


CONTENTS

PREFACE 25



1 Introduction: Matter, Energy, and Measurement 46

- 1.1 The Study of Chemistry 48**
The Atomic and Molecular Perspective of Chemistry 48
Why Study Chemistry? 49
 - 1.2 Classifications of Matter 51**
States of Matter 51 Pure Substances 51
Elements 52 Compounds 53 Mixtures 54
 - 1.3 Properties of Matter 56**
Physical and Chemical Changes 56 Separation of
Mixtures 57
 - 1.4 The Nature of Energy 59**
Kinetic Energy and Potential Energy 59
 - 1.5 Units of Measurement 61**
SI Units 61 Length and Mass 63
Temperature 63 Derived SI Units 64 Volume 64
Density 65 Units of Energy 65
 - 1.6 Uncertainty in Measurement 68**
Precision and Accuracy 68 Significant Figures 69
Significant Figures in Calculations 70
 - 1.7 Dimensional Analysis 72**
Conversion Factors 72 Using Two or More Conversion
Factors 74 Conversions Involving Volume 75
- Chapter Summary and Key Terms 77**
Learning Outcomes 78 Key Equations 78
Exercises 79 Additional Exercises 83

Chemistry Put to Work Chemistry and the
Chemical Industry 50

A Closer Look The Scientific Method 61

Chemistry Put to Work Chemistry in the News 67

Strategies for Success Estimating Answers 74

Strategies for Success The Importance of
Practice 76

Strategies for Success The Features of This
Book 76



2 Atoms, Molecules, and Ions 86

- 2.1 The Atomic Theory of Matter 88**
 - 2.2 The Discovery of Atomic Structure 89**
Cathode Rays and Electrons 89 Radioactivity 91
The Nuclear Model of the Atom 92
 - 2.3 The Modern View of Atomic Structure 93**
Atomic Numbers, Mass Numbers, and Isotopes 95
 - 2.4 Atomic Weights 97**
The Atomic Mass Scale 97 Atomic Weight 97
 - 2.5 The Periodic Table 99**
 - 2.6 Molecules and Molecular Compounds 102**
Molecules and Chemical Formulas 102 Molecular and
Empirical Formulas 102 Picturing Molecules 103
 - 2.7 Ions and Ionic Compounds 104**
Predicting Ionic Charges 105 Ionic Compounds 106
 - 2.8 Naming Inorganic Compounds 109**
Names and Formulas of Ionic Compounds 109
Names and Formulas of Acids 113 Names and
Formulas of Binary Molecular Compounds 114
 - 2.9 Some Simple Organic Compounds 115**
Alkanes 115 Some Derivatives of Alkanes 116
- Chapter Summary and Key Terms 118**
Learning Outcomes 118 Key Equations 119
Exercises 119 Additional Exercises 124

A Closer Look Basic Forces 95

A Closer Look The Mass Spectrometer 98

A Closer Look What Are Coins Made Of? 101

Chemistry and Life Elements Required by Living
Organisms 108

Strategies for Success How to Take a Test 117



3 Chemical Reactions and Reaction Stoichiometry 126

3.1 Chemical Equations 128

Balancing Equations 128 A Step-by-Step Example of Balancing a Chemical Equation 129 Indicating the States of Reactants and Products 131

3.2 Simple Patterns of Chemical Reactivity 132

Combination and Decomposition Reactions 132 Combustion Reactions 134

3.3 Formula Weights 134

Formula and Molecular Weights 135 Percentage Composition from Chemical Formulas 136

3.4 Avogadro's Number and the Mole 137

Molar Mass 138 Interconverting Masses and Moles 140 Interconverting Masses and Numbers of Particles 141

3.5 Empirical Formulas from Analyses 142

Molecular Formulas from Empirical Formulas 144 Combustion Analysis 145

3.6 Quantitative Information from Balanced Equations 146

3.7 Limiting Reactants 150

Theoretical and Percent Yields 152

Chapter Summary and Key Terms 154

Learning Outcomes 154 Key Equations 154

Exercises 155 Additional Exercises 161

Integrative Exercises 162 Design an Experiment 163

Strategies for Success Problem Solving 136

Chemistry and Life Glucose Monitoring 140

Strategies for Success Design an Experiment 153



4 Reactions in Aqueous Solution 164

4.1 General Properties of Aqueous Solutions 166

Electrolytes and Nonelectrolytes 166

How Compounds Dissolve in Water 167 Strong and Weak Electrolytes 168

4.2 Precipitation Reactions 170

Solubility Guidelines for Ionic Compounds 170 Exchange (Metathesis) Reactions 171 Ionic Equations and Spectator Ions 173

4.3 Acids, Bases, and Neutralization Reactions 174

Acids 174 Bases 175 Strong and Weak Acids and Bases 176 Identifying Strong and Weak Electrolytes 176 Neutralization Reactions and Salts 178 Neutralization Reactions with Gas Formation 180

4.4 Oxidation-Reduction Reactions 181

Oxidation and Reduction 181 Oxidation Numbers 182 Oxidation of Metals by Acids and Salts 184 The Activity Series 185

4.5 Concentrations of Solutions 188

Molarity 188 Expressing the Concentration of an Electrolyte 189 Interconverting Molarity, Moles, and Volume 190 Dilution 191

4.6 Solution Stoichiometry and Chemical Analysis 192

Titration 194

Chapter Summary and Key Terms 197

Learning Outcomes 198 Key Equations 198

Exercises 198 Additional Exercises 203

Integrative Exercises 204 Design an Experiment 205

Chemistry Put to Work Antacids 180

Strategies for Success Analyzing Chemical Reactions 188



5 Thermochemistry 206

5.1 The Nature of Chemical Energy 208

5.2 The First Law of Thermodynamics 210

System and Surroundings 210 Internal Energy 211 Relating ΔE to Heat and Work 212 Endothermic and Exothermic Processes 214 State Functions 214

5.3 Enthalpy 216

Pressure-Volume Work 216 Enthalpy Change 218

5.4 Enthalpies of Reaction 220

5.5 Calorimetry 222

Heat Capacity and Specific Heat 223

Constant-Pressure Calorimetry 224

Bomb Calorimetry (Constant-Volume Calorimetry) 226

- 5.6 Hess's Law** 227
- 5.7 Enthalpies of Formation** 230
Using Enthalpies of Formation to Calculate Enthalpies of Reaction 232
- 5.8 Bond Enthalpies** 234
Bond Enthalpies and the Enthalpies of Reactions 236
- 5.9 Foods and Fuels** 238
Foods 238 Fuels 240 Other Energy Sources 241
Chapter Summary and Key Terms 244
Learning Outcomes 245 **Key Equations** 245
Exercises 246 **Additional Exercises** 252
Integrative Exercises 254 **Design an Experiment** 255
-
- A Closer Look** Energy, Enthalpy, and *P-V* Work 219
- A Closer Look** Using Enthalpy as a Guide 222
- Chemistry and Life** The Regulation of Body Temperature 227
- Chemistry Put to Work** The Scientific and Political Challenges of Biofuels 242

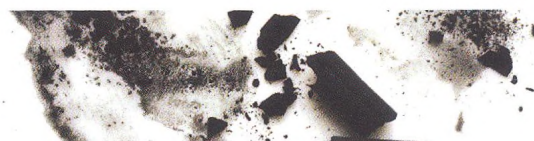


6 Electronic Structure of Atoms 256

- 6.1 The Wave Nature of Light** 258
- 6.2 Quantized Energy and Photons** 260
Hot Objects and the Quantization of Energy 260
The Photoelectric Effect and Photons 261
- 6.3 Line Spectra and the Bohr Model** 263
Line Spectra 263 Bohr's Model 264 The Energy States of the Hydrogen Atom 265 Limitations of the Bohr Model 268
- 6.4 The Wave Behavior of Matter** 268
The Uncertainty Principle 270
- 6.5 Quantum Mechanics and Atomic Orbitals** 271
Orbitals and Quantum Numbers 272
- 6.6 Representations of Orbitals** 275
The *s* Orbitals 275 The *p* Orbitals 277 The *d* and *f* Orbitals 278
- 6.7 Many-Electron Atoms** 278
Orbitals and Their Energies 279 Electron Spin and the Pauli Exclusion Principle 280
- 6.8 Electron Configurations** 280
Hund's Rule 282 Condensed Electron Configurations 284 Transition Metals 284 The Lanthanides and Actinides 285

6.9 Electron Configurations and the Periodic Table 285

- Anomalous Electron Configurations 288
Chapter Summary and Key Terms 290
Learning Outcomes 291 **Key Equations** 292
Exercises 292 **Additional Exercises** 297
Integrative Exercises 299 **Design an Experiment** 299
-
- A Closer Look** Measurement and the Uncertainty Principle 270
- A Closer Look** Thought Experiments and Schrödinger's Cat 273
- A Closer Look** Probability Density and Radial Probability Functions 277
- Chemistry and Life** Nuclear Spin and Magnetic Resonance Imaging 281



7 Periodic Properties of the Elements 300

- 7.1 Development of the Periodic Table** 302
- 7.2 Effective Nuclear Charge** 303
- 7.3 Sizes of Atoms and Ions** 306
Periodic Trends in Atomic Radii 308 Periodic Trends in Ionic Radii 308
- 7.4 Ionization Energy** 312
Variations in Successive Ionization Energies 312
Periodic Trends in First Ionization Energies 313
Electron Configurations of Ions 314
- 7.5 Electron Affinity** 316
Periodic Trends in Electron Affinity 317
- 7.6 Metals, Nonmetals, and Metalloids** 317
Metals 318 Nonmetals 320 Metalloids 322
- 7.7 Trends for Group 1A and Group 2A Metals** 322
Group 1A: The Alkali Metals 322 Group 2A: The Alkaline Earth Metals 326
- 7.8 Trends for Selected Nonmetals** 327
Hydrogen 327 Group 6A: The Oxygen Group 328
Group 7A: The Halogens 329 Group 8A: The Noble Gases 331
- Chapter Summary and Key Terms** 332
Learning Outcomes 333 **Key Equations** 333
Exercises 334 **Additional Exercises** 338

Integrative Exercises 340 Design an Experiment 341

A Closer Look Effective Nuclear Charge 306

Chemistry Put to Work Ionic Size and Lithium-Ion Batteries 311

Chemistry and Life The Improbable Development of Lithium Drugs 325



8 Basic Concepts of Chemical Bonding 342

8.1 Lewis Symbols and the Octet Rule 344

The Octet Rule 344

8.2 Ionic Bonding 345

Energetics of Ionic Bond Formation 346 Electron Configurations of Ions of the *s*- and *p*-Block Elements 348 Transition Metal Ions 349

8.3 Covalent Bonding 350

Lewis Structures 351 Multiple Bonds 352

8.4 Bond Polarity and Electronegativity 353

Electronegativity 353 Electronegativity and Bond Polarity 354 Dipole Moments 355 Comparing Ionic and Covalent Bonding 358

8.5 Drawing Lewis Structures 359

Formal Charge and Alternative Lewis Structures 361

8.6 Resonance Structures 363

Resonance in Benzene 365

8.7 Exceptions to the Octet Rule 366

Odd Number of Electrons 367 Less Than an Octet of Valence Electrons 367 More Than an Octet of Valence Electrons 368

8.8 Strengths and Lengths of Covalent Bonds 369

Chapter Summary and Key Terms 372

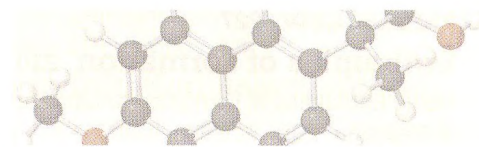
Learning Outcomes 373 Key Equations 373

Exercises 373 Additional Exercises 378

Integrative Exercises 379 Design an Experiment 381

A Closer Look Calculation of Lattice Energies: The Born–Haber Cycle 349

A Closer Look Oxidation Numbers, Formal Charges, and Actual Partial Charges 363



9 Molecular Geometry and Bonding Theories 382

9.1 Molecular Shapes 384

9.2 The VSEPR Model 386

Applying the VSEPR Model to Determine Molecular Shapes 387 Effect of Nonbonding Electrons and Multiple Bonds on Bond Angles 391 Molecules with Expanded Valence Shells 391 Shapes of Larger Molecules 394

9.3 Molecular Shape and Molecular Polarity 396

9.4 Covalent Bonding and Orbital Overlap 398

9.5 Hybrid Orbitals 399

sp Hybrid Orbitals 399 *sp*² and *sp*³ Hybrid Orbitals 401 Hypervalent Molecules 403 Hybrid Orbital Summary 403

9.6 Multiple Bonds 405

Resonance Structures, Delocalization, and π Bonding 409 General Conclusions about σ and π Bonding 411

9.7 Molecular Orbitals 412

Molecular Orbitals of the Hydrogen Molecule 412 Bond Order 414

9.8 Bonding in Period 2 Diatomic Molecules 415

Molecular Orbitals for Li_2 and Be_2 416 Molecular Orbitals from *2p* Atomic Orbitals 417 Electron Configurations for B_2 through Ne_2 420 Electron Configurations and Molecular Properties 421 Heteronuclear Diatomic Molecules 424

Chapter Summary and Key Terms 426

Learning Outcomes 427 Key Equations 428

Exercises 428 Additional Exercises 433

Integrative Exercises 436 Design an Experiment 437

Chemistry and Life The Chemistry of Vision 411

A Closer Look Phases in Atomic and Molecular Orbitals 418

Chemistry Put to Work Orbitals and Energy 425



10 Gases 438

- 10.1 Characteristics of Gases** 440
- 10.2 Pressure** 441
Atmospheric Pressure and the Barometer 441
- 10.3 The Gas Laws** 444
The Pressure–Volume Relationship: Boyle’s Law 444
The Temperature–Volume Relationship: Charles’s Law 445
The Quantity–Volume Relationship: Avogadro’s Law 446
- 10.4 The Ideal-Gas Equation** 447
Relating the Ideal-Gas Equation and the Gas Laws 450
- 10.5 Further Applications of the Ideal-Gas Equation** 451
Gas Densities and Molar Mass 451
Volumes of Gases in Chemical Reactions 453
- 10.6 Gas Mixtures and Partial Pressures** 454
Partial Pressures and Mole Fractions 455
- 10.7 The Kinetic-Molecular Theory of Gases** 456
Distributions of Molecular Speed 457
Application of Kinetic-Molecular Theory to the Gas Laws 458
- 10.8 Molecular Effusion and Diffusion** 459
Graham’s Law of Effusion 460
Diffusion and Mean Free Path 461
- 10.9 Real Gases: Deviations from Ideal Behavior** 463
The van der Waals Equation 465
- Chapter Summary and Key Terms** 467
Learning Outcomes 468
Key Equations 468
Exercises 468
Additional Exercises 474
Integrative Exercises 476
Design an Experiment 477

Strategies for Success Calculations Involving Many Variables 449

A Closer Look The Ideal-Gas Equation 458

Chemistry Put to Work Gas Separations 462



11 Liquids and Intermolecular Forces 478

- 11.1 A Molecular Comparison of Gases, Liquids, and Solids** 480
- 11.2 Intermolecular Forces** 482
Dispersion Forces 483
Dipole–Dipole Interactions 484
Hydrogen Bonding 485
Ion–Dipole Forces 488
Comparing Intermolecular Forces 488
- 11.3 Select Properties of Liquids** 489
Viscosity 490
Surface Tension 491
Capillary Action 492
- 11.4 Phase Changes** 493
Energy Changes Accompany Phase Changes 493
Heating Curves 494
Critical Temperature and Pressure 495
- 11.5 Vapor Pressure** 497
Volatility, Vapor Pressure, and Temperature 498
Vapor Pressure and Boiling Point 499
- 11.6 Phase Diagrams** 500
The Phase Diagrams of H₂O and CO₂ 501
- 11.7 Liquid Crystals** 503
Types of Liquid Crystals 503
- Chapter Summary and Key Terms** 506
Learning Outcomes 507
Exercises 507
Additional Exercises 512
Integrative Exercises 514
Design an Experiment 515

Chemistry Put to Work Ionic Liquids 491

A Closer Look The Clausius–Clapeyron Equation 499



12 Solids and Modern Materials 516

- 12.1 Classification of Solids** 518
- 12.2 Structures of Solids** 519
Crystalline and Amorphous Solids 519
Unit Cells and Crystal Lattices 519
Filling the Unit Cell 521

12.3 Metallic Solids 522

The Structures of Metallic Solids 523 Close Packing 524 Alloys 527

12.4 Metallic Bonding 530

Electron-Sea Model 530 Molecular Orbital Model 531

12.5 Ionic Solids 533

Structures of Ionic Solids 534

12.6 Molecular Solids 538**12.7 Covalent-Network Solids 538**

Semiconductors 539 Semiconductor Doping 541

12.8 Polymers 544

Making Polymers 545 Structure and Physical Properties of Polymers 548

12.9 Nanomaterials 550

Semiconductors on the Nanoscale 550 Metals on the Nanoscale 551 Carbon on the Nanoscale 553

Chapter Summary and Key Terms 556

Learning Outcomes 557 Key Equations 557

Exercises 558 Additional Exercises 565

Integrative Exercises 566 Design an Experiment 567

A Closer Look X-ray Diffraction 522

Chemistry Put to Work Alloys of Gold 529

Chemistry Put to Work Solid-State Lighting 543

Chemistry Put to Work Modern Materials in the Automobile 547

Chemistry Put to Work Microporous and Mesoporous Materials 552



13 Properties of Solutions 568

13.1 The Solution Process 570

The Natural Tendency toward Mixing 570 The Effect of Intermolecular Forces on Solution Formation 571 Energetics of Solution Formation 572 Solution Formation and Chemical Reactions 574

13.2 Saturated Solutions and Solubility 574**13.3 Factors Affecting Solubility 576**

Solute-Solvent Interactions 576 Pressure Effects 578 Temperature Effects 581

13.4 Expressing Solution Concentration 582

Mass Percentage, ppm, and ppb 582 Mole Fraction, Molarity, and Molality 583 Converting Concentration Units 584

13.5 Colligative Properties 586

Vapor-Pressure Lowering 586 Boiling-Point Elevation 588 Freezing-Point Depression 589 Osmosis 591 Determination of Molar Mass from Colligative Properties 594

13.6 Colloids 596

Hydrophilic and Hydrophobic Colloids 597 Colloidal Motion in Liquids 599

Chapter Summary and Key Terms 600

Learning Outcomes 601 Key Equations 602

Exercises 602 Additional Exercises 608

Integrative Exercises 609 Design an Experiment 611

Chemistry and Life Fat-Soluble and Water-Soluble Vitamins 577

Chemistry and Life Blood Gases and Deep-Sea Diving 581

A Closer Look Ideal Solutions with Two or More Volatile Components 588

A Closer Look The van't Hoff Factor 595

Chemistry and Life Sickle-Cell Anemia 599



14 Chemical Kinetics 612

14.1 Factors That Affect Reaction Rates 614**14.2 Reaction Rates 615**

Change of Rate with Time 616 Instantaneous Rate 617 Reaction Rates and Stoichiometry 618

14.3 Concentration and Rate Laws 619

Reaction Orders: The Exponents in the Rate Law 621 Magnitudes and Units of Rate Constants 623 Using Initial Rates to Determine Rate Laws 624

14.4 The Change of Concentration with Time 625

First-Order Reactions 625 Second-Order Reactions 627 Zero-Order Reactions 629 Half-Life 629

14.5 Temperature and Rate 631

The Collision Model 631 The Orientation Factor 632 Activation Energy 632 The Arrhenius Equation 634 Determining the Activation Energy 635

14.6 Reaction Mechanisms 637

Elementary Reactions 637 Multistep Mechanisms 637 Rate Laws for Elementary Reactions 639 The Rate-Determining Step for a Multistep Mechanism 640 Mechanisms with a Slow Initial Step 641 Mechanisms with a Fast Initial Step 642

14.7 Catalysis 644

Homogeneous Catalysis 644 Heterogeneous Catalysis 646 Enzymes 647

Chapter Summary and Key Terms 652
Learning Outcomes 652 Key Equations 653
Exercises 653 Additional Exercises 661
Integrative Exercises 664 Design an Experiment 665

A Closer Look Using Spectroscopic Methods to Measure Reaction Rates: Beer's Law 620

Chemistry Put to Work Methyl Bromide in the Atmosphere 630

Chemistry Put to Work Catalytic Converters 648

Chemistry and Life Nitrogen Fixation and Nitrogenase 650

**15 Chemical Equilibrium 666****15.1 The Concept of Equilibrium 669****15.2 The Equilibrium Constant 671**

Evaluating K_c 673 Equilibrium Constants in Terms of Pressure, K_p 674 Equilibrium Constants and Units 675

15.3 Understanding and Working with Equilibrium Constants 676

The Magnitude of Equilibrium Constants 676
 The Direction of the Chemical Equation and K 677
 Relating Chemical Equation Stoichiometry and Equilibrium Constants 678

15.4 Heterogeneous Equilibria 680**15.5 Calculating Equilibrium Constants 682****15.6 Applications of Equilibrium Constants 684**

Predicting the Direction of Reaction 685 Calculating Equilibrium Concentrations 686

15.7 Le Châtelier's Principle 688

Change in Reactant or Product Concentration 690
 Effects of Volume and Pressure Changes 691 Effect of Temperature Changes 693 The Effect of Catalysts 695

Chapter Summary and Key Terms 698
Learning Outcomes 699 Key Equations 699
Exercises 700 Additional Exercises 705
Integrative Exercises 706 Design an Experiment 707

Chemistry Put to Work The Haber Process 672

A Closer Look Temperature Changes and Le Châtelier's Principle 695

Chemistry Put to Work Controlling Nitric Oxide Emissions 698

**16 Acid–Base Equilibria 708****16.1 Arrhenius Acids and Bases 710****16.2 Brønsted–Lowry Acids and Bases 711**

The H^+ Ion in Water 711 Proton-Transfer Reactions 711 Conjugate Acid–Base Pairs 712 Relative Strengths of Acids and Bases 714

16.3 The Autoionization of Water 716

The Ion Product of Water 716

16.4 The pH Scale 718

pOH and Other “p” Scales 720 Measuring pH 721

16.5 Strong Acids and Bases 722

Strong Acids 722 Strong Bases 723

16.6 Weak Acids 724

Calculating K_a from pH 725 Percent Ionization 726 Using K_a to Calculate pH 727 Polyprotic Acids 731

16.7 Weak Bases 734

Types of Weak Bases 734

16.8 Relationship Between K_a and K_b 737**16.9 Acid–Base Properties of Salt Solutions 740**

An Anion's Ability to React with Water 740
 A Cation's Ability to React with Water 740
 Combined Effect of Cation and Anion in Solution 741

16.10 Acid–Base Behavior and Chemical Structure 743

Factors That Affect Acid Strength 743 Binary Acids 744 Oxyacids 745 Carboxylic Acids 747

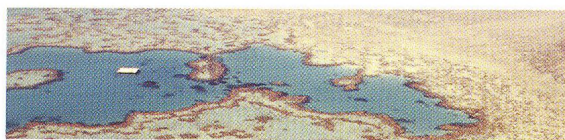
16.11 Lewis Acids and Bases 748

Chapter Summary and Key Terms 751
Learning Outcomes 751 Key Equations 752
Exercises 752 Additional Exercises 757
Integrative Exercises 759 Design an Experiment 759

A Closer Look Polyprotic Acids 733

Chemistry Put to Work Amines and Amine Hydrochlorides 739

Chemistry and Life The Amphiprotic Behavior of Amino Acids 747



17 Additional Aspects of Aqueous Equilibria 760

17.1 The Common-Ion Effect 762

17.2 Buffers 765

Composition and Action of Buffers 765 Calculating the pH of a Buffer 767 Buffer Capacity and pH Range 770 Addition of Strong Acids or Bases to Buffers 770

17.3 Acid–Base Titrations 773

Strong Acid–Strong Base Titrations 774 Weak Acid–Strong Base Titrations 776 Titrating with an Acid–Base Indicator 780 Titrations of Polyprotic Acids 782

17.4 Solubility Equilibria 783

The Solubility-Product Constant, K_{sp} 784 Solubility and K_{sp} 785

17.5 Factors That Affect Solubility 787

The Common-Ion Effect 787 Solubility and pH 788 Formation of Complex Ions 790 Amphoterism 793

17.6 Precipitation and Separation of Ions 795

Selective Precipitation of Ions 796

17.7 Qualitative Analysis for Metallic Elements 797

Chapter Summary and Key Terms 800
Learning Outcomes 801 Key Equations 801
Exercises 802 Additional Exercises 807
Integrative Exercises 808 Design an Experiment 809

Chemistry and Life Blood as a Buffered Solution 773

A Closer Look Limitations of Solubility Products 787

Chemistry and Life Tooth Decay and Fluoridation 790

A Closer Look Lead Contamination in Drinking Water 794



18 Chemistry of the Environment 810

18.1 Earth's Atmosphere 812

Composition of the Atmosphere 813

Photochemical Reactions in the Atmosphere 814
Ozone in the Stratosphere 817

18.2 Human Activities and Earth's Atmosphere 818

The Ozone Layer and Its Depletion 818 Sulfur Compounds and Acid Rain 820 Nitrogen Oxides and Photochemical Smog 823 Greenhouse Gases: Water Vapor, Carbon Dioxide, and Climate 824

18.3 Earth's Water 828

The Global Water Cycle 828 Salt Water: Earth's Oceans and Seas 829 Freshwater and Groundwater 830

18.4 Human Activities and Water Quality 831

Dissolved Oxygen and Water Quality 832 Water Purification: Desalination 832 Water Purification: Municipal Treatment 833

18.5 Green Chemistry 836

Supercritical Solvents 838 Greener Reagents and Processes 838

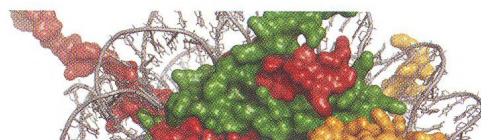
Chapter Summary and Key Terms 841
Learning Outcomes 841 Exercises 842
Additional Exercises 847 Integrative Exercises 848 Design an Experiment 849

A Closer Look Other Greenhouse Gases 827

A Closer Look The Ogallala Aquifer—A Shrinking Resource 831

A Closer Look Fracking and Water Quality 834

Chemistry and Life Ocean Acidification 836



19 Chemical Thermodynamics 850

19.1 Spontaneous Processes 852

Seeking a Criterion for Spontaneity 853 Reversible and Irreversible Processes 854

19.2 Entropy and the Second Law of Thermodynamics 856

The Relationship between Entropy and Heat 856 ΔS for Phase Changes 857 The Second Law of Thermodynamics 858

19.3 The Molecular Interpretation of Entropy and the Third Law of Thermodynamics 859

Expansion of a Gas at the Molecular Level 859 Boltzmann's Equation and Microstates 860 Molecular Motions and Energy 862 Making Qualitative Predictions about ΔS 863 The Third Law of Thermodynamics 865

19.4 Entropy Changes in Chemical Reactions 866

Temperature Variation of Entropy 866 Standard Molar Entropies 867 Calculating the Standard Entropy Change for a Reaction 868 Entropy Changes in the Surroundings 868

19.5 Gibbs Free Energy 869

Standard Free Energy of Formation 872

19.6 Free Energy and Temperature 874

19.7 Free Energy and the Equilibrium Constant 876

Free Energy under Nonstandard Conditions 876 Relationship between ΔG° and K 878

Chapter Summary and Key Terms 880

Learning Outcomes 881 Key Equations 881

Exercises 882 Additional Exercises 888

Integrative Exercises 890 Design an Experiment 891

A Closer Look The Entropy Change When a Gas Expands Isothermally 858

Chemistry and Life Entropy and Human Society 866

A Closer Look What's "Free" About Free Energy? 873

Chemistry and Life Driving Nonspontaneous Reactions: Coupling Reactions 879



20 Electrochemistry 892

20.1 Oxidation States and Oxidation-Reduction Reactions 894

20.2 Balancing Redox Equations 896

Half-Reactions 896 Balancing Equations by the Method of Half-Reactions 896 Balancing Equations for Reactions Occurring in Basic Solution 899

20.3 Voltaic Cells 901

20.4 Cell Potentials under Standard Conditions 904

Standard Reduction Potentials 905 Strengths of Oxidizing and Reducing Agents 910

20.5 Free Energy and Redox Reactions 912

Emf, Free Energy, and the Equilibrium Constant 913

20.6 Cell Potentials under Nonstandard Conditions 915

The Nernst Equation 916 Concentration Cells 918

20.7 Batteries and Fuel Cells 921

Lead-Acid Battery 922 Alkaline Battery 922 Nickel-Cadmium and Nickel-Metal Hydride Batteries 922 Lithium-Ion Batteries 923 Hydrogen Fuel Cells 923

20.8 Corrosion 926

Corrosion of Iron (Rusting) 926 Preventing Corrosion of Iron 927

20.9 Electrolysis 928

Quantitative Aspects of Electrolysis 930

Chapter Summary and Key Terms 933

Learning Outcomes 934 Key Equations 934

Exercises 934 Additional Exercises 941

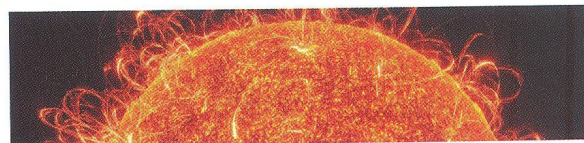
Integrative Exercises 942 Design an Experiment 943

A Closer Look Electrical Work 915

Chemistry and Life Heartbeats and Electrocardiography 920

Chemistry Put to Work Batteries for Hybrid and Electric Vehicles 924

Chemistry Put to Work Electrometallurgy of Aluminum 931



21 Nuclear Chemistry 944

21.1 Radioactivity and Nuclear Equations 946

Nuclear Equations 946 Types of Radioactive Decay 947

21.2 Patterns of Nuclear Stability 949

Neutron-to-Proton Ratio 949 Radioactive Decay Chains 951 Further Observations 952

21.3 Nuclear Transmutations 953

Accelerating Charged Particles 954 Reactions Involving Neutrons 955 Transuranium Elements 955

21.4 Rates of Radioactive Decay 956

Radiometric Dating 957 Calculations Based on Half-Life 959

21.5 Detection of Radioactivity 961

Radiotracers 961

21.6 Energy Changes in Nuclear Reactions 963

Nuclear Binding Energies 965

21.7 Nuclear Power: Fission 966

Nuclear Reactors 969 Nuclear Waste 971

21.8 Nuclear Power: Fusion 972**21.9 Radiation in the Environment and Living Systems 974**

Radiation Doses 975

Chapter Summary and Key Terms 977

Learning Outcomes 978 Key Equations 979

Exercises 979 Additional Exercises 983

Integrative Exercises 984 Design an Experiment 985

Chemistry and Life Medical Applications of Radiotracers 962**A Closer Look** The Dawning of the Nuclear Age 969**A Closer Look** Nuclear Synthesis of the Elements 973**Chemistry and Life** Radiation Therapy 976**22 Chemistry of the Nonmetals 986****22.1 Periodic Trends and Chemical Reactions 988**

Chemical Reactions 989

22.2 Hydrogen 990

Isotopes of Hydrogen 990 Properties of Hydrogen 991 Production of Hydrogen 992 Uses of Hydrogen 993 Binary Hydrogen Compounds 993

22.3 Group 18: The Noble Gases 994

Noble-Gas Compounds 995

22.4 Group 17: The Halogens 996

Properties and Production of the Halogens 996 Uses of the Halogens 998 The Hydrogen Halides 998 Interhalogen Compounds 998 Oxyacids and Oxyanions 998

22.5 Oxygen 999

Properties of Oxygen 999 Production of Oxygen 1000 Uses of Oxygen 1000 Ozone 1000 Oxides 1000 Peroxides and Superoxides 1002

22.6 The Other Group 16 Elements: S, Se, Te, and Po 1002

Occurrence and Production of S, Se, and Te 1003 Properties and Uses of Sulfur, Selenium, and Tellurium 1003 Sulfides 1003 Oxides, Oxyacids, and Oxyanions of Sulfur 1004

22.7 Nitrogen 1006

Properties of Nitrogen 1006 Production and Uses of Nitrogen 1006 Hydrogen Compounds of Nitrogen 1006 Oxides and Oxyacids of Nitrogen 1007

22.8 The Other Group 15 Elements: P, As, Sb, and Bi 1009

Occurrence, Isolation, and Properties of Phosphorus 1010 Phosphorus Halides 1010 Oxy Compounds of Phosphorus 1011

22.9 Carbon 1013

Elemental Forms of Carbon 1013 Oxides of Carbon 1014 Carbonic Acid and Carbonates 1015 Carbides 1016

22.10 The Other Group 14 Elements: Si, Ge, Sn, and Pb 1016

General Characteristics of the Group 14 Elements 1016 Occurrence and Preparation of Silicon 1017 Silicates 1017 Glass 1019 Silicones 1020

22.11 Boron 1020

Chapter Summary and Key Terms 1022 Learning Outcomes 1023 Exercises 1023 Additional Exercises 1027 Integrative Exercises 1028 Design an Experiment 1029

A Closer Look The Hydrogen Economy 992**Chemistry and Life** Nitroglycerin, Nitric Oxide, and Heart Disease 1009**Chemistry and Life** Arsenic in Drinking Water 1012**Chemistry Put to Work** Carbon Fibers and Composites 1014**23 Transition Metals and Coordination Chemistry 1030****23.1 The Transition Metals 1032**

Physical Properties 1033 Electron Configurations and Oxidation States 1034 Magnetism 1035

23.2 Transition-Metal Complexes 1036

The Development of Coordination Chemistry: Werner's Theory 1037 The Metal-Ligand Bond 1039 Charges, Coordination Numbers, and Geometries 1040

23.3 Common Ligands in Coordination Chemistry 1041

Metals and Chelates in Living Systems 1043

23.4 Nomenclature and Isomerism in Coordination Chemistry 1047

Isomerism 1049 Structural Isomerism 1049 Stereoisomerism 1050

23.5 Color and Magnetism in Coordination Chemistry 1053

Color 1053 Magnetism of Coordination Compounds 1055

23.6 Crystal-Field Theory 1055

Electron Configurations in Octahedral Complexes 1059 Tetrahedral and Square-Planar Complexes 1061

Chapter Summary and Key Terms 1065

Learning Outcomes 1065 Exercises 1066

Additional Exercises 1070 Integrative

Exercises 1072 Design an Experiment 1073

A Closer Look Entropy and the Chelate Effect 1045

Chemistry and Life The Battle for Iron in Living Systems 1046

A Closer Look Charge-Transfer Color 1063



24 The Chemistry of Life: Organic and Biological Chemistry 1074

24.1 General Characteristics of Organic Molecules 1076

The Structures of Organic Molecules 1076
The Stability of Organic Compounds 1077 Solubility and Acid-Base Properties of Organic Compounds 1077

24.2 Introduction to Hydrocarbons 1078

Structures of Alkanes 1079 Structural Isomers 1079 Nomenclature of Alkanes 1080 Cycloalkanes 1083 Reactions of Alkanes 1083

24.3 Alkenes, Alkynes, and Aromatic Hydrocarbons 1085

Alkenes 1085 Alkynes 1087 Addition Reactions of Alkenes and Alkynes 1088 Aromatic Hydrocarbons 1089 Stabilization of π Electrons by Delocalization 1090 Substitution Reactions of Aromatic Hydrocarbons 1090

24.4 Organic Functional Groups 1092

Alcohols 1092 Ethers 1094 Aldehydes and Ketones 1094 Carboxylic Acids and Esters 1095 Amines and Amides 1098

24.5 Chirality in Organic Chemistry 1099**24.6 Introduction to Biochemistry 1101****24.7 Proteins 1101**

Amino Acids 1101 Polypeptides and Proteins 1103 Protein Structure 1104

24.8 Carbohydrates 1106

Disaccharides 1107 Polysaccharides 1108

24.9 Lipids 1109

Fats 1109 Phospholipids 1110

24.10 Nucleic Acids 1111

Chapter Summary and Key Terms 1115

Learning Outcomes 1116 Exercises 1116

Additional Exercises 1121 Integrative

Exercises 1122 Design an Experiment 1123

Chemistry Put to Work Gasoline 1084

A Closer Look Mechanism of Addition Reactions 1089

Strategies for Success What Now? 1114

APPENDICES

A Mathematical Operations 1124

B Properties of Water 1131

C Thermodynamic Quantities for Selected Substances at 298.15 K (25 °C) 1132

D Aqueous Equilibrium Constants 1136

E Standard Reduction Potentials at 25 °C 1138

ANSWERS TO SELECTED EXERCISES 1139

ANSWERS TO GIVE IT SOME THOUGHT 1169

ANSWERS TO GO FIGURE 1175

ANSWERS TO SELECTED PRACTICE EXERCISES 1181

GLOSSARY 1189

PHOTO AND ART CREDITS 1207

INDEX 1211