

TABLE OF CONTENTS

SECTION 1: BASIC CONSTANTS, UNITS, AND CONVERSION FACTORS

| | |
|---|------|
| CODATA Recommended Values of the Fundamental Physical Constants: 2014..... | 1-1 |
| Standard Atomic Weights | 1-10 |
| Atomic Masses and Abundances | 1-12 |
| Electron Configuration and Ionization Energy of Neutral Atoms in the Ground State | 1-16 |
| International Temperature Scale of 1990 (ITS-90)..... | 1-17 |
| International System of Units (SI)..... | 1-18 |
| Units for Magnetic Properties | 1-22 |
| Conversion Factors for Energy Units | 1-23 |
| Descriptive Terms for Solubility | 1-23 |
| Conversion Factors for Pressure Units | 1-24 |
| Conversion Factors for Thermal Conductivity Units..... | 1-24 |
| Conversion Factors for Electrical Resistivity Units..... | 1-24 |
| Values of the Gas Constant in Different Unit Systems | 1-25 |

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 of Inorganic Chemistry | 2-16 |
| Representation of Chemical Structures with the IUPAC International Chemical Identifier (InChI) | 2-22 |
| Scientific Abbreviations, Acronyms, and Symbols | 2-24 |
| Thermodynamic Functions and Relations..... | 2-37 |
| Nobel Laureates in Chemistry and Physics..... | 2-38 |

SECTION 3: PHYSICAL CONSTANTS OF ORGANIC COMPOUNDS

| | |
|--|------|
| Physical Constants of Organic Compounds | 3-1 |
| Diamagnetic Susceptibility of Selected Organic Compounds | 3-56 |

SECTION 4: PROPERTIES OF THE ELEMENTS AND INORGANIC COMPOUNDS

| | |
|---|------|
| The Elements | 4-1 |
| Physical Constants of Inorganic Compounds | 4-39 |
| Physical Properties of the Rare-Earth Metals | 4-51 |
| Melting, Boiling, Triple, and Critical Points of the Elements | 4-58 |
| Heat Capacity of the Elements at 25 °C | 4-61 |
| Vapor Pressure of the Metallic Elements— Equations..... | 4-62 |
| Vapor Pressure of the Metallic Elements— Data | 4-64 |
| Density of Molten Elements and Representative Salts | 4-66 |
| Magnetic Susceptibility of the Elements and Inorganic Compounds | 4-68 |
| Index of Refraction of Inorganic Liquids..... | 4-74 |
| Physical and Optical Properties of Minerals | 4-75 |
| Crystallographic Data on Minerals..... | 4-82 |

SECTION 5: THERMOCHEMISTRY, KINETICS, ELECTROCHEMISTRY, AND SOLUTION CHEMISTRY

| | |
|--|------|
| CODATA Key Values for Thermodynamics | 5-1 |
| Standard Thermodynamic Properties of Chemical Substances..... | 5-3 |
| Thermodynamic Properties as a Function of Temperature | 5-42 |
| Thermodynamic Properties of Aqueous Ions..... | 5-64 |
| Heat of Combustion | 5-66 |
| Energy Content of Fuels | 5-67 |
| Chemical Reaction Rate Constants for Atmospheric Studies | 5-68 |
| Ionization Constant of Water..... | 5-88 |
| Ionization Constant of Normal and Heavy Water | 5-89 |
| Electrical Conductivity of Water..... | 5-89 |
| Electrical Conductivity of Aqueous Solutions..... | 5-90 |
| Standard KCl Solutions for Calibrating Conductivity Cells..... | 5-91 |
| Molar Conductivity of Aqueous HF, HCl, HBr, and HI | 5-92 |
| Equivalent Conductivity of Electrolytes in Aqueous Solution..... | 5-93 |
| Ionic Conductivity and Diffusion at Infinite Dilution | 5-94 |

| | |
|--|-------|
| Electrochemical Series..... | 5-97 |
| Dissociation Constants of Inorganic Acids and Bases..... | 5-104 |
| Dissociation Constants of Organic Acids and Bases..... | 5-105 |
| Activity Coefficients of Acids, Bases, and Salts..... | 5-115 |
| Mean Activity Coefficients of Electrolytes as a Function of Concentration..... | 5-117 |
| Enthalpy of Dilution of Acids..... | 5-122 |
| Enthalpy of Solution of Electrolytes..... | 5-123 |
| pH Scale for Aqueous Solutions..... | 5-124 |
| Buffer Solutions Giving Round Values of pH at 25 °C..... | 5-128 |
| Concentrative Properties of Aqueous Solutions..... | 5-129 |
| Solubility of Selected Gases in Water..... | 5-145 |
| Solubility of Carbon Dioxide in Water at Various Temperatures and Pressures..... | 5-147 |
| Aqueous Solubility and Henry's Law Constants of Organic Compounds..... | 5-148 |
| Aqueous Solubility of Inorganic Compounds at Various Temperatures..... | 5-178 |
| Octanol–Water Partition Coefficients..... | 5-184 |
| Solubility Product Constants of Inorganic Salts..... | 5-188 |
| Solubility of Common Salts at Ambient Temperatures..... | 5-190 |
| Solubility of Hydrocarbons in Seawater..... | 5-191 |
| Solubility of Organic Compounds in Pressurized Hot Water..... | 5-192 |
| Solubility Chart for Inorganic Salts..... | 5-194 |

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..... | 6-14 |
| Permittivity (Dielectric Constant) of Water at Various Frequencies..... | 6-15 |
| Thermophysical Properties of Air..... | 6-16 |
| Thermophysical Properties of Fluids..... | 6-22 |
| Thermophysical Properties of Selected Fluids at Saturation..... | 6-38 |
| Virial Coefficients of Selected Gases..... | 6-47 |
| Mean Free Path and Related Properties of Gases..... | 6-64 |
| Influence of Pressure on Freezing Points..... | 6-65 |
| Critical Constants of Organic Compounds..... | 6-66 |
| Critical Constants of Inorganic Compounds..... | 6-89 |
| Sublimation Pressure of Solids..... | 6-92 |
| Vapor Pressure..... | 6-94 |
| Vapor Pressure of Fluids at Temperatures below 300 K..... | 6-124 |
| Vapor Pressure of Saturated Salt Solutions..... | 6-133 |
| Enthalpy of Vaporization..... | 6-134 |
| Enthalpy of Fusion..... | 6-150 |
| Compressibility and Expansion Coefficients of Liquids..... | 6-160 |
| Temperature and Pressure Dependence of Liquid Density..... | 6-162 |
| Properties of Cryogenic Fluids..... | 6-167 |
| Properties of Liquid Helium..... | 6-168 |
| Properties of Refrigerants..... | 6-169 |
| Properties of Gas Clathrate Hydrates..... | 6-172 |
| Ionic Liquids..... | 6-183 |
| Surface Tension of Common Liquids..... | 6-186 |
| Surface Tension of Aqueous Mixtures..... | 6-190 |
| Surface Active Chemicals (Surfactants)..... | 6-191 |
| Permittivity (Dielectric Constant) of Liquids..... | 6-194 |
| Permittivity (Dielectric Constant) of Gases..... | 6-216 |
| Azeotropic Data for Binary Mixtures..... | 6-217 |
| Viscosity of Gases..... | 6-232 |
| Viscosity of Liquids..... | 6-234 |
| Thermal Conductivity of Gases..... | 6-238 |
| Thermal Conductivity of Liquids..... | 6-240 |
| Diffusion in Gases..... | 6-245 |

| | |
|---|-------|
| Diffusion of Gases in Water..... | 6-247 |
| Diffusion Coefficients in Liquids at Infinite Dilution..... | 6-248 |

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..... | 7-16 |
| Standard Transformed Gibbs Energies of Formation for Biochemical Reactants | 7-18 |
| Apparent Equilibrium Constants for Enzyme-Catalyzed Reactions..... | 7-20 |
| Apparent Equilibrium Thermodynamics of Protein-Ligand Binding Reactions..... | 7-23 |
| Thermodynamic Quantities for the Ionization Reactions of Buffers in Water..... | 7-32 |
| Biological Buffers..... | 7-35 |
| Typical pH Values of Biological Materials and Foods..... | 7-36 |
| Properties and Functions of Common Drugs | 7-37 |
| Chemical Constituents of Human Blood..... | 7-58 |
| Chemical Composition of the Human Body | 7-60 |

SECTION 8: ANALYTICAL CHEMISTRY

| | |
|--|------|
| Abbreviations and Symbols Used in Analytical Chemistry..... | 8-1 |
| Basic Instrumental Techniques of Analytical Chemistry..... | 8-6 |
| Analytical Standardization and Calibration | 8-10 |
| Figures of Merit | 8-16 |
| Mass- and Volume-Based Concentration Units..... | 8-17 |
| Detection of Outliers in Measurements | 8-18 |
| Properties of Carrier Gases for Gas Chromatography | 8-19 |
| Common Symbols Used in Gas and Liquid Chromatographic Schematic Diagrams | 8-20 |
| Stationary Phases for Porous-Layer Open Tubular Columns..... | 8-21 |
| Coolants for Cryotrapping | 8-22 |
| Properties of Common Cross-Linked Silicone Stationary Phases | 8-23 |
| Detectors for Gas Chromatography | 8-24 |
| Varieties of Hyphenated Gas Chromatography with Mass Spectrometry | 8-26 |
| Gas Chromatographic Retention Indices..... | 8-28 |
| Eluotropic Values of Solvents on Octadecylsilane and Octylsilane | 8-30 |
| Instability of HPLC Solvents | 8-31 |
| Detectors for Liquid Chromatography | 8-32 |
| Solvents for Ultraviolet Spectrophotometry | 8-33 |
| Correlation Table for Ultraviolet Active Functionalities..... | 8-34 |
| Middle-Range Infrared Absorption Correlation Charts | 8-37 |
| Common Spurious Infrared Absorption Bands..... | 8-43 |
| Nuclear Spins, Moments, and Other Data Related to NMR Spectroscopy..... | 8-44 |
| Properties of Important NMR Nuclei | 8-47 |
| Proton NMR Absorption of Major Chemical Families | 8-48 |
| Proton NMR Correlation Chart for Major Organic Functional Groups | 8-53 |
| Proton NMR Shifts of Common Organic Liquids | 8-54 |
| Proton Chemical Shifts of Contaminants in Deuterated Solvents | 8-60 |
| ¹³ C-NMR Absorptions of Major Functional Groups..... | 8-61 |
| ¹³ C-NMR Chemical Shifts of Common Organic Solvents | 8-62 |
| ¹⁵ N-NMR Chemical Shifts of Major Chemical Families | 8-63 |
| Natural Abundance of Important Isotopes | 8-65 |
| Common Mass Spectral Fragmentation Patterns of Organic Compound Families..... | 8-66 |
| Common Mass Spectral Fragments Lost..... | 8-68 |
| Major Reference Masses in the Spectrum of Heptacosylfluorotributylamine (Perfluorotributylamine) | 8-69 |
| Mass Spectral Peaks of Common Organic Liquids | 8-70 |
| Common Spurious Signals Observed in Mass Spectrometers | 8-77 |
| Chlorine-Bromine Combination Isotope Intensities in Mass Spectral Patterns | 8-78 |
| Reduction of Weighings in Air to Vacuo | 8-79 |
| Standards for Laboratory Weights..... | 8-80 |
| Indicators for Acids and Bases | 8-82 |

| | |
|---|------|
| Preparation of Special Analytical Reagents | 8-83 |
| Organic Analytical Reagents for the Determination of Inorganic Ions | 8-88 |

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 | 9-55 |
| Atomic Radii of the Elements | 9-56 |
| Dipole Moments | 9-58 |
| Hindered Internal Rotation..... | 9-66 |
| Bond Dissociation Energies | 9-71 |
| Electronegativity | 9-101 |
| Force Constants for Bond Stretching..... | 9-102 |
| Fundamental Vibrational Frequencies of Small Molecules | 9-103 |
| Spectroscopic Constants of Diatomic Molecules | 9-105 |

SECTION 10: ATOMIC, MOLECULAR, AND OPTICAL PHYSICS

| | |
|--|--------|
| Line Spectra of the Elements | 10-1 |
| Persistent Lines of the Neutral Atomic Elements | 10-2 |
| Atomic Transition Probabilities..... | 10-52 |
| Electron Affinities | 10-55 |
| Proton Affinities | 10-76 |
| Polarizabilities of Atoms and Molecules..... | 10-94 |
| Ionization Energies of Atoms and Atomic Ions | 10-110 |
| Ionization Energies of Gas-Phase Molecules..... | 10-114 |
| Attenuation Coefficients for High-Energy Electromagnetic Radiation | 10-131 |
| Classification of Electromagnetic Radiation..... | 10-137 |
| Sensitivity of the Human Eye to Light of Different Wavelengths | 10-139 |
| Blackbody Radiation..... | 10-140 |
| Characteristics of Infrared Detectors | 10-142 |
| Index of Refraction of Inorganic Crystals..... | 10-143 |
| Refractive Index and Transmittance of Representative Glasses | 10-147 |
| Index of Refraction of Water | 10-148 |
| Index of Refraction of Liquids for Calibration Purposes..... | 10-149 |
| Index of Refraction of Air..... | 10-150 |
| Index of Refraction of Gases..... | 10-151 |

SECTION 11: NUCLEAR AND PARTICLE PHYSICS

| | |
|--|-------|
| Summary Tables of Particle Properties | 11-1 |
| Table of the Isotopes..... | 11-2 |
| Neutron Scattering and Absorption Properties | 11-41 |
| Cosmic Radiation | 11-54 |

SECTION 12: PROPERTIES OF SOLIDS

| | |
|---|-------|
| Techniques for Materials Characterization | 12-1 |
| Symmetry of Crystals | 12-6 |
| Ionic Radii in Crystals | 12-12 |
| Polarizabilities of Atoms and Ions in Solids | 12-14 |
| Crystal Structures and Lattice Parameters of Allotropes of the Elements | 12-16 |
| Phase Transitions in the Solid Elements at Atmospheric Pressure | 12-20 |
| The Madelung Constant and Crystal Lattice Energy | 12-22 |
| Elastic Constants of Single Crystals..... | 12-23 |
| Electrical Resistivity Of Pure Metals | 12-28 |
| Electrical Resistivity of Selected Alloys | 12-29 |
| Electrical Resistivity of Graphite Materials | 12-31 |
| Permittivity (Dielectric Constant) of Inorganic Solids | 12-32 |
| Curie Temperature of Selected Ferroelectric Crystals..... | 12-41 |
| Properties of Antiferroelectric Crystals..... | 12-42 |
| Dielectric Constants of Glasses..... | 12-42 |
| Properties of Superconductors | 12-43 |
| High-Temperature Superconductors | 12-58 |

| | |
|--|--------|
| Organic Superconductors | 12-60 |
| Properties of Semiconductors | 12-62 |
| Selected Properties of Semiconductor Solid Solutions | 12-75 |
| Properties of Organic Semiconductors | 12-77 |
| Diffusion Data for Semiconductors | 12-81 |
| Properties of Magnetic Materials..... | 12-89 |
| Organic Magnets | 12-97 |
| Electron Inelastic Mean Free Paths | 12-98 |
| Electron Stopping Powers | 12-100 |
| Electron Work Function of the Elements..... | 12-102 |
| Secondary Electron Emission | 12-103 |
| Optical Properties of Selected Elements | 12-104 |
| Optical Properties of Selected Inorganic and Organic Solids | 12-108 |
| Elasto-Optic, Electro-Optic, and Magneto-Optic Constants | 12-113 |
| Nonlinear Optical Constants | 12-125 |
| Properties of Selected Materials atCryogenic Temperatures | 12-128 |
| Heat Capacity of Selected Solids | 12-134 |
| Thermal and Physical Properties of Pure Metals | 12-135 |
| Thermal Conductivity of Metals and Semiconductors as a Function Of Temperature | 12-137 |
| Thermal Conductivity of Alloys as a Function of Temperature | 12-138 |
| Thermal Conductivity of Crystalline Dielectrics | 12-139 |
| Thermal Conductivity of Ceramics and Other Insulating Materials | 12-141 |
| Thermal Conductivity of Glasses..... | 12-143 |
| Thermoelectric Properties of Metals and Semiconductors..... | 12-146 |
| Fermi Energy and Related Properties of Metals | 12-148 |

SECTION 13: POLYMER PROPERTIES

| | |
|---|-------|
| Abbreviations Used in Polymer Science and Technology | 13-1 |
| Physical Properties of Selected Polymers | 13-3 |
| Nomenclature for Organic Polymers..... | 13-5 |
| Solvents for Common Polymers..... | 13-9 |
| Glass Transition Temperature for Selected Polymers | 13-10 |
| Dielectric Constant of Selected Polymers | 13-17 |
| Pressure–Volume–Temperature Relationships for Polymer Melts..... | 13-18 |
| Vapor Pressures (Solvent Activities) for Binary Polymer Solutions | 13-23 |
| Solubility Parameters of Selected Polymers | 13-28 |

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 | 14-11 |
| Geological Time Scale..... | 14-12 |
| Acceleration Due to Gravity | 14-13 |
| 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 Irradiance at the Earth..... | 14-18 |
| U.S. Standard Atmosphere (1976)..... | 14-19 |
| Geographical and Seasonal Variations in Solar Radiation | 14-25 |
| Major World Earthquakes | 14-26 |
| Infrared Absorption by the Earth’s Atmosphere..... | 14-30 |
| Atmospheric Concentration of Carbon Dioxide, 1959–2017 | 14-31 |
| Global Temperature Trend, 1880–2017 | 14-32 |
| Global Warming Potential of Greenhouse Gases..... | 14-33 |
| Speed of Sound in Various Media | 14-35 |
| Attenuation and Speed of Sound in Air as a Function of Humidity and Frequency | 14-37 |
| Speed of Sound in Dry Air..... | 14-38 |

SECTION 15: PRACTICAL LABORATORY DATA

| | |
|---|-------|
| Standard ITS-90 Thermocouple Tables..... | 15-1 |
| 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 | 15-22 |
| Density of Solvents as a Function of Temperature..... | 15-26 |
| Dependence of Boiling Point on Pressure | 15-27 |
| Ebullioscopic Constants for Calculation of Boiling Point Elevation..... | 15-28 |
| Cryoscopic Constants for Calculation of Freezing Point Depression | 15-29 |
| Freezing Point Lowering by Electrolytes in Aqueous Solution | 15-30 |
| Correction of Barometer Readings to 0 °C Temperature | 15-31 |
| Determination of Relative Humidity from Dew Point..... | 15-32 |
| Determination of Relative Humidity from Wet and Dry Bulb Temperatures | 15-33 |
| Constant Humidity Solutions | 15-34 |
| Standard Salt Solutions for Humidity Calibration..... | 15-35 |
| Low-Temperature Baths for Maintaining Constant Temperature | 15-35 |
| Metals and Alloys with Low-Melting Temperature..... | 15-36 |
| Characteristics of Particles and Particle Dispersoids | 15-37 |
| Density of Various Solids..... | 15-38 |
| Density of Sulfuric Acid..... | 15-39 |
| Density of Ethanol–Water Mixtures..... | 15-40 |
| Dielectric Strength of Insulating Materials..... | 15-41 |
| Coefficient of Friction | 15-46 |

SECTION 16: HEALTH AND SAFETY INFORMATION

| | |
|---|-------|
| Abbreviations Used in the Assessment and Presentation of Laboratory Hazards | 16-1 |
| Incompatible Chemicals..... | 16-2 |
| Explosion (Shock) Hazards..... | 16-4 |
| Water-Reactive Chemicals..... | 16-5 |
| Testing Requirements for Peroxidizable Compounds | 16-5 |
| Tests for the Presence of Peroxides..... | 16-6 |
| Pyrophoric Compounds – Compounds That Are Reactive with Air | 16-6 |
| Flammability Hazards of Common Solvents | 16-7 |
| Selection of Laboratory Gloves..... | 16-9 |
| Selection of Protective Laboratory Garments..... | 16-9 |
| Selection of Respirator Cartridges and Filters | 16-10 |
| Materials Compatible with and Resistant to 72% Perchloric Acid..... | 16-11 |
| Protective Clothing Levels..... | 16-12 |
| Chemical Fume Hoods and Biological Safety Cabinets..... | 16-13 |
| Gas Cylinder Safety and Stamped Markings | 16-15 |
| Flammability of Chemical Substances | 16-16 |
| Nanomaterial Safety Guidelines | 16-33 |
| Threshold Limits for Airborne Contaminants | 16-35 |
| Laser Hazards in the Laboratory | 16-48 |
| General Characteristics of Ionizing Radiation for the Purpose of Practical Application of Radiation Protection..... | 16-50 |
| Radiation Safety Units..... | 16-51 |
| Relative Dose Ranges from Ionizing Radiation..... | 16-53 |
| Annual Limits on Intakes of Radionuclides | 16-55 |
| Chemical Carcinogens | 16-58 |

APPENDIX A: SOURCES OF PHYSICAL AND CHEMICAL DATA A-1**INDEX** I-1