.22	92 Uranium	U	238.029[b,c,e]
41 Niobium	Nb	92.9064[a]	93 Neptunium	Np	237.0482[f]
42 Molybdenum	Mo	95.9_4	94 Plutonium	Pu	—
43 Technetium	Tc	—	95 Americium	Am	—
44 Ruthenium	Ru	101.0_7	96 Curium	Cm	—
45 Rhodium	Rh	102.9055[a]	97 Berkelium	Bk	—
46 Palladium	Pd	106.4	98 Californium	Cf	—
47 Silver	Ag	107.868[c]	99 Einsteinium	Es	—
48 Cadmium	Cd	112.40	100 Fermium	Fm	—
49 Indium	In	114.82	101 Mendelevium	Md	—
50 Tin	Sn	118.6_9	102 Nobelium	No	—
51 Antimony	Sb	121.7_5	103 Lawrencium	Lr	—
52 Tellurium	Te	127.6_0			

[a] Element with only one stable nuclide.
[b] Element with one predominant isotope (about 99 to 100 per cent abundance); errors in abundance determinations have a correspondingly small effect on the confidence in the value of A_r(E).
[c] Element for which the value of A_r(E) derives its reliability from calibrated measurements (i.e. from comparisons with synthetic mixtures of known isotopic composition).
[d] Element for which known variations in isotopic abundance in terrestrial material prevent a more precise atomic weight being given: A_r(E) values should be applicable to any 'normal' material.
[e] Element for which values of A_r may be found in commercially available products that differ from the tabulated value of A_r(E) because of inadvertent or undisclosed changes of isotopic composition.
[f] Element for which the value of A_r is that of the most commonly available long-lived nuclide.
[g] Element for which geological specimens are known in which the element has an anomalous isotopic composition.

ATOMIC WEIGHTS OF THE ELEMENTS

TABLE OF RELATIVE ATOMIC MASSES OF SELECTED NUCLIDES

Name	Symbol	Atomic number	Mass number	Relative atomic mass	Half-life*	
Hydrogen	H	1	1	1.007825		
(Deuterium)	(D)	1	2	2.014102		
(Tritium)	(T)	1	3	3.016050	12.33	a
Helium	He	2	3	3.016030		
			4	4.00260		
Lithium	Li	3	6	6.01512		
			7	7.01600		
Boron	B	5	10	10.01294		
			11	11.00931		
Carbon	C	6	12	12 Exactly		
			13	13.003355		
			14	14.00324	5730	a
Nitrogen	N	7	14	14.003074		
			15	15.00011		
Oxygen	O	8	16	15.994915		
			17	16.999133		
			18	17.99916		
Magnesium	Mg	12	24	23.98504		
			25	24.98584		
			26	25.98259		
Silicon	Si	14	28	27.97693		
			29	28.97650		
			30	29.97377		
Sulfur	S	16	32	31.97207		
			33	32.97146		
			34	33.96787		
			36	35.96708		
Argon	Ar	18	36	35.96755		
			38	37.96273		
			40	39.96238		
Calcium	Ca	20	40	39.96259		
			42	41.9586		
			43	42.9588		
			44	43.9555		
			46	45.9537		
			48	47.9525		
Copper	Cu	29	63	62.9296		
			65	64.9278		
Strontium	Sr	38	84	83.9134		
			86	85.9093		
			87	86.9089		
			88	87.9056		
Technetium	Tc	43	97	96.9064	2.6×10^6	a
			99	98.9062	2.13×10^5	a
Promethium	Pm	61	145	144.9128	18	a
			147	146.9152	2.6234	a

Name	Symbol	Atomic number	Mass number	Relative atomic mass	Half-life*	
Lead	Pb	82	204	203.9730		
			206	205.9745		
			207	206.9759		
			208	207.9767		
Polonium	Po	84	209	208.9824	102	a
			210	209.9829	138.38	d
Astatine	At	85	210	209.987	8.1	hr
Radon	Rn	86	222	222.0176	3.824	d
Francium	Fr	87	223	223.0198	22	min
Radium	Ra	88	226	226.0254	1.60×10^3	a
Actinium	Ac	89	227	227.0278	21.77	a
Thorium	Th	90	232	232.0381	1.40×10^{10}	a
Protactinium	Pa	91	231	231.0359	3.25×10^4	a
Uranium	U	92	233	233.0397	1.59×10^5	a
			234	234.0410	2.44×10^5	a
			235	235.0439	7.10×10^8	a
			236	236.0456	2.42×10^7	a
			238	238.0508	4.49×10^9	a
Neptunium	Np	93	237	237.0482	2.14×10^6	a
Plutonium	Pu	94	238	238.0496	87.8	a
			239	239.0522	2.439×10^4	a
			240	240.0538	6.54×10^3	a
			241	241.0569	15	a
			242	242.0588	3.87×10^5	a
			244	244.0642	8.3×10^7	a
Americium	Am	95	241	241.0568	433	a
			243	243.0614	7.37×10^3	a
Curium	Cm	96	242	242.0589	163	d
			243	243.0614	28	a
			244	244.0628	17.9	a
			245	245.0655	8.7×10^3	a
			246	246.0672	4.65×10^3	a
			247	247.0704	1.54×10^7	a
			248	248.0724	3.4×10^5	a
			250	250.0784	1.1×10^4	a
Berkelium	Bk	97	247	247.0703	1.4×10^3	a
			249	249.0750	311	d
Californium	Cf	98	251	251.0796	900	a
			252	252.0817	2.64	a
			254	254.0874	60	d
Einsteinium	Es	99	253	253.0848	20.47	d
			254	254.0881	276	d
Fermium	Fm	100	257	257.0951	82	d
Mendelevium	Md	101	257	257.0956	5	hr
			258	not given	55	d
Nobelium	No	102	255	255.0933	3.2	min
Lawrencium	Lr	103	256	256.0986	35	s

* a = year; d = day; hr = hour; min = minute; s = second

Division of Physical Chemistry of IUPAC published its *Manual of Symbols and Terminology for Physicochemical Quantities and Units*[8]. Section III on the Explanation of Terms published with the former *Report*[1] should be considered superseded by the recommendations of the latter[8]. In particular the term 'atomic weight of an element' is an alternative for the term 'relative atomic mass of an element' which is 'the ratio of the average mass per atom of a natural nuclidic composition of an element to $\frac{1}{12}$ of the mass of an atom of nuclide ^{12}C. Example: $A_r(Cl) = 34.453$. The concept of relative atomic mass may be extended to other specified nuclidic compositions, but the natural nuclidic composition is assumed unless some other composition is specified.' Readers should note especially that atomic weights are thus dimensionless numbers.

The values of $A_r(E)$ given in the Table of Atomic Weights apply to elements as they exist in 'normal materials'. A 'normal material' is one that contains as a major constituent a specified element with an atomic weight value that does not display a significant difference from the accepted value of that atomic weight because of:

(i) its radiogenic source;
(ii) its extraterrestrial origin;
(iii) artificial isotopic fractionation;
(iv) artificial nuclear reaction;
(v) a rare geological occurrence in small quantity.

RELATIVE ATOMIC MASSES OF SELECTED NUCLIDES

In this *1971 Report* the Commission has expanded the Table of Relative Atomic Masses of Selected Nuclides (formerly called Table of Atomic Masses of Selected Isotopes) to include the following: (i) all stable isotopes of elements whose isotopic composition is known to vary in nature or to have been varied extensively as a result of artificial processes, that is all those elements that are given the footnotes d, e or g in the Table of Atomic Weights; and (ii) all those radioactive nuclides previously included in the 1969 Tables of Selected Radioactive Isotopes and of Atomic Masses of Selected Isotopes (with the exception of ^{143}Pm). In this way users can calculate the atomic weight characteristic of specific samples of known isotopic contents. The publication of the Table of Selected Radioactive Isotopes is discontinued but the half-life values of the radioisotopes are included in the Table of Relative Atomic Masses of Selected Nuclides. These half-lives are taken from a recently assembled and critically evaluated compilation by N. E. Holden and F. W. Walker[9].

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