BRIEF CONTENTS

Density 57 Linits

conversion Pactors

CATHING UNITONNES

PREFACE 25

- Introduction: Matter, Energy, and Measurement 46
- 2 Atoms, Molecules, and Ions 89
- **Chemical Reactions and Stoichiometry 134** 3
- **Reactions in Aqueous Solution 175** 4
- 5 **Thermochemistry 219**
- **Electronic Structure of Atoms 274** 6
- **Periodic Properties of the Elements 323 Basic Concepts of Chemical Bonding 369** 8 **Molecular Geometry and Bonding Theories 412** 9 Gases 472 10 11 Liquids and Intermolecular Forces 517 Solids and Modern Materials 560 12 13 **Properties of Solutions 613 Chemical Kinetics 658** 14 **Chemical Equilibrium 715** 15 Acid–Base Equilibria 757 16 Additional Aspects of Aqueous Equilibria 813 17 **Chemistry of the Environment 864** 18 **Chemical Thermodynamics 904** 19 **Electrochemistry 950** 20

21 **Nuclear Chemistry 1007 Chemistry of the Nonmetals 1052** 22 **Transition Metals and Coordination Chemistry 1102** 23 The Chemistry of Organic Compounds 1149 24 **Stereochemistry of Organic Compounds 1185** 25 Chemistry of Alkenes and Alkynes 1210 26 Alcohols, Haloalkanes, and Ethers 1253 27 28 Aldehydes, Ketones, and Carbohydrates 1292 **Carboxylic Acids and their Derivatives 1332** 29 Benzene and its Derivatives 1371 30 31 Nitrogen-Containing Organic Compounds 1402 32 Solving Molecular Structure 1452 **APPENDICES**

A Mathematical Operations 1504

B Properties of Water **1510**

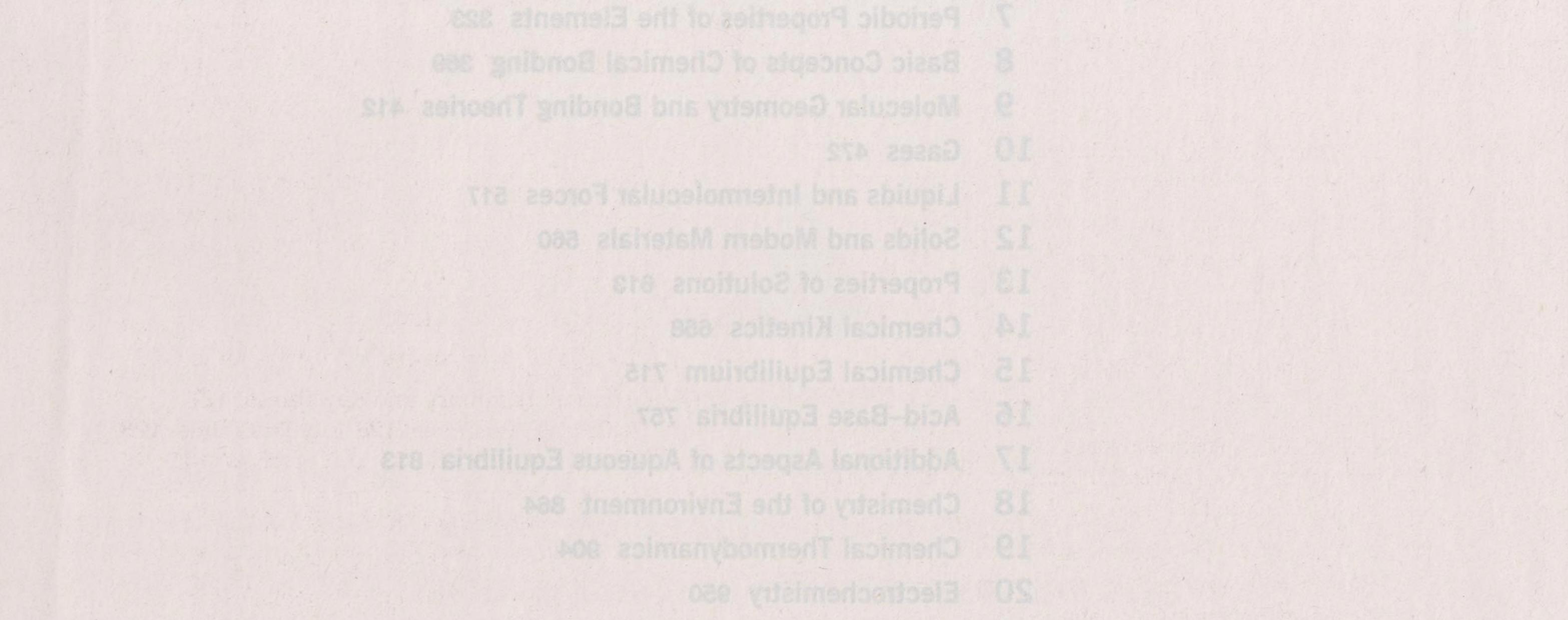
C Thermodynamic Quantities for Selected Substances at 298.15 K (25 °C) 1511

9

D Aqueous Equilibrium Constants 1515

E Standard Reduction Potentials at 25 °C 1517

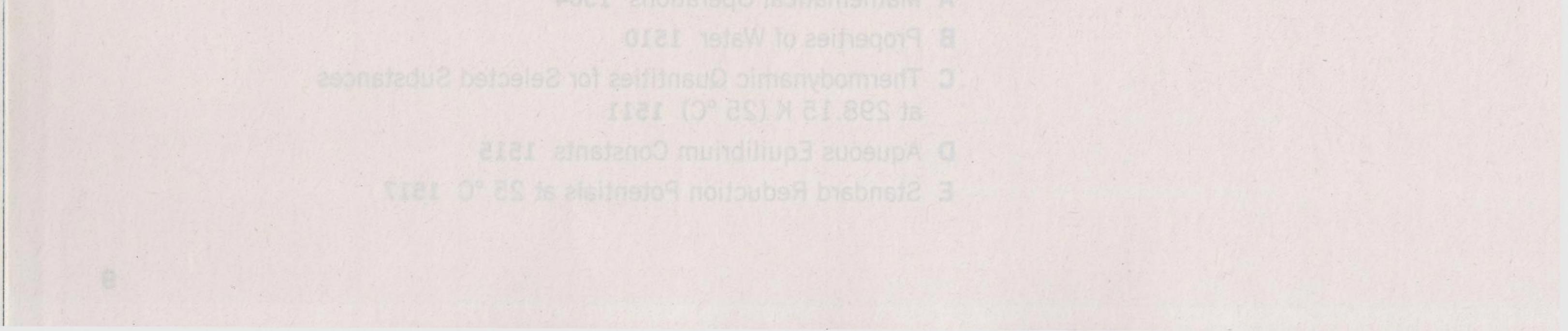
ANSWERS TO SELECTED EXERCISES 1518 ANSWERS TO GO FIGURE 1573 ANSWERS TO SELECTED PRACTICE EXERCISES 1579 GLOSSARY 1589 PHOTO AND ART CREDITS 1613 INDEX 1615



Electronic Structure of Atoms 274

1. Introduction: Matter, Energy, and Measurement 46

21 Nuclear Chemistry 1007
22 Chemistry of the Nonmetails 1032
23 Transition Metals and Coordination Chemistry 1102
24 The Chemistry of Organic Compounds 1143
25 Stareochemistry of Organic Compounds 1185
26 Chemistry of Alkenes and Alkynes 1210
27 Alcohols, Haloalkanes, and Ethers 1232
28 Aldehydes, Ketones, and Carbohydrates 1292
29 Carbonylic Acids and their Derivatives 1371
30 Benzene and Its Derivatives 1371
31 Nitrogen-Containing Organic Compounds 1403
32 Solving Molecular Structure 1452
33 Alfahydes (Compounds 1404)



PREFACE 25

Introduction: Matter, Energy, and Measurement 46 The Study of Chemistry 46

2.3 The Modern View of Atomic Structure 97 Atomic Numbers, Mass Numbers, and Isotopes 98 2.4 Atomic Weights 101 The Atomic Mass Scale 102 Atomic Weight 102 2.5 The Periodic Table 104 2.6 Molecules and Molecular **Compounds 108** Molecules and Chemical Formulas 108 Molecular and

The Atomic and Molecular Perspective of Chemistry 47 Why Study Chemistry? 48

1.2 Classifications of Matter 50

States of Matter 50 Pure Substances 51 Elements 52 Compounds 52 Mixtures 54

1.3 Properties of Matter 56

Physical and Chemical Changes 56 Separation of Mixtures 56

1.4 The Nature of Energy 60

Kinetic Energy and Potential Energy 60

1.5 Units of Measurement 62

SI Units 63 Length and Mass 65 Temperature 65 Derived SI Units 65 Volume 66 Density 67 Units of Energy 67

1.6 Uncertainty in Measurement 71

Precision and Accuracy 71 Significant Figures 72 Significant Figures in Calculations 73

Empirical Formulas 109 Picturing Molecules 109

2.7 Ions and Ionic Compounds 111

Predicting Ionic Charges 112 Ionic Compounds 113

2.8 Naming Inorganic Compounds 116

Names and Formulas of Ionic Compounds 117 Names and Formulas of Acids 121 Names and Formulas of Binary Molecular Compounds 122

2.9 Some Simple Organic **Compounds** 124

Alkanes 124 Some Derivatives of Alkanes 125

Chapter Summary and Key Terms 127 Learning Outcomes 128 Key Equations 128 **Exercises 128 Additional Exercises 131**

A Closer Look Basic Forces 99 A Closer Look The Mass Spectrometer 103 **Chemistry and Life** Elements Required by Living

1.7 Dimensional Analysis 76

Conversion Factors 77 Using Two or More Conversion Factors 78 Conversions Involving Volume 79

Chapter Summary and Key Terms 81 Learning Outcomes 82 Key Equations 82 Exercises 82 Additional Exercises 86

Chemistry Put to Work Chemistry and the Chemical Industry 49

A Closer Look The Scientific Method 63 Chemistry Put to Work Chemistry in the News 69 Strategies for Success Estimating Answers 78 Strategies for Success The Importance of Practice 80 Strategies for Success The Features of This Book 80 Organisms 115 Strategies for Success How to Take a Test 126

O Chemical Reactions and Stoichiometry 134

3.1 The Conservation of Mass, **Chemical Equations**, and **Stoichiometry 134**

> How to Balance Chemical Equations 135 A Step-by-Step Example of Balancing a Chemical Equation 136

Simple Patterns of Chemical 3.2 **Reactivity: Combination,** Decomposition, and Combustion 139

Atoms, Molecules,

and lons 89

2.1 The Atomic Theory of Matter 89 2.2 The Discovery of Atomic Structure 92 Cathode Rays and Electrons 92 Radioactivity 94 The Nuclear Model of the Atom 95

Combination and Decomposition Reactions 140 **Combustion Reactions 141** 3.3 Formula Weights and Elemental **Compositions of Substances 143** Formula and Molecular Weights 144 Elemental Compositions of Substances 144

11

3.4 Avogadro's Number and the Mole; Molar Mass 146

The Mole and Avogadro's Number 147 Molar Mass 147 Converting Between Masses, Moles, and Atoms/Molecules/Ions 148

- 3.5 Formula Weights and Elemental **Compositions of Substances 152** Molecular Formulas from Empirical Formulas 154 **Combustion Analysis** 155
- 3.6 Reaction Stoichiometry 158
- Limiting Reactants 162 3.7

Theoretical and Percent Yields 165

Chapter Summary and Key Terms 168

Exercises 213 Additional Exercises 216 Integrative Exercises 218 Design an **Experiment 218**

Chemistry Put to Work Antacids 191 Strategies for Success Analyzing Chemical Reactions 200

D Thermochemistry 219 5.1 The Nature of Chemical Energy 219 5.2 The First Law of

Learning Outcomes 168 Key Equations 168 **Exercises 169 Additional Exercises 172 Integrative Exercises 173 Design an Experiment 174**

Strategies for Success Problem Solving 145 **Chemistry and Life** Glucose Monitoring 149 Strategies for Success Design an Experiment 166

4 Reactions in Aqueous Solution 175

- 4.1 General Properties of Aqueous **Solutions 175** Electrolytes and Nonelectrolytes 176

Thermodynamics 223

System and Surroundings 223 Internal Energy 224 Relating ΔE to Heat and Work 225 Endothermic and Exothermic Processes 227 State Functions 228

5.3 Enthalpy 230

Pressure–Volume Work 231 Enthalpy Change 232

- 5.4 Enthalpies of Reaction 234
- 5.5 Calorimetry 238

Heat Capacity and Specific Heat 239 Constant-Pressure Calorimetry 240 Bomb Calorimetry (Constant-Volume Calorimetry) 242

- 5.6 Hess's Law 244
- 5.7 Enthalpies of Formation 248

Using Enthalpies of Formation to Calculate Enthalpies of Reaction 250

5.8 Bond Enthalpies 254

How Compounds Dissolve in Water 177 Strong and Weak Electrolytes 178

4.2 Precipitation Reactions 180

Solubility Guidelines for Ionic Compounds 180 Exchange (Metathesis) Reactions 182 Ionic Equations and Spectator Ions 183

4.3 Acids, Bases, and Neutralization **Reactions 185**

Acids 186 Bases 186 Strong and Weak Acids and Bases 187 Identifying Strong and Weak Electrolytes 187 Neutralization Reactions and Salts 189 Neutralization Reactions with Gas Formation 191

4.4 Oxidation-Reduction Reactions 193

Oxidation and Reduction 193 Oxidation Numbers 194 Oxidation of Metals by Acids and Salts 196 The Activity Series 197

Concentrations of Solutions 201 4.5

Bond Enthalpies and the Enthalpies of Reactions 255

5.9 Foods and Fuels 258

Foods 259 Fuels 261 Other Energy Sources 261

Chapter Summary and Key Terms 264 Learning Outcomes 265 Key Equations 265 **Exercises 266 Additional Exercises 270** Integrative Exercises 272 Design an **Experiment 273**

A Closer Look Energy, Enthalpy, and P-V Work 233 A Closer Look Using Enthalpy as a Guide 236 **Chemistry and Life** The Regulation of Body Temperature 243 Chemistry Put to Work The Scientific and Political Challenges of Biofuels 262



Molarity 201 Expressing the Concentration of an Electrolyte 201 Interconverting Molarity, Moles, and Volume 203 Dilution 204

4.6 Solution Stoichiometry and **Chemical Analysis 207**

Titrations 208

Chapter Summary and Key Terms 212 Learning Outcomes 213 Key Equations 213

O Electronic Structure of Atoms 274

6.1 The Wave Nature of Light 274 6.2 Quantized Energy and Photons 278 Hot Objects and the Quantization of Energy 278 The Photoelectric Effect and Photons 279

6.3 Line Spectra and the Bohr Model 281

Line Spectra 281 Bohr's Model 283 The Energy States of the Hydrogen Atom 283 Limitations of the Bohr Model 286

6.4 The Wave Behavior of Matter 287

The Uncertainty Principle 289

6.5 Quantum Mechanics and Atomic **Orbitals 291**

Orbitals and Quantum Numbers 292

6.6 Representations of Orbitals 296

The s Orbitals 296 The p Orbitals 298 The d and f Orbitals 299

Many-Electron Atoms 300 6.7

7.7 Trends for Group 1 and Group 2 Metals 349

Group 1: The Alkali Metals 349 Group 2: The Alkaline Earth Metals 353

7.8 Trends for Selected Nonmetals 354 Hydrogen 354 Group 16: The Oxygen Group 355 Group 17: The Halogens 356 Group 18: The Noble Gases 358

> **Chapter Summary and Key Terms** 360 Learning Outcomes 361 Key Equations 361 Exercises 361 Additional Exercises 365 Integrative Exercises 367 Design an **Experiment 368**

A Closer Look Effective Nuclear Charge 329

Orbitals and Their Energies 301 Electron Spin and the Pauli Exclusion Principle 301

6.8 Electron Configurations 303

Hund's Rule 305 Condensed Electron Configurations 306 Transition Metals 307 The Lanthanides and Actinides 308

6.9 Electron Configurations and the **Periodic Table 309**

Anomalous Electron Configurations 312

Chapter Summary and Key Terms 314 Learning Outcomes 315 Key Equations 315 **Exercises 316 Additional Exercises 319** Integrative Exercises 321 Design an Experiment 322

A Closer Look Measurement and the Uncertainty Principle 290 A Closer Look Thought Experiments and

Chemistry Put to Work Ionic Size and Lithium-Ion Batteries 335

Chemistry and Life The Improbable Development of Lithium Drugs 352

O Basic Concepts of **Chemical Bonding 369**

8.1 Lewis Symbols and the Octet Rule 369 Lewis Symbols 370 The Octet Rule 370

8.2 Ionic Bonding 371

Energetics of Ionic Bond Formation 373 Electron Configurations of lons of the s- and p-Block Elements 375 Transition Metal Ions 376

8.3 Covalent Bonding 378

Schrödinger's Cat 293

A Closer Look Probability Density and Radial **Probability Functions 298**

Chemistry and Life Nuclear Spin and Magnetic **Resonance Imaging 304**

Periodic Properties of the Elements 323

7.1 Development of the Periodic Table 323 7.2 Effective Nuclear Charge 326 7.3 Sizes of Atoms and Ions 330

Periodic Trends in Atomic Radii 332 Periodic Trends in Ionic Radii 332

7.4 Ionization Energy 336

Lewis Structures 379 Multiple Bonds 380

8.4 **Bond Polarity and Electronegativity 381**

Electronegativity 382 Electronegativity and Bond Polarity 382 Dipole Moments 384 Comparing Ionic and Covalent Bonding 387

8.5 Drawing Lewis Structures 388

Formal Charge and Alternative Lewis Structures 390

8.6 Resonance Structures 393

Resonance in Benzene 395

8.7 Exceptions to the Octet Rule 397 Odd Number of Electrons 397 Less Than an Octet of Valence Electrons 397 More Than an Octet of Valence Electrons 398

Strengths and Lengths of Covalent 8.8 Bonds 400 Chapter Summary and Key Terms 404

Variations in Successive Ionization Energies 337 Periodic Trends in First Ionization Energies 338 Electron Configurations of Ions 339

7.5 Electron Affinity 341

Periodic Trends in Electron Affinity 342

7.6 Metals, Nonmetals, and Metalloids 343 Metals 344 Nonmetals 346 Metalloids 347

Learning Outcomes 405 Key Equations 405 **Exercises 406 Additional Exercises 408 Integrative Exercises** 409 Design an Experiment 411

A Closer Look Calculation of Lattice Energies: The Born–Haber Cycle 376 A Closer Look Oxidation Numbers, Formal Charges, and Actual Partial Charges 392

9 Molecular Geometry and Bonding Theories 412

- 9.1 Molecular Shapes 412
- 9.2 The VSEPR Model 416

Applying the VSEPR Model to Determine Molecular Shapes 417 Effect of Nonbonding Electrons and Multiple Bonds on Bond Angles 421 Molecules with Expanded Valence Shells 421 Shapes of Larger Molecules 424

9.3 Molecular Shape and Molecular Polarity 426

10.4 The Ideal Gas Equation 483

Relating the Ideal Gas Equation and the Gas Laws 486 Gas Densities and Molar Mass 487 Volumes of Gases in Chemical Reactions 489

10.5 Gas Mixtures and Partial Pressures 491

Partial Pressures and Mole Fractions 493

10.6 The Kinetic-Molecular Theory of Gases 494

> Distributions of Molecular Speed 495 Application of Kinetic-Molecular Theory to the Gas Laws 496

10.7 Molecular Effusion and Diffusion 498 Graham's Law of Effusion 499 Diffusion and Mean

9.4 Covalent Bonding and Orbital Overlap 429

9.5 Hybrid Orbitals 431

sp Hybrid Orbitals 432 *sp*² and *sp*³ Hybrid Orbitals 433 Hypervalent Molecules 434 Hybrid Orbital Summary 436

9.6 Multiple Bonds 438

Resonance Structures, Delocalization, and π Bonding 442 General Conclusions about σ and π Bonding 444

9.7 Molecular Orbitals 445

Molecular Orbitals of the Hydrogen Molecule 446 Bond Order 448

9.8 Bonding in Period 2 Diatomic Molecules 450

Molecular Orbitals for Li₂ and Be₂ 451 Molecular Orbitals from 2*p* Atomic Orbitals 452 Electron Configurations for B₂ through Ne₂ 455 Electron Configurations and Molecular Properties 456 Heteronuclear Diatomic Molecules 459 Free Path 501

10.8 Real Gases: Deviations from Ideal Behavior 503

The van der Waals Equation 506

Chapter Summary and Key Terms 508 Learning Outcomes 509 Key Equations 509 Exercises 509 Additional Exercises 514 Integrative Exercises 515 Design an Experiment 516

Chemistry and Life Blood Pressure 478
Strategies for Success Calculations Involving Many Variables 485
A Closer Look The Ideal Gas Equation 497
Chemistry Put to Work Gas Separations 502

Chapter Summary and Key Terms 462 Learning Outcomes 463 Key Equations 463 Exercises 463 Additional Exercises 467 Integrative Exercises 470 Design an Experiment 471

A Closer Look Phases in Atomic and Molecular Orbitals 453

Chemistry Put to Work Orbitals and Energy 460

10 Gases 472

10.1 Characteristics of Gases 472

Liquids and Intermolecular Forces 517

11.1 A Molecular Comparison of Gases, Liquids, and Solids 517

11.2 Intermolecular Forces 520

Dispersion Forces 522 Dipole–Dipole Interactions 523 Hydrogen Bonding 524 Ion–Dipole Forces 527 Comparing Intermolecular Forces 527

11.3 Select Properties of Liquids 529 Viscosity 530 Surface Tension 531 Capillary Action 532

11.4 Phase Changes 533

Energy Changes Accompany Phase Changes 534 Heating Curves 535 Critical Temperature and Pressure 536

10.2 Pressure 474

Atmospheric Pressure and the Barometer 475 **10.3 The Gas Laws 479** The Pressure–Volume Relationship: Boyle's Law 480 The Temperature–Volume Relationship: Charles's Law 480 The Quantity–Volume Relationship: Avogadro's Law 481 11.5 Vapor Pressure 539

Volatility, Vapor Pressure, and Temperature 540
Vapor Pressure and Boiling Point 540

11.6 Phase Diagrams 542

The Phase Diagrams of H₂O and CO₂ 544

11.7 Liquid Crystals 547

Types of Liquid Crystals 547

Chapter Summary and Key Terms 552 Learning Outcomes 552 Exercises 553 Additional Exercises 556 Integrative Exercises 558 Design an Experiment 559

Chemistry Put to Work Ionic Liquids 531 A Closer Look The Clausius–Clapeyron Equation 541 Chemistry and Life Liquid Crystal Displays 549

12 Solids and Modern Materials 560

13.3 Factors Affecting Solubility 621

Solute–Solvent Interactions 621 Pressure Effects 623 Temperature Effects 626

13.4 Expressing Solution Concentration 628

Mass Percentage, ppm, and ppb 628 Mole Fraction, Molarity, and Molality 629 Converting Concentration Units 631

13.5 Colligative Properties 633

Vapor–Pressure Lowering 633 Boiling-Point Elevation 636 Freezing-Point Depression 637 Osmosis 639 Determination of Molar Mass from Colligative Properties 640 13.6 Colloids 644

Hydrophilic and Hydrophobic Colloids 645 Colloidal Motion in Liquids 647

12.1 Classification of Solids 560

Crystalline and Amorphous Solids 562 Unit Cells and Crystal Lattices 562 Filling the Unit Cell 564

12.2 Metallic Solids 567

The Structures of Metallic Solids 568 Close Packing 568 Alloys 572 Metallic Bonding 574 Electron-Sea Model 575 Molecular Orbital Model 575

12.3 Ionic Solids 579

Structures of Ionic Solids 580

12.4 Covalent Solids 584

Molecular Solids 585 Covalent-Network Solids 586 Semiconductors 586 Semiconductor Doping 589

12.5 Polymers 591

Making Polymers 593 Structure and Physical Properties of Polymers 596

12.6 Nanomaterials 598

Chapter Summary and Key Terms 649 Learning Outcomes 650 Key Equations 650 Exercises 651 Additional Exercises 655 Integrative Exercises 656 Design an Experiment 657

Chemistry and Life Fat-Soluble and Water-Soluble Vitamins 623 Chemistry and Life Blood Gases and Deep-Sea Diving 627

A Closer Look Ideal Solutions with Two or More Volatile Components 635

A Closer Look The van't Hoff Factor 642 Chemistry and Life Sickle-Cell Anemia 647

14.1 Factors That Affect Reaction Rates 658

Change of Rate with Time 662 Instantaneous

Rate 663 Reaction Rates and Stoichiometry 664

4 Chemical Kinetics 658

14.2 Reaction Rates 660

Semiconductors on the Nanoscale 599 Metals on the Nanoscale 599 Carbon on the Nanoscale 601 **Chapter Summary and Key Terms 604** Learning Outcomes 605 Key Equations 606 Exercises 606 Additional Exercises 610 Integrative Exercises 612 Design an Experiment 612

A Closer Look X-ray Diffraction 565 Chemistry Put to Work Alloys of Gold 574 Chemistry Put to Work Solid-State Lighting 590 Chemistry Put to Work Modern Materials in the Automobile 595 Chemistry Put to Work Microporous and

Mesoporous Materials 600

565Reaction Orders: The Exponents in the Rate Law 669of Gold 574Magnitudes and Units of Rate Constants 670State Lighting 590Using Initial Rates to Determine Rate Laws 671

14.4 The Change of Concentration with Time 673

14.3 Concentration and Rate Laws 666

First-Order Reactions 674 Second-Order Reactions 676 Zero-Order Reactions 677 Half-Life 678

14.5 Temperature and Rate 680

The Collision Model 681 The Orientation Factor 681 Activation Energy 681 The Arrhenius Equation 684 Determining the Activation Energy 685 **14.6 Reaction Mechanisms 687** Elementary Reactions 688 Multistep Mechanisms 688 Rate Laws for Elementary Reactions 689 The Rate-Determining Step for a Multistep Mechanism 690 Mechanisms with a Slow Initial Step 691 Mechanisms with a Fast Initial Step 693

L O Properties of Solutions 613

13.1 The Solution Process 613

The Natural Tendency toward Mixing 614 The Effect of Intermolecular Forces on Solution Formation 615 Energetics of Solution Formation 616 Solution Formation and Chemical Reactions 617
13.2 Saturated Solutions and Solubility 619

Catalysis 695 14.7

Homogeneous Catalysis 696 Heterogeneous Catalysis 697 Enzymes 699

Chapter Summary and Key Terms 703 Learning Outcomes 704 Key Equations 704 **Exercises 705 Additional Exercises 710** Integrative Exercises 713 Design an **Experiment 714**

A Closer Look Using Spectroscopic Methods to Measure Reaction Rates: Beer's Law 667 Chemistry Put to Work Bromomethane in the Atmosphere 679 Chemistry Put to Work Catalytic Converters 699

16 Acid–Base Equilibria 757

16.1 Acid–Base Equilibria 757

Arrhenius Acids and Bases 758 Brønsted-Lowry Acids and Bases 758 The H⁺ Ion in Water 758 Proton-Transfer Reactions 759 Conjugate Acid–Base Pairs 760 Relative Strengths of Acids and Bases 761

- 16.2 The Autoionization of Water 764 The Ion Product of Water 765
- 16.3 The pH Scale 767 pOH and Other "p" Scales 769 Measuring pH 769 16.4 Strong Acids and Bases 772

Chemistry and Life Nitrogen Fixation and Nitrogenase 701

15 Chemical Equilibrium 715

Chapter Summary and Key Terms 649

Learning Outcomes 050 Key Eauseday

15.1 The Concept of Equilibrium 715 15.2 The Equilibrium Constant 718

> Evaluating K_c 721 Equilibrium Constants in Terms of Pressure, Kp 722 Equilibrium Constants and Units 723

15.3 Understanding and Working with **Equilibrium Constants 724**

The Magnitude of Equilibrium Constants 725 The Direction of the Chemical Equation and K 726 **Relating Chemical Equation Stoichiometry and**

Strong Acids 773 Strong Bases 773 16.5 Weak Acids 775 Calculating K_a from pH 776 Percent Ionization 777 Using K_a to Calculate pH 778 Polyprotic Acids 782 Types of Weak Bases 788 Relationship Between K_ and K_ 789 Solutions 792 An Anion's Ability to React with Water 793 A Cation's Ability to React with Water 793

16.6 Weak Bases 786

16.7 Acid-Base Properties of Salt

Combined Effect of Cation and Anion in Solution 795

16.8 Acid–Base Behavior and Chemical Structure 797

Factors That Affect Acid Strength 797 Binary Acids 798 Oxyacids 798 Carboxylic Acids 801 Lewis Acids and Bases 802 **Chapter Summary and Key Terms** 805

Equilibrium Constants 726 Heterogeneous Equilibria 728 15.4 Calculating Equilibrium **Constants 731**

Applications of Equilibrium Constants 734 Predicting the Direction of Reaction 734 Calculating Equilibrium Concentrations 735

15.5 Le Châtelier's Principle 738

Change in Reactant or Product Concentration 740 Effects of Volume and Pressure Changes 742 Effect of Temperature Changes 743 The Effect of Catalysts 745

Chapter Summary and Key Terms 749 Learning Outcomes 749 Key Equations 750 **Exercises 750 Additional Exercises 754 Integrative Exercises 755 Design an Experiment 756**

Learning Outcomes 806 Key Equations 806 **Exercises 807 Additional Exercises 810** Integrative Exercises 812 Design an Experiment 812

A Closer Look Polyprotic Acids 784 Chemistry Put to Work Amines and Amine Hydrochlorides 791 **Chemistry and Life** The Amphiprotic Behavior of Amino Acids 801

Additional Aspects of Aqueous Equilibria 813 17.1 The Common-Ion Effect 813 17.2 **Buffers** 817

Chemistry Put to Work The Haber Process 720 A Closer Look Temperature Changes and Le Châtelier's Principle 745 Chemistry Put to Work Controlling Nitric Oxide Emissions 748

Composition and Action of Buffers 818 Calculating the pH of a Buffer 819 Buffer Capacity and pH Range 823 Addition of Strong Acids or Bases to Buffers 823 17.3 Acid-Base Titrations 826 Strong Acid–Strong Base Titrations 827 Weak Acid– Strong Base Titrations 829 Titrating with an Acid-Base Indicator 833 Titrations of Polyprotic Acids 835

17.4 Solubility Equilibria 837

The Solubility-Product Constant, K_{sp} 838 Solubility and K_{sp} 839

17.5 Factors That Affect Solubility 841

The Common-Ion Effect 842 Solubility and pH 843 Formation of Complex Ions 845 Amphoterism 848 17.6 Precipitation and Separation of Ions 850

> Selective Precipitation of Ions 852 Qualitative Analysis for Metallic Elements 852

Chapter Summary and Key Terms Learning Outcomes **857** Key Equations Exercises **858** Additional Exercises Integrative Exercises **862** Design an

19 Chemical Thermodynamics 904

19.1 Spontaneous Processes 904 Seeking a Criterion for Spontaneity 907 Reversible

and Irreversible Processes 907

19.2 Entropy and the Second Law of Thermodynamics 910

The Relationship between Entropy and Heat 910 ΔS for Phase Changes 911 The Second Law of Thermodynamics 912

19.3 The Molecular Interpretation of Entropy and the Third Law of Thermodynamics 914

Experiment 863

Chemistry and Life Blood as a Buffered Solution 825 A Closer Look Limitations of Solubility Products 841 Chemistry and Life Tooth Decay and Fluoridation 845 A Closer Look Lead Contamination in Drinking Water 849

18 Chemistry of the Environment 864

18.1 Earth's Atmosphere 864

Composition of the Atmosphere 865 Photochemical Reactions in the Atmosphere 868 Ozone in the Stratosphere 870 18.2 Human Activities and Earth's Expansion of a Gas at the Molecular Level 914 Boltzmann's Equation and Microstates 916 Molecular Motions and Energy 917 Making Qualitative Predictions about ΔS 918 The Third Law of Thermodynamics 920

19.4 Entropy Changes in Chemical Reactions 922

Temperature Variation of Entropy 923 Standard Molar Entropies 923 Calculating the Standard Entropy Change for a Reaction 924 Entropy Changes in the Surroundings 924

19.5 Gibbs Free Energy 926 Standard Free Energy of Formation 929 19.6 Free Energy and Temperature 932 19.7 Free Energy and the Equilibrium Constant 935

Atmosphere 872

The Ozone Layer and Its Depletion 873 Sulfur Compounds and Acid Rain 874 Nitrogen Oxides and Photochemical Smog 875 Greenhouse Gases: Water Vapor, Carbon Dioxide, and Climate 877

18.3 Earth's Water 881

The Global Water Cycle 882 Salt Water: Earth's Oceans and Seas 882 Freshwater and Groundwater 884

18.4 Human Activities and Water Quality 885

Dissolved Oxygen and Water Quality 885 Water Purification: Desalination 886 Water Purification: Municipal Treatment 887

18.5 Green Chemistry 891

Supercritical Solvents 893 Greener Reagents and Processes 893

Chapter Summary and Key Terms 896

Free Energy under Nonstandard Conditions 935 Relationship between ΔG° and K 938

Chapter Summary and Key Terms Learning Outcomes **942** Key Equations Exercises **943** Additional Exercises Integrative Exercises **948** Design an Experiment

A Closer Look The Entropy Change When a Gas Expands Isothermally 912

Chemistry and Life Entropy and Human Society 921 A Closer Look What's "Free" About Free Energy? 931 Chemistry and Life Driving Nonspontaneous Reactions: Coupling Reactions 939



Learning Outcomes 897 Exercises 897 Additional Exercises 901 Integrative Exercises 902 Design an Experiment 903

A Closer Look Other Greenhouse Gases 880 A Closer Look Fracking and Water Quality 888 Chemistry and Life Ocean Acidification 890

Carbon 1086 .Carbonic Acid and Carbonates 1088

 20.1 Oxidation States and Oxidation-Reduction Reactions 950
 20.2 Balancing Redox Equations 953 Half-Reactions 954 Balancing Equations by the Method of Half-Reactions 954 Balancing Equations for Reactions Occurring in Basic Solution 957

20.3 Voltaic Cells 959 20.4 Cell Potentials under Standard **Conditions 963**

Standard Reduction Potentials 965 Strengths of Oxidizing and Reducing Agents 968

20.5 Free Energy and Redox Reactions 972 Emf, Free Energy, and the Equilibrium Constant 974 20.6 Cell Potentials under Nonstandard **Conditions 977** The Nernst Equation 977 Concentration Cells 980 20.7 Batteries and Fuel Cells 984

Lead–Acid Battery 985 Alkaline Battery 985 Nickel-Cadmium and Nickel-Metal Hydride Batteries 985 Lithium-Ion Batteries 986 Hydrogen 21.6 Radiation in the Environment and Living Systems 1041 Radiation Doses 1042 **Chapter Summary and Key Terms** 1045 Learning Outcomes 1046 Key Equations 1047 **Exercises 1047 Additional Exercises 1049** Integrative Exercises 1051 Design an **Experiment 1051**

> **Chemistry and Life** Medical Applications of Radiotracers 1028 A Closer Look The Dawning of the Nuclear Age 1035 A Closer Look Nuclear Synthesis of the Elements 1039 **Chemistry and Life** Radiation Therapy 1044

Fuel Cells 986

20.8 Corrosion 990

Corrosion of Iron (Rusting) 991 Preventing Corrosion of Iron 992

20.9 Electrolysis 993

Quantitative Aspects of Electrolysis 995

Chapter Summary and Key Terms 999 Learning Outcomes 1000 Key Equations 1000 **Exercises 1000 Additional Exercises 1004 Integrative Exercises 1005 Design an Experiment 1006**

A Closer Look Electrical Work 976 **Chemistry and Life Heartbeats and** Electrocardiography 981 Chemistry Put to Work Batteries for Hybrid and Electric Vehicles 987 Chemistry Put to Work Electrometallurgy of

22 Chemistry of the Nonmetals 1052

22.1 Periodic Trends and Chemical **Reactions** 1052 Chemical Reactions 1055 22.2 Hydrogen 1056

Isotopes of Hydrogen 1057 Properties of Hydrogen 1057 Production of Hydrogen 1058 Uses of Hydrogen 1059 Binary Hydrogen Compounds 1059

- 22.3 Group 18: The Noble Gases 1061 Noble Gas Compounds 1062
- 22.4 Group 17: The Halogens 1064 Properties and Production of the Halogens 1064

Aluminum 996

21 Nuclear Chemistry 1007

21.1 Radioactivity and Nuclear

Equations 1007

Nuclear Equations 1009 Types of Radioactive Decay 1009

21.2 Patterns of Nuclear Stability 1012

Neutron-to-Proton Ratio 1013 Radioactive Decay Chains 1014 Further Observations 1015 Nuclear Transmutations 1016 Accelerating Charged Particles 1017 Reactions Involving Neutrons 1018 Transuranium Elements 1018

21.3 Rates of Radioactive Decay 1020 Radiometric Dating 1021 Calculations Based on

Uses of the Halogens 1066 The Hydrogen Halides 1066 Interhalogen Compounds 1066 Oxyacids and Oxyanions 1066

22.5 Oxygen 1068

Properties of Oxygen 1068 Production of Oxygen 1069 Uses of Oxygen 1069 Ozone 1069 Oxides 1069 Peroxides and Superoxides 1070

22.6 The Other Group 16 Elements: S, Se, **Te, and Po** 1072

Occurrence and Production of S, Se, and Te 1073 Properties and Uses of Sulfur, Selenium, and Tellurium 1073 Sulfides 1074 Oxides, Oxyacids, and Oxyanions of Sulfur 1074

22.7 Nitrogen 1076

Properties of Nitrogen 1077 Production and Uses of Nitrogen 1077 Hydrogen Compounds of Nitrogen 1078 Oxides and Oxyacids of Nitrogen 1078

Half-Life 1023 21.4 Detection of Radioactivity 1026 Radiotracers 1027 21.5 Energy Changes in Nuclear **Reactions 1029** Nuclear Binding Energies 1031 Nuclear Power: Fission 1033 Nuclear Reactors 1036 Nuclear Waste 1037 Nuclear Power: Fusion 1038

22.8 The Other Group 15 Elements: P, As, Sb, and Bi 1081 Occurrence, Isolation, and Properties of Phosphorus 1082 Phosphorus Halides 1082 Oxy Compounds of Phosphorus 1083 Carbon 1085 22.9 Elemental Forms of Carbon 1086 Oxides of Carbon 1086 Carbonic Acid and Carbonates 1088 Carbides 1088

22.10 The Other Group 14 Elements: Si, Ge, Sn, and Pb 1089

General Characteristics of the Group 14 Elements 1090 Occurrence and Preparation of Silicon 1090 Silicates 1091 Glass 1092 Silicones 1092 22.11 Boron 1093

> Chapter Summary and Key Terms 1096 Learning Outcomes 1097 Exercises 1097 Additional Exercises 1100 Integrative Exercises 1100 Design an Experiment 1101

A Closer Look The Hydrogen Economy 1058 Chemistry and Life Nitroglycerin, Nitric Oxide, and Heart Disease 1080

Chemistry and Life Arsenic in Drinking Water 1084 Chemistry Put to Work Carbon Fibers and Composites 1087 24 The Chemistry of Organic Compounds 1149

24.1 General Characteristics of Organic Molecules 1149

> The Structure of Organic Molecules 1150 The Stabilities of Organic Molecules 1150

24.2 An Introduction to Hydrocarbons 1151 Alkanes 1153 Applications and Physical Properties of Alkanes 1154 Homologous Series 1154

24.3 Structures of Alkanes 1155

Alkane Shape and Conformations 1158

23 Transition Metals and Coordination Chemistry 1102

23.1 The Transition Metals 1102
Physical Properties 1104 Electron Configurations and Oxidation States 1105 Magnetism 1106
23.2 Transition-Metal Complexes 1108
The Development of Coordination Chemistry: Werner's Theory 1109 The Metal–Ligand Bond 1111
Charges, Coordination Numbers, and Geometries 1112

Constitutional/Structural Isomers 1159 24.4 Alkane Nomenclature 1162 24.5 Cycloalkanes 1165 24.6 Organic Functional Groups 1169 24.7 Reactions of Alkanes 1172 Combustion 1173 Classification of C and H 1174 Free-Radical Reactions and Electron Movement 1175 Chapter Summary and Key Terms 1178 Key Skills 1179 Key Equations 1179 Exercises 1179 Additional Exercises 1183 Integrative Exercises 1183 Design an Experiment 1184

> Chemistry and Life Petroleum Products 1156 Chemistry and Life Structure–Activity Relationships 1171 A Closer Look Reactivity by Carbon Classification 1176

23.3 Common Ligands in Coordination Chemistry 1114 Metals and Chelates in Living Systems 1116

23.4 Nomenclature and Isomerism in Coordination Chemistry 1121

> Isomerism 1123 Constitutional Isomerism 1124 Stereoisomerism 1124

23.5 Color and Magnetism in Coordination Chemistry 1128

> Color 1128 Magnetism of Coordination Compounds 1129

23.6 Crystal-Field Theory 1131

Electron Configurations in Octahedral Complexes 1134 Tetrahedral and Square-Planar Complexes 1136

Chapter Summary and Key Terms 1141 Learning Outcomes 1141 Exercises 1142 Additional Exercises 1145 Integrative 25 Stereochemistry of Organic Compounds 1185

- 25.1 Stereochemistry in Organic Chemistry 1185
 25.2 Cis-Trans Isomerism in Cycloalkanes 1188
 25.3 Chirality in Organic Compounds 1190
 25.4 Measuring Optical Activity 1194
 25.5 Absolute Stereochemistry 1197 Using Priority Rules to Find a Stereocenter's Absolute Configuration 1197
 25.6 Molecules with More than
 - One Stereocenter 1201

Exercises 1147 Design an Experiment 1148

A Closer Look Entropy and the Chelate Effect 1118 Chemistry and Life The Battle for Iron in Living Systems 1119

A Closer Look Charge-Transfer Color 1138

29.2 Preparation of Carboxylic Acids 1338

Resolution: Separating Enantiomers 1202

Chapter Summary and Key Terms 1205 Key Skills 1206 Key Equations 1206 Exercises 1206 Additional Exercises 1208 Integrative Exercises 1208 Design an Experiment 1209

Chemistry and Life Chiral Drugs 1199

26 Chemistry of Alkenes and Alkynes 1210

26.1 The Structure of Unsaturated Hydrocarbons 1210

The π -bond 1211 Bonding in Alkenes 1212 Bonding in Alkynes 1214

26.2 Isomerism and Nomenclature 1217 Isomerism in Alkenes—The *E*, *Z* System 1219 Alkynes 1220

26.3 Arrow Notation and Resonance
Structures: Electron Counting 1222
26.4 Electrophilic Addition Reactions 1226

27.6 Haloalkanes to Alkenes: β-Elimination 1276
27.7 Substitution versus Elimination 1280 E1 and S_N1 Reactions 1281 Chapter Summary and Key Terms 1286 Key Skills 1286 Key Equations 1286 Exercises 1287 Additional Exercises 1290 Integrative Exercises 1290 Design an Experiment 1291

> Chemistry and Life Vitamin D 1256 Chemistry and Life The Solubility Nexus 1258 A Closer Look Crown Ethers 1267 A Closer Look Molecularity 1274 A Closer Look Nucleophile or Lewis Base? 1281

Addition Reactions Involving HX (X = Cl, Br, I) 1226 Addition Reactions Involving H₂O 1230 Halogenation: Addition of Br₂ and Cl₂ 1231 Halohydrin Formation 1232 Alkanes from Alkenes: Catalytic Hydrogenation 1237

26.6 Addition Polymerization 1240

Making Polymers 1241 Structure and Physical Properties of Addition Polymers 1243

Chapter Summary and Key Terms 1248 Key Skills 1249 Key Equations 1249 Exercises 1249 Integrative Exercises 1251 Design an Experiment 1252

Chemistry and Life Terpenes and Isoprene 1216 Chemistry and Life The Chemistry of Vision 1223 A Closer Look Describing Charge 1224 A Closer Look Stereochemistry in Halohydrin Formation 1235 A Closer Look Hydrogenation 1238 Chemistry and Life Recycling Plastics 1244 Chemistry and Life The Accidental Discovery of Teflon® 1246 Chemistry and Life Vulcanization 1246 Chemistry and Life Polymerization versus Macrocyclization 1285

28 Aldehydes, Ketones, and Carbohydrates 1292

28.1 Aldehydes, Ketones, and the Carbonyl Group 1292
28.2 Preparation of Aldehydes and Ketones 1297

Oxidation of 1° and 2° Alcohols 1298 Ozonolysis 1299

28.3 Reactions of Aldehydes and Ketones 1300

> Addition of Carbon Nucleophiles—Grignard Reactions 1301 Addition of Nitrogen and Oxygen Nucleophiles: Formation of Imines and Acetals 1304 Reduction Reactions 1306 Cyanohydrins 1307 Tautomerism in Aldehydes and Ketones 1309 Halogenation of Aldehydes and Ketones 1310

27 Alcohols, Haloalkanes, and Ethers 1253

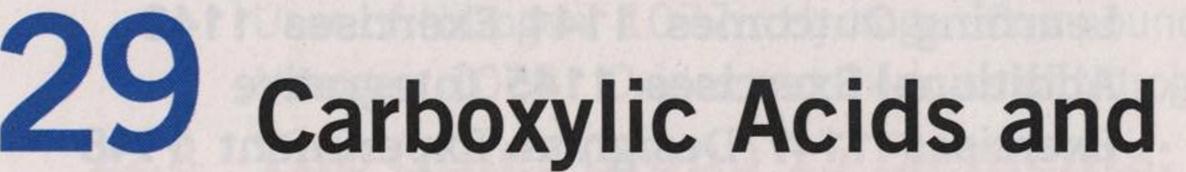
27.1 Alcohols: Structure, Properties, and Nomenclature 1253
Common Alcohols 1257 Naming Alcohols 1257 Classifying Alcohols 1261
27.2 Haloalkanes 1262
27.3 Ethers: Structure, Properties,

28.4 Carbohydrates 1313

Monosaccharides 1314 Cyclic versus Open-Chain Structures 1317 Oligosaccharides and Polysaccharides 1320

Chapter Summary and Key Terms 1327 Key Skills 1327 Key Equations 1328 Exercises 1328 Integrative Exercises 1331 Design an Experiment 1331

Chemistry and Life Glucosamine 1318 Chemistry and Life Cyclodextrins 1321 Chemistry and Life Vitamin C 1324



and Nomenclature 1264

 Naming Ethers 1266

 27.4 Reactions of Alcohols 1268

 Alkoxides 1269 Basicity of
 Alcohols 1269 Alcohols to
 Haloalkanes 1269 Dehydration of Alcohols 1270

 27.5 Nucleophilic Substitution Reactions

 of Haloalkanes 1272

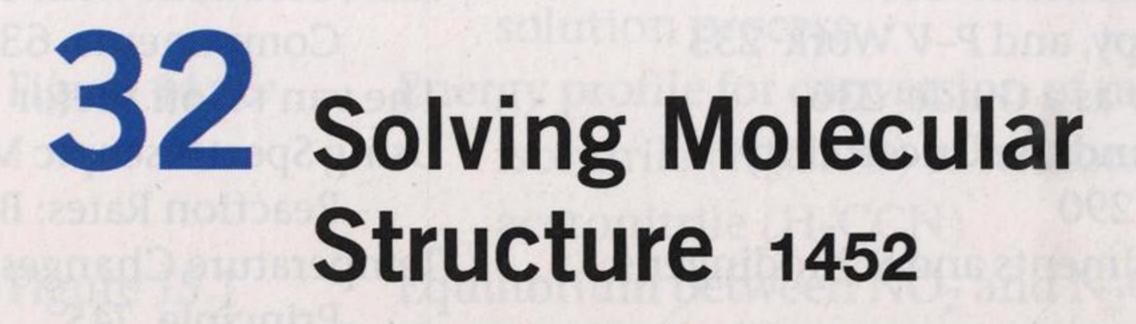
 Carboxylic Acids and Their Derivatives 1332
 29.1 Carboxylic Acids 1332 Structure, Properties, and Nomenclature 1333 Acidity 1335
 29.2 Preparation of Carboxylic Acids 1338
 29.3 Esters and Esterification 1342 29.4 Fats, Oils, and Waxes 1347 Soaps and Detergents 1350 29.5 Acid Chlorides, Anhydrides, and **Nucleophilic Acyl Substitution 1353** Nucleophilic Acyl Substitution 1356 29.6 Condensation Polymerization 1359 Polymers for Medicine 1362 **Chapter Summary and Key Terms** 1365 Key Skills 1366 Key Equations 1366 **Exercises 1367 Integrative Exercises 1369** Design an Experiment 1370

> **Chemistry and Life Steroids 1354** Chemistry and Life Towards the Plastic Car 1361 **Chemistry and Life** Biodegradable Sutures 1363

31.4 Nucleic Acids and DNA 1438

Chapter Summary and Key Terms 1446 **Key Skills 1446 Key Equations 1446 Exercises 1447 Integrative Exercises 1450 Design an Experiment 1451**

Chemistry and Life Amines and Amine Hydrochlorides 1406 A Closer Look Sickle-Cell Anemia 1420 **Chemistry and Life B Group Vitamins 1436**



SU Benzene and its Derivatives 1371

- 30.1 The Structure of Benzene 1371 Bonding in Benzene 1372
- **30.2 Isomerism and Nomenclature** in Aromatic Compounds 1375

Phenols 1378

- 30.3 Aromaticity 1380
- 30.4 Acidity of Phenols 1382
- **30.5 Electrophilic Aromatic Substitution** (EAS) Reactions 1386 **Directing Groups and Substitution Effects** 1389

32.1 The Electromagnetic Spectrum 1452 32.2 Infrared (IR) Spectroscopy 1455 The Spring Model 1456 Measuring IR Spectra 1458 32.3 Nuclear Magnetic Resonance (NMR) **Spectroscopy** 1463 Nuclear Magnetic Resonance Frequencies 1466 The Chemical Shift 1467 Sample Preparation 1468 Interpreting NMR Spectra 1469 Integration 1472 Spin–Spin Coupling 1474 ¹³C NMR Spectra 1476 32.4 Mass Spectrometry 1480 Electron Impact Ionization Mass Spectrometry 1481 Interpreting Mass Spectra 1483 **Compound Identification Using** 32.5 Spectra 1487 Deducing the Molecular Formula of an Organic Compound 1487 Chemical Wet Testing: Tests for Functional Groups 1489 Using Analysis from Instrumental Techniques 1490

Chapter Summary and Key Terms 1397 Key Skills 1397 Key Equations 1398 **Exercises 1398 Integrative Exercises 1400 Design an Experiment 1401**

Chemistry and Life The Discovery of Liquid Crystals 1376 A Closer Look Organic Dyes 1388

31 Nitrogen-Containing Organic Compounds 1402

31.1 Amines and the Amide Bond 1402 Amines 1403 Reactivity of Amines 1408 Synthesis of Amines 1410 Amides 1412 31.2 Amino Acids 1416 Acid–Base Properties 1419 Reactions Involving

Chapter Summary and Key Terms 1495 Key Skills 1496 Key Equations 1496 **Exercises 1496 Integrative Exercises 1499** Design an Experiment 1502

A Closer Look Using Spectroscopic Methods to Measure Reaction Rates 1454

APPENDICES

- A Mathematical Operations 1503
- **B** Properties of Water 1510
- **C** Thermodynamic Quantities for Selected Substances at 298.15 K (25 °C) 1511
- **D** Aqueous Equilibrium Constants 1515
- E Standard Reduction Potentials at 25 °C 1517

The Importance of Practice 30.

ANSWERS TO SELECTED EXERCISES 1518 ANSWERS TO GO FIGURE 1573

Amino Acids 1424

31.3 Proteins, Peptides, and Enzymes 1426 Coding Peptides 1428 Protein Structure 1430 Enzymes 1432 Sequencing of Peptides and Proteins 1434

ANSWERS TO SELECTED PRACTICE EXERCISES 1579

GLOSSARY 1589 PHOTO AND ART CREDITS 1613

Sample Exercise 8.2 Charges on lons

INDEX 1615