

CRC

HANDBOOK OF
CHEMISTRY
and
PHYSICS

DAVID R. LIDE
Editor-in-Chief

89TH

EDITION
2008-2009

TABLE OF CONTENTS

SECTION 1: BASIC CONSTANTS, UNITS, AND CONVERSION FACTORS

CODATA Recommended Values of the Fundamental Physical Constants: 2006.....	1-1
Standard Atomic Weights (2007).....	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
Nomenclature for Chemical Compounds	2-13
Nomenclature for Inorganic Ions and Ligands	2-14
Organic Substituent Groups and Ring Systems	2-21
Scientific Abbreviations and Symbols.....	2-25
Greek, Russian, and Hebrew Alphabets	2-36
Definitions of Scientific Terms	2-37
Thermodynamic Functions and Relations	2-62

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 Systems	5-66
Heat of Combustion.....	5-70
Energy Content of Fuels	5-71

Electrical Conductivity of Water.....	5-72
Electrical Conductivity of Aqueous Solutions.....	5-73
Standard KCl Solutions for Calibrating Conductivity Cells.....	5-74
Molar Conductivity of Aqueous HF, HCl, HBr, and HI.....	5-75
Equivalent Conductivity of Electrolytes in Aqueous Solution.....	5-76
Ionic Conductivity and Diffusion at Infinite Dilution.....	5-77
Activity Coefficients of Acids, Bases, and Salts.....	5-80
Mean Activity Coefficients of Electrolytes as a Function of Concentration.....	5-82
Enthalpy of Dilution of Acids.....	5-86
Enthalpy of Solution of Electrolytes.....	5-87
Enthalpy of Hydration of Gases.....	5-88
Chemical Kinetic Data for Stratospheric Modeling.....	5-92

SECTION 6: FLUID PROPERTIES

Thermodynamic Properties of Air.....	6-1
Properties of Water in the Range 0–100°C.....	6-4
Enthalpy of Vaporization of Water.....	6-4
Fixed Point Properties of H ₂ O and D ₂ O.....	6-5
Thermal Conductivity of Saturated H ₂ O and D ₂ O.....	6-5
Standard Density of Water.....	6-6
Properties of Ice and Supercooled Water.....	6-8
Volumetric Properties of Aqueous Sodium Chloride Solutions.....	6-9
Density of D ₂ O.....	6-10
Vapor Pressure of Ice.....	6-10
Vapor Pressure of Water from 0 to 370°C.....	6-11
Boiling Point of Water at Various Pressures.....	6-13
Melting Point of Ice as a Function of Pressure.....	6-13
Properties of Water and Steam as a Function of Temperature and Pressure.....	6-14
Permittivity (Dielectric Constant) of Water as a Function of Temperature and Pressure.....	6-16
Permittivity (Dielectric Constant) of Water at Various Frequencies.....	6-17
Thermophysical Properties of Fluids.....	6-18
Virial Coefficients of Selected Gases.....	6-27
Van der Waals Constants for Gases.....	6-36
Mean Free Path and Related Properties of Gases.....	6-37
Influence of Pressure on Freezing Points.....	6-38
Critical Constants.....	6-39
Sublimation Pressure of Solids.....	6-59
Vapor Pressure.....	6-61
Vapor Pressure of Fluids at Temperatures below 300 K.....	6-91
Vapor Pressure of Saturated Salt Solutions.....	6-99
IUPAC Recommended Data for Vapor Pressure Calibration.....	6-100
Enthalpy of Vaporization.....	6-101
Enthalpy of Fusion.....	6-119
Pressure and Temperature Dependence of Liquid Density.....	6-129
Properties of Cryogenic Fluids.....	6-131
Properties of Liquid Helium.....	6-132
Properties of Refrigerants.....	6-133
Properties of Gas Clathrate Hydrates.....	6-136
Ionic Liquids.....	6-141
Density and Specific Volume of Mercury.....	6-145
Thermal Properties of Mercury.....	6-146
Melting Curve of Mercury.....	6-147
Vapor Pressure of Mercury.....	6-148
Surface Tension of Common Liquids.....	6-149
Surface Tension of Aqueous Mixtures.....	6-153
Permittivity (Dielectric Constant) of Liquids.....	6-154
Permittivity (Dielectric Constant) of Gases.....	6-176
Azeotropic Data for Binary Mixtures.....	6-177
Viscosity of Gases.....	6-196
Viscosity of Liquids.....	6-197
Viscosity of Carbon Dioxide along the Saturation Line.....	6-202
Viscosity and Density of Aqueous Hydroxide Solutions.....	6-203
Viscosity of Liquid Metals.....	6-204

Thermal Conductivity of Gases.....	6-206
Thermal Conductivity of Liquids.....	6-208
Diffusion in Gases.....	6-213
Diffusion of Gases in Water.....	6-215
Diffusion Coefficients in Liquids at Infinite Dilution.....	6-216

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
Thermodynamic Quantities for the Ionization Reactions of Buffers in Water.....	7-19
Biological Buffers.....	7-22
Typical pH Values of Biological Materials and Foods.....	7-23
Chemical Composition of the Human Body.....	7-24
Nutrient Values of Foods.....	7-25

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.....	8-116
Solubility Product Constants.....	8-122
Solubility of Common Salts at Ambient Temperatures.....	8-125
Solubility of Hydrocarbons in Seawater.....	8-126
Solubility of Organic Compounds in Pressurized Hot Water.....	8-128
Solubility Chart.....	8-131
Reduction of Weighings in Air to Vacuo.....	8-133
Volume of One Gram of Water.....	8-134
Properties of Carrier Gases for Gas Chromatography.....	8-135
Solvents for Ultraviolet Spectrophotometry.....	8-136
¹³ C Chemical Shifts of Useful NMR Solvents.....	8-137
Mass Spectral Peaks of Common Organic Solvents.....	8-138

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
Lattice Energies	12-19
The Madelung Constant and Crystal Lattice Energy	12-32
Elastic Constants of Single Crystals.....	12-33
Electrical Resistivity of Pure Metals	12-39
Electrical Resistivity of Selected Alloys	12-41
Electrical Resistivity of Graphite Materials.....	12-44
Permittivity (Dielectric Constant) of Inorganic Solids	12-45
Curie Temperature of Selected Ferroelectric Crystals	12-54
Properties of Antiferroelectric Crystals	12-55
Dielectric Constants of Glasses	12-56
Properties of Superconductors.....	12-57
High-Temperature Superconductors	12-73
Organic Superconductors	12-75

Properties of Semiconductors.....	12-78
Selected Properties of Semiconductor Solid Solutions	12-91
Properties of Organic Semiconductors.....	12-93
Diffusion Data for Semiconductors	12-97
Properties of Magnetic Materials	12-105
Organic Magnets.....	12-114
Electron Inelastic Mean Free Paths	12-117
Electron Work Function of the Elements.....	12-119
Secondary Electron Emission	12-120
Optical Properties of Selected Elements	12-121
Optical Properties of Selected Inorganic and Organic Solids.....	12-146
Elasto-Optic, Electro-Optic, and Magneto-Optic Constants	12-165
Nonlinear Optical Constants	12-179
Phase Diagrams	12-182
Heat Capacity of Selected Solids	12-200
Thermal and Physical Properties of Pure Metals	12-201
Thermal Conductivity of Metals and Semiconductors as a Function of Temperature.....	12-203
Thermal Conductivity of Alloys as a Function of Temperature	12-205
Thermal Conductivity of Crystalline Dielectrics	12-206
Thermal Conductivity of Ceramics and Other Insulating Materials	12-208
Thermal Conductivity of Glasses	12-210
Fermi Energy and Related Properties of Metals.....	12-214
Commercial Metals and Alloys	12-216
Hardness of Minerals and Ceramics	12-217

SECTION 13: POLYMER PROPERTIES

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

SECTION 14: GEOPHYSICS, ASTRONOMY, AND ACOUSTICS

Astronomical Constants	14-1
Properties of the Solar System	14-2
Satellites of the Planets	14-4
Interstellar Molecules.....	14-6
Mass, Dimensions, and Other Parameters of the Earth.....	14-9
Geological Time Scale	14-11
Acceleration Due to Gravity	14-12
Density, Pressure, and Gravity as a Function of Depth within the Earth	14-13
Ocean Pressure as a Function of Depth and Latitude	14-14
Properties of Seawater	14-15
Abundance of Elements in the Earth's Crust and in the Sea	14-17
Solar Spectral Irradiance	14-18
U.S. Standard Atmosphere (1976).....	14-19
Geographical and Seasonal Variation in Solar Radiation	14-25
Weather-Related Scales.....	14-26
Infrared Absorption by the Earth's Atmosphere.....	14-28
Atmospheric Concentration of Carbon Dioxide, 1958–2004	14-29
Mean Temperatures in the United States, 1900–1992.....	14-31
Global Temperature Trend, 1856–2004.....	14-33
Global Warming Potential of Greenhouse Gases	14-34
Atmospheric Electricity	14-36
Speed of Sound in Various Media	14-43
Attenuation and Speed of Sound in Air as a Function of Humidity and Frequency	14-45
Speed of Sound in Dry Air	14-46
Musical Scales	14-47
Characteristics of Human Hearing	14-48

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.....	16-41
Protection against Ionizing Radiation	16-46
Annual Limits on Intakes of Radionuclides.....	16-47
Chemical Carcinogens	16-51

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 t -Distribution	A-91
Percentage Points, Chi-Square Distribution	A-91
Percentage Points, F -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
--------------------	------------