



HANDBOOK OF
CHEMISTRY
and
PHYSICS

DAVID R. LIDE
Editor-in-Chief

90TH

EDITION
2009 - 2010

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

<i>Symbols and Terminology for Physical and Chemical Quantities</i>	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

Properties of Superconductors	12-59
High-Temperature Superconductors	12-75
Organic Superconductors	12-77
Properties of Semiconductors.....	12-80
Selected Properties of Semiconductor Solid Solutions	12-93
Properties of Organic Semiconductors.....	12-95
Diffusion Data for Semiconductors	12-99
Properties of Magnetic Materials	12-107
Organic Magnets	12-116
Electron Inelastic Mean Free Paths	12-119
Electron Work Function of the Elements	12-121
Secondary Electron Emission	12-122
Optical Properties of Selected Elements	12-123
Optical Properties of Selected Inorganic and Organic Solids.....	12-148
Elasto-Optic, Electro-Optic, and Magneto-Optic Constants	12-167
Nonlinear Optical Constants	12-181
Phase Diagrams	12-184
Heat Capacity of Selected Solids	12-202
Thermal and Physical Properties of Pure Metals	12-203
Thermophysical Properties of Stainless Steel 310.....	12-205
Thermal Conductivity of Metals and Semiconductors as a Function of Temperature.....	12-206
Thermal Conductivity of Alloys as a Function of Temperature	12-208
Thermal Conductivity of Crystalline Dielectrics.....	12-209
Thermal Conductivity of Ceramics and Other Insulating Materials.....	12-211
Thermal Conductivity of Glasses	12-213
Thermoelectric Properties of Metals and Semiconductors.....	12-217
Fermi Energy and Related Properties of Metals.....	12-219
Properties of Commercial Metals and Alloys.....	12-221
Hardness of Minerals and Ceramics	12-222

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
Solubility Parameters of Selected Polymers.....	13-70

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.....	14-7
Mass, Dimensions, and Other Parameters of the Earth	14-10
Geological Time Scale	14-12
Acceleration Due to Gravity.....	14-13
Density, Pressure, and Gravity as a Function of Depth Within the Earth.....	14-14
Ocean Pressure as a Function of Depth and Latitude.....	14-15
Properties of Seawater.....	14-16
Abundance of Elements in the Earth's Crust and in the Sea	14-18
Solar Spectral Irradiance	14-19
U.S. Standard Atmosphere (1976).....	14-20
Geographical and Seasonal Variation in Solar Radiation.....	14-26
Major World Earthquakes	14-27
Weather-Related Scales.....	14-31
Infrared Absorption by the Earth's Atmosphere.....	14-33
Atmospheric Concentration of Carbon Dioxide, 1958-2004.....	14-34
Mean Temperatures in the United States, 1900-1992.....	14-36
Global Temperature Trend, 1856-2004.....	14-38
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
--------------------	------------