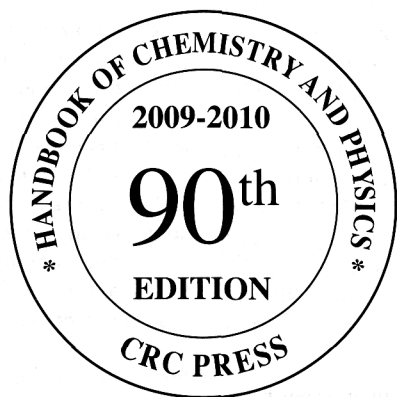


CRC Handbook of Chemistry and Physics

A Ready-Reference Book of Chemical and Physical Data



Editor-in-Chief

David R. Lide, Ph.D.

Former Director, Standard Reference Data

National Institute of Standards and Technology

Associate Editor

W. M. "Mickey" Haynes, Ph.D.

Scientist Emeritus

National Institute of Standards and Technology



CRC Press

Taylor & Francis Group

Boca Raton London New York

CRC Press is an imprint of the
Taylor & Francis Group, an **informa** business

TABLE OF CONTENTS

SECTION 1: BASIC CONSTANTS, UNITS, AND CONVERSION FACTORS

CODATA Recommended Values of the Fundamental Physical Constants.....	1-1
Standard Atomic Weights (2008).....	1-12
Atomic Masses and Abundances.....	1-14
Electron Configuration and Ionization Energy of Neutral Atoms in the Ground State.....	1-18
International Temperature Scale of 1990 (ITS-90).....	1-20
Conversion of Temperatures from the 1948 and 1968 Scales to ITS-90.....	1-21
International System of Units (SI).....	1-23
Units for Magnetic Properties.....	1-27
Conversion Factors.....	1-28
Conversion of Temperatures.....	1-38
Conversion Factors for Energy Units.....	1-39
Conversion Factors for Pressure Units.....	1-40
Conversion Factors for Thermal Conductivity Units.....	1-41
Conversion Factors for Electrical Resistivity Units.....	1-42
Conversion Factors for Chemical Kinetics.....	1-43
Conversion Factors for Ionizing Radiation.....	1-44
Values of the Gas Constant in Different Unit Systems.....	1-46

SECTION 2: SYMBOLS, TERMINOLOGY, AND NOMENCLATURE

Symbols and Terminology for Physical and Chemical Quantities.....	2-1
Expression of Uncertainty of Measurements.....	2-13
Nomenclature for Chemical Compounds.....	2-15
Nomenclature for Inorganic Ions and Ligands.....	2-16
Organic Substituent Groups and Ring Systems.....	2-23
Representation of Chemical Structures with the IUPAC International Chemical Identifier (InChI).....	2-27
Scientific Abbreviations, Acronyms, and Symbols.....	2-29
Greek, Russian, and Hebrew Alphabets.....	2-42
Definitions of Scientific Terms.....	2-43
Thermodynamic Functions and Relations.....	2-68
Nobel Laureates in Chemistry and Physics.....	2-69

SECTION 3: PHYSICAL CONSTANTS OF ORGANIC COMPOUNDS

Physical Constants of Organic Compounds.....	3-1
Synonym Index of Organic Compounds.....	3-524
Molecular Formula Index of Organic Compounds.....	3-549
CAS Registry Number Index of Organic Compounds.....	3-634
Diamagnetic Susceptibility of Selected Organic Compounds.....	3-672

SECTION 4: PROPERTIES OF THE ELEMENTS AND INORGANIC COMPOUNDS

The Elements.....	4-1
Physical Constants of Inorganic Compounds.....	4-43
Formula Index of Inorganic Compounds.....	4-102
CAS Registry Number Index of Inorganic Compounds.....	4-115
Physical Properties of the Rare Earth Metals.....	4-127
Melting, Boiling, Triple, and Critical Point Temperatures of the Elements.....	4-133
Heat Capacity of the Elements at 25 °C.....	4-135
Vapor Pressure of the Metallic Elements — Equations.....	4-136
Vapor Pressure of the Metallic Elements — Data.....	4-138
Density of Molten Elements and Representative Salts.....	4-139
Magnetic Susceptibility of the Elements and Inorganic Compounds.....	4-142
Index of Refraction of Inorganic Liquids.....	4-148
Physical and Optical Properties of Minerals.....	4-149
Crystallographic Data on Minerals.....	4-156

SECTION 5: THERMOCHEMISTRY, ELECTROCHEMISTRY, AND KINETICS

CODATA Key Values for Thermodynamics.....	5-1
Standard Thermodynamic Properties of Chemical Substances.....	5-4
Thermodynamic Properties as a Function of Temperature.....	5-43

Thermodynamic Properties of Aqueous Ions	5-66
Heat of Combustion.....	5-68
Energy Content of Fuels.....	5-69
Electrical Conductivity of Water.....	5-70
Electrical Conductivity of Aqueous Solutions.....	5-71
Standard KCl Solutions for Calibrating Conductivity Cells	5-72
Molar Conductivity of Aqueous HF, HCl, HBr, and HI.....	5-73
Equivalent Conductivity of Electrolytes in Aqueous Solution.....	5-74
Ionic Conductivity and Diffusion at Infinite Dilution	5-75
Activity Coefficients of Acids, Bases, and Salts	5-78
Mean Activity Coefficients of Electrolytes as a Function of Concentration	5-80
Enthalpy of Dilution of Acids.....	5-84
Enthalpy of Solution of Electrolytes	5-85
Enthalpy of Hydration of Gases.....	5-86
Chemical Kinetic Data for Stratospheric Modeling.....	5-90

SECTION 6: FLUID PROPERTIES

Thermophysical Properties of Water and Steam.....	6-1
Vapor Pressure and Other Saturation Properties of Water	6-5
Standard Density of Water	6-7
Fixed Point Properties of H ₂ O and D ₂ O.....	6-9
Properties of Saturated Liquid D ₂ O.....	6-10
Properties of Ice and Supercooled Water.....	6-12
Vapor Pressure of Ice.....	6-13
Melting Point of Ice as a Function of Pressure.....	6-13
Permittivity (Dielectric Constant) of Water at Various Frequencies.....	6-14
Thermophysical Properties of Air	6-15
Thermophysical Properties of Fluids	6-21
Virial Coefficients of Selected Gases.....	6-38
Van der Waals Constants for Gases.....	6-47
Mean Free Path and Related Properties of Gases.....	6-48
Influence of Pressure on Freezing Points	6-49
Critical Constants.....	6-50
Sublimation Pressure of Solids	6-70
Vapor Pressure	6-72
Vapor Pressure of Fluids at Temperatures below 300 K.....	6-102
Vapor Pressure of Saturated Salt Solutions.....	6-110
IUPAC Recommended Data for Vapor Pressure Calibration.....	6-111
Enthalpy of Vaporization	6-112
Enthalpy of Fusion	6-130
Pressure and Temperature Dependence of Liquid Density	6-140
Volumetric Properties of Aqueous Sodium Chloride Solutions.....	6-142
Properties of Cryogenic Fluids	6-143
Properties of Liquid Helium.....	6-144
Properties of Refrigerants.....	6-145
Properties of Gas Clathrate Hydrates.....	6-148
Ionic Liquids.....	6-153
Density and Specific Volume of Mercury.....	6-157
Thermal Properties of Mercury	6-158
Melting Curve of Mercury.....	6-159
Vapor Pressure of Mercury.....	6-160
Surface Tension of Common Liquids.....	6-161
Surface Tension of Aqueous Mixtures.....	6-165
Permittivity (Dielectric Constant) of Liquids	6-166
Permittivity (Dielectric Constant) of Gases.....	6-188
Azeotropic Data for Binary Mixtures.....	6-189
Viscosity of Gases.....	6-208
Viscosity of Liquids.....	6-209
Viscosity of Carbon Dioxide along the Saturation Line	6-214
Viscosity and Density of Aqueous Hydroxide Solutions	6-215
Viscosity of Liquid Metals	6-216
Thermal Conductivity of Gases.....	6-218
Thermal Conductivity of Liquids.....	6-220

Diffusion in Gases	6-225
Diffusion of Gases in Water	6-227
Diffusion Coefficients in Liquids at Infinite Dilution	6-228

SECTION 7: BIOCHEMISTRY

Properties of Amino Acids	7-1
Structures of Common Amino Acids	7-3
Properties of Purine and Pyrimidine Bases	7-5
The Genetic Code	7-6
Properties of Fatty Acids and Their Methyl Esters	7-7
Composition and Properties of Common Oils And Fats	7-9
Carbohydrate Names and Symbols	7-14
Standard Transformed Gibbs Energies of Formation for Biochemical Reactants	7-16
Apparent Equilibrium Constants for Enzyme-Catalyzed Reactions	7-19
Thermodynamic Quantities for the Ionization Reactions of Buffers in Water	7-23
Biological Buffers	7-26
Typical pH Values of Biological Materials and Foods	7-27
Structure and Functions of Some Common Drugs	7-28
Chemical Constituents of Human Blood	7-45
Chemical Composition of the Human Body	7-48
Nutrient Values of Foods	7-49

SECTION 8: ANALYTICAL CHEMISTRY

Preparation of Special Analytical Reagents	8-1
Standard Solutions of Acids, Bases, and Salts	8-5
Standard Solutions of Oxidation and Reduction Reagents	8-7
Organic Analytical Reagents for the Determination of Inorganic Substances	8-8
Flame and Bead Tests	8-13
Acid-Base Indicators	8-15
Fluorescent Indicators	8-18
Conversion Formulas for Concentration of Solutions	8-19
Electrochemical Series	8-20
Reduction and Oxidation Potentials for Certain Ion Radicals	8-30
pH Scale for Aqueous Solutions	8-32
Practical pH Measurements on Natural Waters	8-37
Buffer Solutions Giving Round Values of pH at 25 °C	8-39
Dissociation Constants of Inorganic Acids and Bases	8-40
Dissociation Constants of Organic Acids and Bases	8-42
Concentrative Properties of Aqueous Solutions: Density, Refractive Index, Freezing Point Depression, and Viscosity	8-52
Ion Product of Water Substance	8-78
Ionization Constant of Normal and Heavy Water	8-79
Solubility of Selected Gases in Water	8-80
Solubility of Carbon Dioxide in Water at Various Temperatures and Pressures	8-84
Aqueous Solubility and Henry's Law Constants of Organic Compounds	8-85
Aqueous Solubility of Inorganic Compounds at Various Temperatures	8-121
Solubility Product Constants	8-127
Solubility of Common Salts at Ambient Temperatures	8-130
Solubility of Hydrocarbons in Seawater	8-131
Solubility of Organic Compounds in Pressurized Hot Water	8-133
Solubility Chart	8-136
Reduction of Weighings in Air to Vacuo	8-138
Volume of One Gram of Water	8-139
Properties of Carrier Gases for Gas Chromatography	8-140
Solvents for Ultraviolet Spectrophotometry	8-141
¹³ C Chemical Shifts of Useful NMR Solvents	8-142
Mass Spectral Peaks of Common Organic Solvents	8-143
Proton NMR Shifts of Common Organic Solvents	8-150

SECTION 9: MOLECULAR STRUCTURE AND SPECTROSCOPY

Bond Lengths in Crystalline Organic Compounds	9-1
Bond Lengths in Organometallic Compounds	9-17
Structure of Free Molecules in the Gas Phase	9-19

Characteristic Bond Lengths in Free Molecules	9-48
Atomic Radii of the Elements	9-49
Dipole Moments	9-50
Hindered Internal Rotation	9-59
Bond Dissociation Energies	9-64
Electronegativity	9-98
Force Constants for Bond Stretching	9-99
Fundamental Vibrational Frequencies of Small Molecules	9-100
Spectroscopic Constants of Diatomic Molecules	9-103
Infrared Correlation Charts	9-108
Nuclear Spins, Moments, and Other Data Related to NMR Spectroscopy	9-113
Proton NMR Chemical Shifts for Characteristic Organic Structures	9-116
¹³ C-NMR Absorptions of Major Functional Groups	9-117

SECTION 10: ATOMIC, MOLECULAR, AND OPTICAL PHYSICS

Line Spectra of the Elements	10-1
NIST Atomic Transition Probabilities	10-93
Electron Affinities	10-156
Proton Affinities	10-174
Atomic and Molecular Polarizabilities	10-193
Ionization Energies of Atoms and Atomic Ions	10-203
Ionization Energies of Gas-Phase Molecules	10-206
X-Ray Atomic Energy Levels	10-224
Electron Binding Energies of the Elements	10-228
Natural Width of X-Ray Lines	10-234
Photon Attenuation Coefficients	10-235
Classification of Electromagnetic Radiation	10-240
Sensitivity of the Human Eye to Light of Different Wavelengths	10-242
Black Body Radiation	10-243
Characteristics of Infrared Detectors	10-245
Index of Refraction of Inorganic Crystals	10-246
Refractive Index and Transmittance of Representative Glasses	10-250
Index of Refraction of Water	10-251
Index of Refraction of Liquids for Calibration Purposes	10-252
Index of Refraction of Air	10-253
Index of Refraction of Gases	10-254
Characteristics of Laser Sources	10-255
Infrared Laser Frequencies	10-261
Infrared and Far-Infrared Absorption Frequency Standards	10-268

SECTION 11: NUCLEAR AND PARTICLE PHYSICS

Summary Tables of Particle Properties	11-1
Table of the Isotopes	11-56
Neutron Scattering and Absorption Properties	11-254
Cosmic Radiation	11-267

SECTION 12: PROPERTIES OF SOLIDS

Techniques for Materials Characterization	12-1
Symmetry of Crystals	12-5
Ionic Radii in Crystals	12-11
Polarizabilities of Atoms and Ions in Solids	12-13
Crystal Structures and Lattice Parameters of Allotropes of the Elements	12-15
Phase Transitions in the Solid Elements at Atmospheric Pressure	12-19
Lattice Energies	12-21
The Madelung Constant and Crystal Lattice Energy	12-34
Elastic Constants of Single Crystals	12-35
Electrical Resistivity of Pure Metals	12-41
Electrical Resistivity of Selected Alloys	12-43
Electrical Resistivity of Graphite Materials	12-46
Permittivity (Dielectric Constant) of Inorganic Solids	12-47
Curie Temperature of Selected Ferroelectric Crystals	12-56
Properties of Antiferroelectric Crystals	12-57
Dielectric Constants of Glasses	12-58

14-4	Properties of Superconductors.....	12-59
81-2	High-Temperature Superconductors.....	12-75
02-2	Organic Superconductors.....	12-77
15-4	Properties of Semiconductors.....	12-80
56-4	Selected Properties of Semiconductor Solid Solutions.....	12-93
62-2	Properties of Organic Semiconductors.....	12-95
	Diffusion Data for Semiconductors.....	12-99
	Properties of Magnetic Materials.....	12-107
1-2-1	Organic Magnets.....	12-116
01-2	Electron Inelastic Mean Free Paths.....	12-119
51-2	Electron Work Function of the Elements.....	12-121
61-2	Secondary Electron Emission.....	12-122
61-2	Optical Properties of Selected Elements.....	12-123
23-2	Optical Properties of Selected Inorganic and Organic Solids.....	12-148
35-2	Elasto-Optic, Electro-Optic, and Magneto-Optic Constants.....	12-167
55-2	Nonlinear Optical Constants.....	12-181
82-2	Phase Diagrams.....	12-184
00-2	Heat Capacity of Selected Solids.....	12-202
04-2	Thermal and Physical Properties of Pure Metals.....	12-203
11-2	Thermophysical Properties of Stainless Steel 310.....	12-205
50-4	Thermal Conductivity of Metals and Semiconductors as a Function of Temperature.....	12-206
61-2	Thermal Conductivity of Alloys as a Function of Temperature.....	12-208
44-2	Thermal Conductivity of Crystalline Dielectrics.....	12-209
28-2	Thermal Conductivity of Ceramics and Other Insulating Materials.....	12-211
36-2	Thermal Conductivity of Glasses.....	12-213
54-2	Thermoelectric Properties of Metals and Semiconductors.....	12-217
3-2	Fermi Energy and Related Properties of Metals.....	12-219
48-2	Properties of Commercial Metals and Alloys.....	12-221
01-2	Hardness of Minerals and Ceramics.....	12-222

SECTION 13: POLYMER PROPERTIES

11-1	Nomenclature for Organic Polymers.....	13-1
11-1	Solvents for Common Polymers.....	13-5
06-1	Glass Transition Temperature for Selected Polymers.....	13-6
	Dielectric Constant of Selected Polymers.....	13-13
	Pressure–Volume–Temperature Relationship for Polymer Melts.....	13-14
1-1-1	Upper Critical (UCST) and Lower Critical (LCST) Solution Temperatures of Binary Polymer Solutions.....	13-19
61-2	Vapor Pressures (Solvent Activities) for Binary Polymer Solutions.....	13-37
62-4	Specific Enthalpies of Solution of Polymers and Copolymers.....	13-42
67-4	Solubility Parameters of Selected Polymers.....	13-70

SECTION 14: GEOPHYSICS, ASTRONOMY, AND ACOUSTICS

60-0	Astronomical Constants.....	14-1
	Properties of the Solar System.....	14-2
	Satellites of the Planets.....	14-4
1-1-1	Interstellar Molecules.....	14-7
5-1	Mass, Dimensions, and Other Parameters of the Earth.....	14-10
5-1	Geological Time Scale.....	14-12
6-1	Acceleration Due to Gravity.....	14-13
6-1	Density, Pressure, and Gravity as a Function of Depth Within the Earth.....	14-14
6-1	Ocean Pressure as a Function of Depth and Latitude.....	14-15
6-1	Properties of Seawater.....	14-16
11-1	Abundance of Elements in the Earth's Crust and in the Sea.....	14-18
21-1	Solar Spectral Irradiance.....	14-19
64-1	U.S. Standard Atmosphere (1976).....	14-20
72-1	Geographical and Seasonal Variation in Solar Radiation.....	14-26
62-1	Major World Earthquakes.....	14-27
11-1	Weather-Related Scales.....	14-31
50-1	Infrared Absorption by the Earth's Atmosphere.....	14-33
80-1	Atmospheric Concentration of Carbon Dioxide, 1958–2004.....	14-34
05-1	Mean Temperatures in the United States, 1900–1992.....	14-36
71-1	Global Temperature Trend, 1856–2004.....	14-38
72-1	Global Warming Potential of Greenhouse Gases.....	14-39

Atmospheric Electricity	14-41
Speed of Sound in Various Media	14-48
Attenuation and Speed of Sound in Air as a Function of Humidity and Frequency	14-50
Speed of Sound in Dry Air.....	14-51
Musical Scales.....	14-52
Characteristics of Human Hearing.....	14-53

SECTION 15: PRACTICAL LABORATORY DATA

Standard ITS-90 Thermocouple Tables.....	15-1
Secondary Reference Points on the ITS-90 Temperature Scale	15-10
Relative Sensitivity of Bayard-Alpert Ionization Gauges to Various Gases.....	15-12
Laboratory Solvents and Other Liquid Reagents.....	15-13
Miscibility of Organic Solvents	15-23
Density of Solvents as a Function of Temperature	15-25
Dependence of Boiling Point on Pressure	15-26
Ebullioscopic Constants for Calculation of Boiling Point Elevation.....	15-27
Cryoscopic Constants for Calculation of Freezing Point Depression	15-28
Freezing Point Lowering by Electrolytes in Aqueous Solution.....	15-29
Correction of Barometer Readings to 0 °C Temperature	15-30
Determination of Relative Humidity from Dew Point.....	15-31
Determination of Relative Humidity from Wet and Dry Bulb Temperatures.....	15-32
Constant Humidity Solutions	15-33
Standard Salt Solutions for Humidity Calibration.....	15-34
Low-Temperature Baths for Maintaining Constant Temperature	15-35
Metals and Alloys with Low Melting Temperature	15-36
Wire Tables.....	15-37
Characteristics of Particles and Particle Dispersoids.....	15-38
Density of Various Solids.....	15-39
Density of Sulfuric Acid.....	15-40
Density of Ethanol–Water Mixtures.....	15-41
Dielectric Strength of Insulating Materials.....	15-42
Coefficient of Friction	15-47
Flame Temperatures	15-49
Allocation of Frequencies in the Radio Spectrum.....	15-50

SECTION 16: HEALTH AND SAFETY INFORMATION

Handling and Disposal of Chemicals in Laboratories.....	16-1
Flammability of Chemical Substances	16-13
Threshold Limits for Airborne Contaminants.....	16-29
Octanol–Water Partition Coefficients.....	16-43
Protection against Ionizing Radiation	16-48
Annual Limits on Intakes of Radionuclides.....	16-49
Chemical Carcinogens	16-53

APPENDIX A: MATHEMATICAL TABLES

Miscellaneous Mathematical Constants.....	A-1
Decimal Equivalents of Common Fractions	A-2
Quadratic Formula.....	A-2
Exponential and Hyperbolic Functions and Their Common Logarithms.....	A-3
Natural Trigonometric Functions to Four Places	A-6
Relation of Angular Functions in Terms of One Another.....	A-8
Derivatives.....	A-9
Integration	A-11
Integrals.....	A-15
Differential Equations.....	A-46
Fourier Series	A-57
Fourier Expansions for Basic Periodic Functions	A-59
The Fourier Transforms.....	A-61
Series Expansion.....	A-65
Vector Analysis	A-68
Orthogonal Curvilinear Coordinates	A-75
Transformation of Integrals	A-77
Bessel Functions	A-78

The Factorial Function	A-80
The Gamma Function	A-81
The Beta Function.....	A-82
The Error Function	A-83
Orthogonal Polynomials.....	A-83
Tables of Orthogonal Polynomials.....	A-86
Clebsch–Gordan Coefficients	A-87
Normal Probability Function	A-88
Percentage Points, Student's <i>t</i> -Distribution.....	A-91
Percentage Points, Chi-Square Distribution.....	A-91
Percentage Points, <i>F</i> -Distribution.....	A-93
Moment of Inertia for Various Bodies of Mass.....	A-97

APPENDIX B: SOURCES OF PHYSICAL AND CHEMICAL DATA.....	B-1
---	------------

INDEX.....	I-1
-------------------	------------