CRC

HANDBOOK of CHEMISTRY and PHYSICS

DAVID R. LIDE
Editor-in-Chief

84TH EDITION
2003-2004

CRC PRESS

More data...
New format...
Physical Constants of Organic Compounds
Completely revised!
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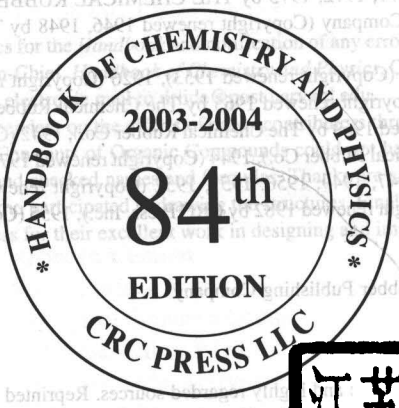
CRC Handbook of Chemistry and Physics

A Ready-Reference Book of Chemical and Physical Data



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Former Director, Standard Reference Data

National Institute of Standards and Technology

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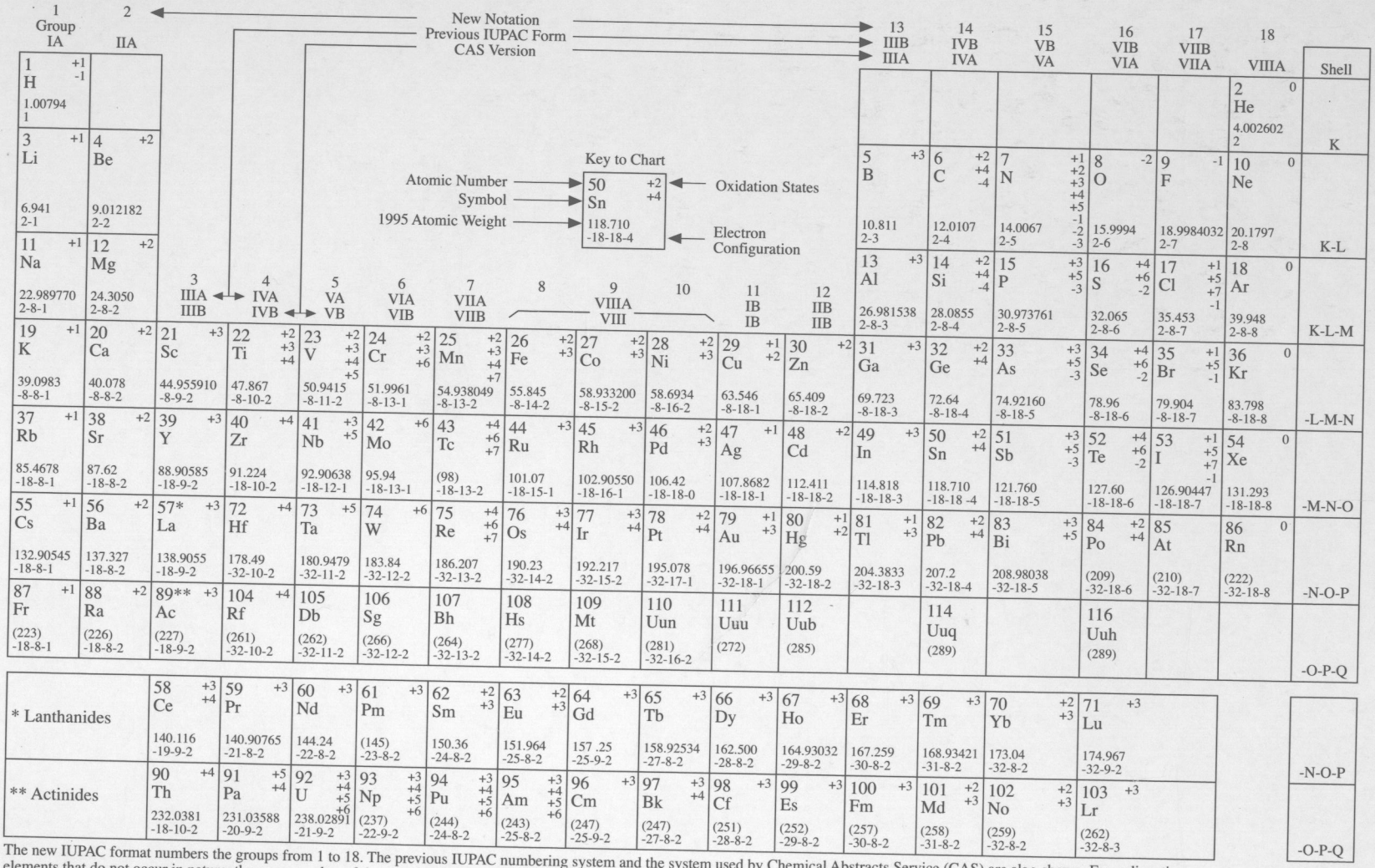

The new IUPAC format numbers the groups from 1 to 18. The previous IUPAC numbering system and the system used by Chemical Abstracts Service (CAS) are also shown. For radioactive elements that do not occur in nature, the mass number of the most stable isotope is given in parentheses.

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1. G. J. Leigh, Editor, *Nomenclature of Inorganic Chemistry*, Blackwell Scientific Publications, Oxford, 1990.
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3. Atomic Weights of the Elements, 1999, *Pure & Appl. Chem.*, 73, 667, 2001.

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84th Edition

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PREFACE

The 84th Edition of the *CRC Handbook of Chemistry and Physics* features a completely new version of the most heavily used table in the book, Physical Constants of Organic Compounds. This is the first revision of the table since 1994. Compounds have been selected for inclusion in the new table by a careful screening of lists of organic compounds that are important in laboratory research, industrial chemistry, environmental protection, drug development, and other active areas. In this way priorities were established for choosing the most significant compounds out of the millions of organic substances that have been reported in the literature. Property data for the selected compounds have been updated, and new structure diagrams, which show much more detail than the previous structures, have been drawn for all the compounds. The format has also been changed. While previously the structures were in a separate part of the book from the data table, the matching structures now appear on a facing page to the tabular data. We hope that users find this layout more convenient, and we welcome comments on the new arrangement.

Other new features of the 84th Edition include:

- An update and expansion of the table of Critical Constants of Fluids, with many new compounds and recently published data.
- A new version of Properties of Refrigerants, which covers fluids now used in refrigeration systems and those being considered as substitutes because of environmental factors.
- A new table on Fermi Energy and Related Properties of Metals.
- New tables of practical laboratory data such as Flame and Bead Tests, Flame Temperatures, and Density of Ethanol-Water Mixtures.
- An update of lists of Chemical Carcinogens and Interstellar Molecules.
- Update of the new feature introduced in the 83rd Edition listing other reliable sources of physical and chemical data. This section, which appears as Appendix B, includes data-oriented journals, institutional data centers, and major handbooks, as well as a list of Web addresses for the most important physical and chemical data sources on the Internet. The Web addresses have been brought up to date for this edition and new sources have been added.

The Editor appreciates suggestions on new topics for the *Handbook* and notification of any errors. Input from users plays a key role in keeping the book up to date. Address all comments to Editor-in-Chief, *Handbook of Chemistry and Physics*, CRC Press LLC, 2000 N.W. Corporate Blvd., Boca Raton, FL 33431. Comments may also be sent by electronic mail to drlide@post.harvard.edu.

The *Handbook of Chemistry and Physics* is dependent on the efforts of many contributors throughout the world. The list of current contributors follows this Preface. The new table of Physical Constants of Organic Compounds could not have been completed without the help of Dr. Fiona Macdonald, who oversaw the structure drawing and checked names and formulas. Thanks are also due to Janice Shackleton, Trupti Desai, Nazila Kamaly, Matt Griffiths, and Lawrence Braschi, who participated in drawing the structures. Finally, I want to thank Susan Fox, Sara Kreisman, and James Yanchak of the editorial group at CRC Press for their excellent work in designing and implementing the new layout of the table.

David R. Lide
February 25, 2003

This Edition is dedicated to my grandchildren:

Mary Eleanor Lide
David Alston Lide, Jr.
Grace Eileen Lide
David Austell Whitcomb
Kate Elizabeth Whitcomb

Note on the Ordering of Chemical Compounds: The decision on the order in which to list chemical compounds in a table is always difficult. An alphabetical list by name has the disadvantage that several different synonyms are often in common use, with the result that a reader may conclude incorrectly that a compound is not present if he looks it up under the wrong name. Listing by common formula is satisfactory for simple inorganic compounds, but is cumbersome for organics. A listing by molecular formula is attractive because clear rules can be given for locating a compound, but the user may have to go to some effort to determine the molecular formula. In this book the choice is made on pragmatic grounds. The long tables, Physical Constants of Organic Compounds and Physical Constants of Inorganic Compound, are ordered by systematic name, but indexes to synonyms, formulas, and CAS Registry Numbers are provided. If the table is very short and includes only familiar substances, the listing is usually alphabetical by common formula or name, The remaining tables are ordered by molecular formula using a modification of the Hill convention. In this convention the molecular formula is written with C first, H second, and then all other elements in alphabetical order of their chemical symbols. For tables with organic compounds only, the sequence of entries is determined by the alphabetical order of elements in the molecular formula and the number of atoms of each element, in ascending order, e.g., C_3H_7Cl, C_3H_7N, C_3H_7NO, $C_3H_7NO_2$, etc. (For organic compounds, a quick way to determine the molecular formula is to use the Physical Constants of Organic Compounds table, which starts on Page 3-1, and its synonym index on Page 3-586.) In tables containing non-carbon compounds, those are listed first, followed by a separate listing of compounds that do contain carbon. This is in contrast to the strict Hill convention as followed by Chemical Abstracts Service, where the molecular formulas beginning with A and B precede the formulas for carbon-containing compounds, while those beginning with D... Z follow. For tabular displays, as opposed to an index, it appears more convenient to the user if the non-carbon compounds are listed as a block, rather than being split by the longer list of carbon compounds.

STANDARD ATOMIC WEIGHTS (2001)

Z	Element	Symbol	Atomic Weight
1	Hydrogen	H	1.00794(7)
2	Helium	He	4.002602(2)
3	Lithium	Li	6.941(2)
4	Beryllium	Be	9.012182(3)
5	Boron	B	10.811(7)
6	Carbon	C	12.0107(8)
7	Nitrogen	N	14.0067(2)
8	Oxygen	O	15.9994(3)
9	Fluorine	F	18.9984032(5)
10	Neon	Ne	20.1797(6)
11	Sodium	Na	22.989770(2)
12	Magnesium	Mg	24.3050(6)
13	Aluminum	Al	26.981538(2)
14	Silicon	Si	28.0855(3)
15	Phosphorus	P	30.973761(2)
16	Sulfur	S	32.065(5)
17	Chlorine	Cl	35.453(2)
18	Argon	Ar	39.948(1)
19	Potassium	K	39.0983(1)
20	Calcium	Ca	40.078(4)
21	Scandium	Sc	44.955910(8)
22	Titanium	Ti	47.867(1)
23	Vanadium	V	50.9415(1)
24	Chromium	Cr	51.9961(6)
25	Manganese	Mn	54.938049(9)
26	Iron	Fe	55.845(2)
27	Cobalt	Co	58.933200(9)
28	Nickel	Ni	58.6934(2)
29	Copper	Cu	63.546(3)
30	Zinc	Zn	65.409(4)
31	Gallium	Ga	69.723(1)
32	Germanium	Ge	72.64(1)
33	Arsenic	As	74.92160(2)
34	Selenium	Se	78.96(3)
35	Bromine	Br	79.904(1)
36	Krypton	Kr	83.798(2)
37	Rubidium	Rb	85.4678(3)
38	Strontium	Sr	87.62(1)
39	Yttrium	Y	88.90585(2)
40	Zirconium	Zr	91.224(2)
41	Niobium	Nb	92.90638(2)
42	Molybdenum	Mo	95.94(2)
43	Technetium	Tc	[97.9072]
44	Ruthenium	Ru	101.07(2)
45	Rhodium	Rh	102.90550(2)
46	Palladium	Pd	106.42(1)
47	Silver	Ag	107.8682(2)
48	Cadmium	Cd	112.411(8)
49	Indium	In	114.818(3)
50	Tin	Sn	118.710(7)
51	Antimony	Sb	121.760(1)
52	Tellurium	Te	127.60(3)
53	Iodine	I	126.90447(3)
54	Xenon	Xe	131.293(6)
55	Cesium	Cs	132.90545(2)
56	Barium	Ba	137.327(7)
57	Lanthanum	La	138.9055(2)
58	Cerium	Ce	140.116(1)
59	Praseodymium	Pr	140.90765(2)
60	Neodymium	Nd	144.24(3)
61	Promethium	Pm	[144.9127]
62	Samarium	Sm	150.36(3)
63	Europium	Eu	151.964(1)
64	Gadolinium	Gd	157.25(3)
65	Terbium	Tb	158.92534(2)
66	Dysprosium	Dy	162.500(1)
67	Holmium	Ho	164.93032(2)
68	Erbium	Er	167.259(3)
69	Thulium	Tm	168.93421(2)
70	Ytterbium	Yb	173.04(3)
71	Lutetium	Lu	174.967(1)
72	Hafnium	Hf	178.49(2)
73	Tantalum	Ta	180.9479(1)
74	Tungsten	W	183.84(1)
75	Rhenium	Re	186.207(1)
76	Osmium	Os	190.23(3)
77	Iridium	Ir	192.217(3)
78	Platinum	Pt	195.078(2)
79	Gold	Au	196.96655(2)
80	Mercury	Hg	200.59(2)
81	Thallium	Tl	204.3833(2)
82	Lead	Pb	207.2(1)
83	Bismuth	Bi	208.98038(2)
84	Polonium	Po	[208.9824]
85	Astatine	At	[209.9871]
86	Radon	Rn	[222.0176]
87	Francium	Fr	[223.0197]
88	Radium	Ra	[226.0254]
89	Actinium	Ac	[227.0277]
90	Thorium	Th	232.0381(1)
91	Protactinium	Pa	231.03588(2)
92	Uranium	U	238.02891(3)
93	Neptunium	Np	[237.0482]
94	Plutonium	Pu	[244.0642]
95	Americium	Am	[243.0614]
96	Curium	Cm	[247.0704]
97	Berkelium	Bk	[247.0703]
98	Californium	Cf	[251.0796]
99	Einsteinium	Es	[252.0830]
100	Fermium	Fm	[257.0951]
101	Mendelevium	Md	[258.0984]
102	Nobelium	No	[259.1010]
103	Lawrencium	Lr	[262.1097]
104	Rutherfordium	Rf	[261.1088]
105	Dubnium	Db	[262.1141]
106	Seaborgium	Sg	[266.1219]
107	Bohrium	Bh	[264.12]
108	Hassium	Hs	[277]
109	Meitnerium	Mt	[268.1388]
110	Ununnilium	Uun	[281]
111	Unununium	Uuu	[272.1535]
112	Ununbium	Uub	[285]
114	Ununquadium	Uuq	[289]
116	Ununhexium	Uuh	[289]

See page 1-12 for further information

Fundamental Physical Constants — Frequently used constants

Quantity	Symbol	Value	Unit	Relative std. uncert. u_r
speed of light in vacuum	c, c_0	299 792 458	$m\ s^{-1}$	(exact)
magnetic constant	μ_0	$4\pi \times 10^{-7}$	$N\ A^{-2}$	
		$= 12.566\,370\,614... \times 10^{-7}$	$N\ A^{-2}$	(exact)
electric constant $1/\mu_0 c^2$	ε_0	$8.854\,187\,817... \times 10^{-12}$	$F\ m^{-1}$	(exact)
Newtonian constant of gravitation	G	$6.673(10) \times 10^{-11}$	$m^3\ kg^{-1}\ s^{-2}$	1.5×10^{-3}
Planck constant	h	$6.626\,068\,76(52) \times 10^{-34}$	J s	7.8×10^{-8}
$h/2\pi$	$\hbar$	$1.054\,571\,596(82) \times 10^{-34}$	J s	7.8×10^{-8}
elementary charge	e	$1.602\,176\,462(63) \times 10^{-19}$	C	3.9×10^{-8}
magnetic flux quantum $h/2e$	Φ_0	$2.067\,833\,636(81) \times 10^{-15}$	Wb	3.9×10^{-8}
conductance quantum $2e^2/h$	G_0	$7.748\,091\,696(28) \times 10^{-5}$	S	3.7×10^{-9}
electron mass	m_e	$9.109\,381\,88(72) \times 10^{-31}$	kg	7.9×10^{-8}
proton mass	m_p	$1.672\,621\,58(13) \times 10^{-27}$	kg	7.9×10^{-8}
proton-electron mass ratio	m_p/m_e	1 836.152 6675(39)		2.1×10^{-9}
fine-structure constant $e^2/4\pi\epsilon_0\hbar c$	α	$7.297\,352\,533(27) \times 10^{-3}$		3.7×10^{-9}
inverse fine-structure constant	α^{-1}	137.035 999 76(50)		3.7×10^{-9}
Rydberg constant $\alpha^2 m_e c/2h$	R_∞	10 973 731.568 549(83)	m^{-1}	7.6×10^{-12}
Avogadro constant	N_A, L	$6.022\,141\,99(47) \times 10^{23}$	mol^{-1}	7.9×10^{-8}
Faraday constant $N_A e$	F	96 485.3415(39)	$C\ mol^{-1}$	4.0×10^{-8}
molar gas constant	R	8.314 472(15)	$J\ mol^{-1}\ K^{-1}$	1.7×10^{-6}
Boltzmann constant R/N_A	k	$1.380\,6503(24) \times 10^{-23}$	$J\ K^{-1}$	1.7×10^{-6}
Stefan-Boltzmann constant $(\pi^2/60)k^4/\hbar^3 c^2$	σ	$5.670\,400(40) \times 10^{-8}$	$W\ m^{-2}\ K^{-4}$	7.0×10^{-6}
		Non-SI units accepted for use with the SI		
electron volt: (e/C) J	eV	$1.602\,176\,462(63) \times 10^{-19}$	J	3.9×10^{-8}
(unified) atomic mass unit $1\ u = m_u = \frac{1}{12}m(^{12}C)$ $= 10^{-3}\ kg\ mol^{-1}/N_A$	u	$1.660\,538\,73(13) \times 10^{-27}$	kg	7.9×10^{-8}

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