## **DETAILED CONTENTS**



## CHAPTER

#### Keys to the Study of Chemistry 2

1.1 Some Fundamental Definitions 4

The States of Matter 4
The Properties of Matter and Its Changes 5
The Central Theme in Chemistry 8
The Importance of Energy in the Study of
Matter 8

1.2 Chemical Arts and the Origins of Modern Chemistry 10

Prechemical Traditions 10
The Phlogiston Fiasco and the Impact of Lavoisier 11

- 1.3 The Scientific Approach: Developing a Model 12
- 1.4 Measurement and Chemical Problem Solving 13

General Features of SI Units 13
Some Important SI Units in Chemistry 14
Units and Conversion Factors
in Calculations 17
A Systematic Approach to Solving
Chemistry Problems 19
Temperature Scales 24
Extensive and Intensive Properties 26

## 1.5 Uncertainty in Measurement: Significant Figures 27

Determining Which Digits Are
Significant 28
Significant Figures: Calculations and
Rounding Off 29
Precision, Accuracy, and Instrument
Calibration 31

CHAPTER REVIEW GUIDE 32 PROBLEMS 35

## CHAPTER

# 2

### The Components of Matter 40

- 2.1 Elements, Compounds, and Mixtures: An Atomic Overview 42
- 2.2 The Observations That Led to an Atomic View of Matter 44
  Mass Conservation 44
  Definite Composition 45
  Multiple Proportions 46
- **2.3 Dalton's Atomic Theory 47**Postulates of the Atomic Theory 47
  How the Theory Explains the Mass Laws 48
- 2.4 The Observations That Led to the Nuclear Atom Model 49

Discovery of the Electron and Its Properties 49 Discovery of the Atomic Nucleus 51

2.5 The Atomic Theory Today 52 Structure of the Atom 53 Atomic Number, Mass Number, and Atomic Symbol 53 Isotopes 54 Atomic Masses of the Elements 55

## TOOLS OF THE LABORATORY: MASS SPECTROMETRY 57

- 2.6 Elements: A First Look at the Periodic Table 58
- 2.7 Compounds: Introduction to Bonding 61

The Formation of Ionic Compounds 61
The Formation of Covalent Substances 63

2.8 Compounds: Formulas, Names, and Masses 65

Binary Ionic Compounds 65 Compounds That Contain Polyatomic Ions 68 Acid Names from Anion Names 70

Acid Names from Anion Names 70 Binary Covalent Compounds 71 The Simplest Organic Compounds: Straight-Chain Alkanes 72 Molecular Masses from Chemical Formulas 72 Representing Molecules with Formulas and Models 75

## 2.9 Mixtures: Classification and Separation 77

An Overview of the Components of Matter 77

## **TOOLS OF THE LABORATORY:**BASIC SEPARATION TECHNIQUES 79

CHAPTER REVIEW GUIDE 80 PROBLEMS 82



## Stoichiometry of Formulas and Equations 90

#### 3.1 The Mole 91

Defining the Mole 92
Determining Molar Mass 92
Converting Between Amount, Mass, and
Number of Chemical Entities 93
The Importance of Mass Percent 98

#### 3.2 Determining the Formula of an Unknown Compound 100

Empirical Formulas 101 Molecular Formulas 102 Chemical Formulas and Molecular Structures; Isomers 105

## **3.3** Writing and Balancing Chemical Equations 107

## 3.4 Calculating Quantities of Reactant and Product 112

Stoichiometrically Equivalent Molar Ratios from the Balanced Equation 112 Reactions That Occur in a Sequence 116 Reactions That Involve a Limiting Reactant 117 Theoretical, Actual, and Percent Reaction Yields 123

CHAPTER REVIEW GUIDE 125 PROBLEMS 130

#### **CHAPTER**



#### Three Major Classes of Chemical Reactions 138

## 4.1 Solution Concentration and the Role of Water as a Solvent 139

The Polar Nature of Water 140
Ionic Compounds in Water 140
Covalent Compounds in Water 143
Expressing Concentration in Terms
of Molarity 144
Amount-Mass-Number Conversions
Involving Solutions 144
Preparing and Diluting Molar Solutions 146

## **4.2** Writing Equations for Aqueous Ionic Reactions 149

#### 4.3 Precipitation Reactions 151

The Key Event: Formation of a Solid from Dissolved Ions 151

Predicting Whether a Precipitate Will Form 151 Stoichiometry of Precipitation Reactions 155

#### 4.4 Acid-Base Reactions 158

The Key Event: Formation of H<sub>2</sub>O from H<sup>+</sup> and OH<sup>-</sup> 161 Proton Transfer in Acid-Base Reactions 162 Stoichiometry of Acid-Base Reactions: Acid-Base Titrations 165

## 4.5 Oxidation-Reduction (Redox) Reactions 168

The Key Event: Movement of Electrons Between Reactants 168 Some Essential Redox Terminology 169 Using Oxidation Numbers to Monitor Electron Charge 170 Stoichiometry of Redox Reactions: Redox Titrations 172

#### 4.6 Elements in Redox Reactions 174

Combination Redox Reactions 174
Decomposition Redox Reactions 176
Displacement Redox Reactions and Activity
Series 177
Combustion Reactions 180

## 4.7 The Reversibility of Reactions and the Equilibrium State 181

CHAPTER REVIEW GUIDE 184 PROBLEMS 189

#### CHAPTER



#### Gases and the Kinetic-Molecular Theory 198

## 5.1 An Overview of the Physical States of Matter 199

#### 5.2 Gas Pressure and Its Measurement 201 Measuring Gas Pressure: Barometers and Manometers 202 Units of Pressure 202

## 5.3 The Gas Laws and Their Experimental Foundations 204

The Relationship Between Volume and Pressure: Boyle's Law 205 The Relationship Between Volume and Temperature: Charles's Law 206 The Relationship Between Volume and Amount: Avogadro's Law 208 Gas Behavior at Standard Conditions 209 The Ideal Gas Law 209 Solving Gas Law Problems 210

## 5.4 Rearrangements of the Ideal Gas Law 216

The Density of a Gas 216
The Molar Mass of a Gas 218
The Partial Pressure of Each Gas in a Mixture of Gases 219
The Ideal Gas Law and Reaction
Stoichiometry 222

## 5.5 The Kinetic-Molecular Theory: A Model for Gas Behavior 224

How the Kinetic-Molecular Theory Explains the Gas Laws 224 Effusion and Diffusion 229 The Chaotic World of Gases: Mean Free Path and Collision Frequency 232

## CHEMICAL CONNECTIONS TO ATMOSPHERIC SCIENCE:

HOW THE GAS LAWS APPLY TO EARTH'S ATMOSPHERE 233

#### 5.6 Real Gases: Deviations from Ideal Behavior 235

Effects of Extreme Conditions on Gas Behavior 235 The van der Waals Equation: Adjusting the Ideal Gas Law 237

CHAPTER REVIEW GUIDE 238 PROBLEMS 241



# 6

#### Thermochemistry: Energy Flow and Chemical Change 250

#### 6.1 Forms of Energy and Their Interconversion 251

Defining the System and Its Surroundings 252 Energy Change ( $\Delta E$ ): Energy Transfer to or from a System 252 Heat and Work: Two Forms of Energy Transfer 252 The Law of Energy Conservation 255 Units of Energy 255 State Functions and the Path Independence of the Energy

#### 6.2 Enthalpy: Changes at Constant Pressure 257

The Meaning of Enthalpy 258 Comparing  $\Delta E$  and  $\Delta H$  259 Exothermic and Endothermic Processes 259

#### 6.3 Calorimetry: Measuring the Heat of a Chemical or Physical Change 261 Specific Heat Capacity 261 The Two Major Types of Calorimetry 262

- .4 Stoichiometry of Thermochemical Equations 266
- 6.5 Hess's Law: Finding ΔH of Any Reaction 267

## 5.6 Standard Enthalpies of Reaction ( $\Delta H_{rxn}^{\circ}$ ) 270

Formation Equations and Their Standard Enthalpy Changes 270 Determining  $\Delta H_{rxn}^{\circ}$  from  $\Delta H_{f}^{\circ}$  Values for Reactants and Products 271

CHEMICAL CONNECTIONS TO ENVIRONMENTAL SCIENCE:

THE FUTURE OF ENERGY USE 273

CHAPTER REVIEW GUIDE 277
PROBLEMS 280

### **CHAPTER**



#### **Quantum Theory and Atomic Structure 286**

#### 7.1 The Nature of Light 287

Change 256

The Wave Nature of Light 288 The Particle Nature of Light 291

#### 7.2 Atomic Spectra 294

Line Spectra and the Rydberg Equation 294 The Bohr Model of the Hydrogen Atom 295

The Energy Levels of the Hydrogen Atom 297

#### ${\it TOOLS~OF~THE~LABORATORY:}$

SPECTROMETRY IN CHEMICAL ANALYSIS 300

## 7.3 The Wave-Particle Duality of Matter and Energy 302

The Wave Nature of Electrons and the Particle Nature of Photons 302 Heisenberg's Uncertainty Principle 305

## 7.4 The Quantum-Mechanical Model of the Atom 306

The Atomic Orbital and the Probable Location of the Electron 306

Quantum Numbers of an Atomic Orbital 308 Quantum Numbers and Energy Levels 309 Shapes of Atomic Orbitals 311 The Special Case of Energy Levels in the Hydrogen Atom 313

CHAPTER REVIEW GUIDE 314 PROBLEMS 316

### **CHAPTER**



#### **Electron Configuration and Chemical Periodicity 322**

## 8.1 Characteristics of Many-Electron Atoms 324

The Electron-Spin Quantum Number 324
The Exclusion Principle 325
Electrostatic Effects and Energy-Level
Splitting 325

## 8.2 The Quantum-Mechanical Model and the Periodic Table 327

Building Up Period 1 327 Building Up Period 2 328 Building Up Period 3 330 Similar Electron Configurations Within Groups 331

Building Up Period 4: The First Transition Series 332

General Principles of Electron Configurations 333

Intervening Series: Transition and Inner Transition Elements 334

#### **8.3** Trends in Three Atomic Properties 336

Trends in Atomic Size 336
Trends in Ionization Energy 339
Trends in Electron Affinity 343

## 8.4 Atomic Properties and Chemical Reactivity 344

Trends in Metallic Behavior 344 Properties of Monatomic lons 346

CHAPTER REVIEW GUIDE 352 PROBLEMS 354



9

## **Models of Chemical Bonding 358**

## 9.1 Atomic Properties and Chemical Bonds 359

The Three Ways Elements Combine 359 Lewis Symbols and the Octet Rule 361

#### 9.2 The Ionic Bonding Model 362

Why Ionic Compounds Form:
The Importance of Lattice Energy 363
Periodic Trends in Lattice Energy 365
How the Model Explains the Properties
of Ionic Compounds 367

#### 9.3 The Covalent Bonding Model 369

The Formation of a Covalent Bond 369 Bonding Pairs and Lone Pairs 370 Properties of a Covalent Bond: Order, Energy, and Length 370 How the Model Explains the Properties of Covalent Substances 373

#### **TOOLS OF THE LABORATORY:**

INFRARED SPECTROSCOPY 374

#### 9.4 Bond Energy and Chemical Change 376

Changes in Bond Energy: Where Does  $\Delta H^{\circ}_{rxn}$  Come From? 376 Using Bond Energies to Calculate  $\Delta H^{\circ}_{rxn}$  376 Bond Strengths and the Heat Released from Fuels and Foods 379

#### 9.5 Between the Extremes: Electronegativity and Bond Polarity 380

Electronegativity 380 Bond Polarity and Partial Ionic Character 382 The Gradation in Bonding Across a Period 384

#### 9.6 An Introduction to Metallic Bonding 385

The Electron-Sea Model 385 How the Model Explains the Properties of Metals 386

CHAPTER REVIEW GUIDE 387 PROBLEMS 389

# CHAPTER 10

#### The Shapes of Molecules 394

#### 10.1 Depicting Molecules and lons with Lewis Structures 395

Applying the Octet Rule to Write Lewis Structures 395 Resonance: Delocalized Electron-Pair Bonding 399 Formal Charge: Selecting the More Important Resonance Structure 401 Lewis Structures for Exceptions to

## 10.2 Valence-Shell Electron-Pair Repulsion (VSEPR) Theory 406

the Octet Rule 402

Electron-Group Arrangements and Molecular Shapes 407

The Molecular Shape with Two Electron Groups (Linear Arrangement) 407 Molecular Shapes with Three Electron Groups (Trigonal Planar Arrangement) 408 Molecular Shapes with Four Electron

Groups (Tetrahedral Arrangement) 409 Molecular Shapes with Five Electron

Groups (Trigonal Bipyramidal Arrangement) 410

Molecular Shapes with Six Electron Groups (Octahedral Arrangement) 411

Using VSEPR Theory to Determine Molecular Shape 412

Molecular Shapes with More Than One Central Atom 415

## 10.3 Molecular Shape and Molecular Polarity 416

Behavior 419

Bond Polarity, Bond Angle, and Dipole Moment 417 The Effect of Molecular Polarity on

CHEMICAL CONNECTIONS TO SENSORY PHYSIOLOGY: MOLECULAR SHAPE, BIOLOGICAL RECEPTORS, AND THE SENSE OF SMELL 420

CHAPTER REVIEW GUIDE 421 PROBLEMS 424



### Theories of Covalent Bonding 428

#### 11.1 Valence Bond (VB) Theory and Orbital **Hybridization 429**

The Central Themes of VB Theory 429 Types of Hybrid Orbitals 430

#### 11.2 Modes of Orbital Overlap and the **Types of Covalent Bonds 436**

a Molecule 439

Orbital Overlap in Single and Multiple Bonds 436 Orbital Overlap and Rotation Within

#### 11.3 Molecular Orbital (MO) Theory and **Electron Delocalization 440**

The Central Themes of MO Theory 440 Homonuclear Diatomic Molecules of Period 2 Elements 442 Two Heteronuclear Diatomic Molecules: HF and NO 446 Two Polyatomic Molecules: Benzene and Ozone 447

**CHAPTER REVIEW GUIDE 448** PROBLEMS 450

# **CHAPTER**

#### Intermolecular Forces: Liquids, Solids, and Phase Changes 454

#### **12.1** An Overview of Physical States and Phase Changes 455

#### 12.2 Quantitative Aspects of Phase Changes 458

Heat Involved in Phase Changes 459 The Equilibrium Nature of Phase Changes 462 Phase Diagrams: Effect of Pressure and

Temperature on Physical State 466

#### **12.3** Types of Intermolecular Forces 468

How Close Can Molecules Approach Each Other? 468 Ion-Dipole Forces 469 Dipole-Dipole Forces 469 The Hydrogen Bond 470

Polarizability and Induced Dipole Forces 471

Dispersion (London) Forces 472

#### 12.4 Properties of the Liquid State 474

Surface Tension 475 Capillarity 475 Viscosity 476

#### 12.5 The Uniqueness of Water 477

Solvent Properties of Water 477 Thermal Properties of Water 477 Surface Properties of Water 478 The Unusual Density of Solid Water 478

#### 12.6 The Solid State: Structure, Properties, and Bonding 479

Structural Features of Solids 479

#### **TOOLS OF THE LABORATORY: X-RAY DIFFRACTION ANALYSIS AND SCANNING TUNNELING MICROSCOPY 486**

Types and Properties of Crystalline Solids 487 Amorphous Solids 490 Bonding in Solids: Molecular Orbital Band Theory 490

#### 12.7 Advanced Materials 493

Electronic Materials 493 Liquid Crystals 495 Ceramic Materials 498 Polymeric Materials 500 Nanotechnology: Designing Materials Atom by Atom 505

**CHAPTER REVIEW GUIDE 507** PROBLEMS 509



#### The Properties of Mixtures: Solutions and Colloids 516

#### 13.1 Types of Solutions: Intermolecular Forces and Solubility 518

Intermolecular Forces in Solution 518 Liquid Solutions and the Role of Molecular Polarity 519

Gas Solutions and Solid Solutions 521

#### 13.2 Intermolecular Forces and Biological Macromolecules 523

The Structures of Proteins 523 Dual Polarity in Soaps, Membranes, and Antibiotics 525 The Structure of DNA 527

#### 13.3 Why Substances Dissolve: Breaking **Down the Solution Process 528**

The Heat of Solution and Its Components 528

The Heat of Hydration: Dissolving Ionic Solids in Water 529

The Solution Process and the Change in Entropy 531

#### 13.4 Solubility as an Equilibrium Process 533 Effect of Temperature on Solubility 534

Effect of Pressure on Solubility 535

#### 13.5 Concentration Terms 536

Molarity and Molality 537 Parts of Solute by Parts of Solution 538 Interconverting Concentration Terms 540

#### 13.6 Colligative Properties of Solutions 541

Nonvolatile Nonelectrolyte Solutions 542 Using Colligative Properties to Find Solute Molar Mass 547

Volatile Nonelectrolyte Solutions 548 Strong Electrolyte Solutions 548 Applications of Colligative Properties 550

#### 13.7 The Structure and Properties of Colloids 552

**CHEMICAL CONNECTIONS TO ENVIRONMENTAL ENGINEERING:** 

**SOLUTIONS AND COLLOIDS IN WATER PURIFICATION 554** 

**CHAPTER REVIEW GUIDE 556** PROBLEMS 559

## **CHAPTER**

### Periodic Patterns in the Main-Group Elements 568

#### 14.1 Hydrogen, the Simplest Atom 569

Where Hydrogen Fits in the Periodic Table 569 Highlights of Hydrogen Chemistry 570

14.2 Trends Across the Periodic Table:

### The Period 2 Elements 571

#### 14.3 Group 1A(1): The Alkali Metals 574

Why the Alkali Metals Are Unusual Physically 574

Why the Alkali Metals Are So Reactive 576

#### 14.4 Group 2A(2): The Alkaline Earth Metals 576

How the Alkaline Earth and Alkali Metals Compare Physically 577 How the Alkaline Earth and Alkali Metals Compare Chemically 577 Diagonal Relationships: Lithium and Magnesium 577

#### **14.5** Group 3A(13): The Boron Family 579

How the Transition Elements Influence This Group's Properties 579 Features That First Appear in This Group's Chemical Properties 579

Highlights of Boron Chemistry 581 Diagonal Relationships: Beryllium and Aluminum 582

#### 14.6 Group 4A(14): The Carbon Family 582

How Type of Bonding Affects Physical Properties 582 How Bonding Changes in This Group's

Compounds 585 Highlights of Carbon Chemistry 585 Highlights of Silicon Chemistry 587

Diagonal Relationships: Boron and Silicon 588

#### 14.7 Group 5A(15): The Nitrogen Family 588

The Wide Range of Physical Behavior 590 Patterns in Chemical Behavior 590 Highlights of Nitrogen Chemistry 591 Highlights of Phosphorus Chemistry 594

#### 14.8 Group 6A(16): The Oxygen Family 596

How the Oxygen and Nitrogen Families Compare Physically 596 How the Oxygen and Nitrogen Families Compare Chemically 598 Highlights of Oxygen Chemistry: Range of Oxide Properties 599 Highlights of Sulfur Chemistry 599

#### 14.9 Group 7A(17): The Halogens 601

Physical Behavior of the Halogens 601 Why the Halogens Are So Reactive 601 Highlights of Halogen Chemistry 603

#### Group 8A(18): The Noble Gases 606

How the Noble Gases and Alkali Metals Contrast Physically 608 How Noble Gases Can Form Compounds 608

**CHAPTER REVIEW GUIDE 608** PROBLEMS 609



#### Organic Compounds and the Atomic Properties of Carbon 616

#### 15.1 The Special Nature of Carbon and the Characteristics of Organic Molecules 617

The Structural Complexity of Organic Molecules 618 The Chemical Diversity of Organic Molecules 618

## 15.2 The Structures and Classes of Hydrocarbons 620

Carbon Skeletons and Hydrogen Skins 620 Alkanes: Hydrocarbons with Only Single Bonds 622 Dispersion Forces and the Physical Properties of Alkanes 625

Constitutional Isomerism 625 Chiral Molecules and Optical Isomerism 626

Alkenes: Hydrocarbons with Double Bonds 628 Restricted Rotation and Geometric (*Cis-Trans*) Isomerism 628 Alkynes: Hydrocarbons with Triple Bonds 630

Aromatic Hydrocarbons: Cyclic Molecules with Delocalized  $\pi$  Electrons 631 Variations on a Theme: Catenated Inorganic Hydrides 632

#### **TOOLS OF THE LABORATORY:**

NUCLEAR MAGNETIC RESONANCE (NMR) SPECTROSCOPY 633

## 15.3 Some Important Classes of Organic Reactions 635

Types of Organic Reactions 635 The Redox Process in Organic Reactions 637

## **15.4** Properties and Reactivities of Common Functional Groups 638

Functional Groups with Only Single Bonds 638 Functional Groups with Double Bonds 643 Functional Groups with Both Single and Double Bonds 646 Functional Groups with Triple Bonds 650

#### 15.5 The Monomer-Polymer Theme I: Synthetic Macromolecules 652 Addition Polymers 652

Condensation Polymers 653

#### 15.6 The Monomer-Polymer Theme II: Biological Macromolecules 654

Sugars and Polysaccharides 654 Amino Acids and Proteins 656 Nucleotides and Nucleic Acids 658

CHEMICAL CONNECTIONS TO GENETICS AND FORENSICS: DNA SEQUENCING AND FINGERPRINTING 663

CHAPTER REVIEW GUIDE 665 PROBLEMS 667

# CHAPTER 16

#### Kinetics: Rates and Mechanisms of Chemical Reactions 674

#### 16.1 Focusing on Reaction Rate 675

#### 16.2 Expressing the Reaction Rate 678

Average, Instantaneous, and Initial Reaction Rates 678 Expressing Rate in Terms of Reactant and Product Concentrations 680

16.3 The Rate Law and Its Components 682

Some Laboratory Methods for Determining the Initial Rate 683

> Determining Reaction Orders 683 Determining the Rate Constant 688

## 16.4 Integrated Rate Laws: Concentration Changes over Time 691

Integrated Rate Laws for First-, Second-, and Zero-Order Reactions 692

Determining Reaction Orders from an Integrated Rate Law 693 Reaction Half-Life 695

#### **16.5** Theories of Chemical Kinetics 699

Collision Theory: Basis of the Rate Law 699 Transition State Theory: What the Activation Energy Is Used For 703

## 16.6 Reaction Mechanisms: The Steps from Reactant to Product 706

Elementary Reactions and Molecularity 706 The Rate-Determining Step of a Reaction Mechanism 708

Correlating the Mechanism with the Rate Law 708

#### 16.7 Catalysis: Speeding Up a Reaction 712

The Basis of Catalytic Action 712 Homogeneous Catalysis 713 Heterogeneous Catalysis 714 Kinetics and Function of Biological Catalysts 714

CHEMICAL CONNECTIONS TO ATMOSPHERIC SCIENCE: DEPLETION OF EARTH'S OZONE LAYER 716

CHAPTER REVIEW GUIDE 718 PROBLEMS 721



#### Equilibrium: The Extent of Chemical Reactions 730

- 17.1 The Equilibrium State and the Equilibrium Constant 731
- 17.2 The Reaction Quotient and the Equilibrium Constant 734

The Changing Value of the Reaction
Quotient 734
Writing the Reaction Quotient in its Varion

Writing the Reaction Quotient in Its Various Forms 735

Terms: Relation Between  $K_c$  and  $K_p$  740

17.4 Comparing Q and K to Determine Reaction Direction 742

17.3 Expressing Equilibria with Pressure

17.5 How to Solve Equilibrium Problems 744

Using Quantities to Find the Equilibrium
Constant 745

Using the Equilibrium Constant to Find Ouantities 747

Problems Involving Mixtures of Reactants and Products 752

#### 17.6 Reaction Conditions and Equilibrium: Le Châtelier's Principle 754

The Effect of a Change in Concentration 754 The Effect of a Change in Pressure (Volume) 757 The Effect of a Change in Temperature 759 The Lack of Effect of a Catalyst 761 Applying Le Châtelier's Principle to the Synthesis of Ammonia 763

CHEMICAL CONNECTIONS TO
CELLULAR METABOLISM: DESIGN AND
CONTROL OF A METABOLIC PATHWAY 765

CHAPTER REVIEW GUIDE 766 PROBLEMS 768

## CHAPTER

#### Acid-Base Equilibria 776

#### 18.1 Acids and Bases in Water 778

Release of H<sup>+</sup> or OH<sup>-</sup> and the Arrhenius Acid-Base Definition 778 Variation in Acid Strength: The Acid-Dissociation Constant (K<sub>a</sub>) 779 Classifying the Relative Strengths of Acids and Bases 781

## 18.2 Autoionization of Water and the pH Scale 782

The Equilibrium Nature of Autoionization: The Ion-Product Constant for Water  $(K_w)$  783

Expressing the Hydronium Ion Concentration: The pH Scale 784

#### 18.3 Proton Transfer and the Brønsted-Lowry Acid-Base Definition 787

Conjugate Acid-Base Pairs 788 Relative Acid-Base Strength and the Net Direction of Reaction 789

#### 18.4 Solving Problems Involving Weak-Acid Equilibria 792

Finding K<sub>a</sub> Given Concentrations 793 Finding Concentrations Given K<sub>a</sub> 794 The Effect of Concentration on the Extent of Acid Dissociation 795 The Behavior of Polyprotic Acids 797

## 18.5 Molecular Properties and Acid Strength 799

Acid Strength of Nonmetal Hydrides 799 Acid Strength of Oxoacids 800 Acidity of Hydrated Metal Ions 801

## 18.6 Weak Bases and Their Relation to Weak Acids 802

Molecules as Weak Bases: Ammonia and the Amines 802

Anions of Weak Acids as Weak Bases 804 The Relation Between  $K_a$  and  $K_b$  of a Conjugate Acid-Base Pair 805

## 18.7 Acid-Base Properties of Salt Solutions 807

Salts That Yield Neutral Solutions 807
Salts That Yield Acidic Solutions 807
Salts That Yield Basic Solutions 807
Salts of Weakly Acidic Cations and Weakly
Basic Anions 808
Salts of Amphiprotic Anions 809

#### 18.8 Generalizing the Brønsted-Lowry Concept: The Leveling Effect 810

## 18.9 Electron-Pair Donation and the Lewis Acid-Base Definition 811

Molecules as Lewis Acids 812 Metal Cations as Lewis Acids 813 An Overview of Acid-Base Definitions 814

CHAPTER REVIEW GUIDE 814 PROBLEMS 817



#### Ionic Equilibria in Aqueous Systems 826

#### 19.1 Equilibria of Acid-Base Buffers 827

What a Buffer Is and How It Works: The Common-Ion Effect 827 The Henderson-Hasselbalch Equation 832 Buffer Capacity and Buffer Range 833 Preparing a Buffer 835

#### 19.2 Acid-Base Titration Curves 837

Monitoring pH with Acid-Base Indicators 837 Strong Acid–Strong Base Titration Curves 838 Weak Acid–Strong Base Titration Curves 840 Weak Base–Strong Acid Titration Curves 843 Titration Curves for Polyprotic Acids 844 Amino Acids as Biological Polyprotic Acids 845

The Ion-Product Expression  $(Q_{sp})$  and the

## 19.3 Equilibria of Slightly Soluble Ionic Compounds 846

Solubility-Product Constant  $(K_{sp})$  846 Calculations Involving the Solubility-Product Constant 848 Effect of a Common Ion on Solubility 850 Effect of pH on Solubility 852 Applying Ionic Equilibria to the Formation of a Limestone Cave 853 Predicting the Formation of a Precipitate:  $Q_{sp}$  vs.  $K_{sp}$  853 Separating lons by Selective Precipitation and Simultaneous Equilibria 856

CHEMICAL CONNECTIONS TO ENVIRONMENTAL SCIENCE: THE ACID-

#### **RAIN PROBLEM 857**

#### **19.4** Equilibria Involving Complex Ions 859

Formation of Complex Ions 859 Complex Ions and the Solubility of Precipitates 861 Complex Ions of Amphoteric Hydroxides 863

CHAPTER REVIEW GUIDE 865 PROBLEMS 868

## CHAPTER 20

## Thermodynamics: Entropy, Free Energy, and the Direction of Chemical Reactions 876

## **20.1** The Second Law of Thermodynamics: Predicting Spontaneous Change 877

The First Law of Thermodynamics Does Not Predict Spontaneous Change 878
 The Sign of ΔH Does Not Predict Spontaneous Change 878
 Freedom of Particle Motion and Dispersal of Kinetic Energy 879
 Entropy and the Number of Microstates 880
 Entropy and the Second Law of Thermodynamics 883
 Standard Molar Entropies and the Third

Predicting Relative S° of a System 883

## **20.2** Calculating the Change in Entropy of a Reaction 888

Entropy Changes in the System: Standard Entropy of Reaction ( $\Delta S_{rxn}^{\circ}$ ) 888 Entropy Changes in the Surroundings: The Other Part of the Total 889 The Entropy Change and the Equilibrium State 891

Spontaneous Exothermic and Endothermic Changes 892

#### 20.3 Entropy, Free Energy, and Work 893

Free Energy Change and Reaction Spontaneity 893 Calculating Standard Free Energy Changes 894 The Free Energy Change and the Work a System Can Do 896 The Effect of Temperature on Reaction Spontaneity 897 Coupling of Reactions to Drive a

Nonspontaneous Change 901
CHEMICAL CONNECTIONS TO
BIOLOGICAL ENERGETICS:

THE UNIVERSAL ROLE OF ATP 902

## 20.4 Free Energy, Equilibrium, and Reaction Direction 903

CHAPTER REVIEW GUIDE 909 PROBLEMS 912



#### Electrochemistry: Chemical Change and Electrical Work 918

## 21.1 Redox Reactions and Electrochemical Cells 919

A Quick Review of Oxidation-Reduction Concepts 919

Half-Reaction Method for Balancing Redox Reactions 920

An Overview of Electrochemical Cells 924

#### 21.2 Voltaic Cells: Using Spontaneous Reactions to Generate Electrical Energy 925

Construction and Operation of a Voltaic Cell 926 Notation for a Voltaic Cell 928 Why Does a Voltaic Cell Work? 929

## 21.3 Cell Potential: Output of a Voltaic Cell 930

Standard Cell Potential ( $E_{cell}^{\circ}$ ) 930 Relative Strengths of Oxidizing and Reducing Agents 933 Using  $E_{half-cell}^{\circ}$  Values to Write Spontaneous Redox Reactions 934 Explaining the Activity Series of the Metals 937

#### 21.4 Free Energy and Electrical Work 939

Standard Cell Potential and the Equilibrium Constant 939

The Effect of Concentration on Cell Potential 941

Following Changes in Potential During Cell Operation 943 Concentration Cells 944

## 21.5 Electrochemical Processes in Batteries 947

Primary (Nonrechargeable) Batteries 947 Secondary (Rechargeable) Batteries 949 Fuel Cells 950

## 21.6 Corrosion: An Environmental Voltaic Cell 951

The Corrosion of Iron 951
Protecting Against the Corrosion
of Iron 953

#### 21.7 Electrolytic Cells: Using Electrical Energy to Drive Nonspontaneous Reactions 954

Construction and Operation of an Electrolytic Cell 954 Predicting the Products of Electrolysis 955 Stoichiometry of Electrolysis: The Relation Between Amounts of Charge and Products 959

## CHEMICAL CONNECTIONS TO BIOLOGICAL ENERGETICS: CELLULAR ELECTROCHEMISTRY AND THE

**PRODUCTION OF ATP 962** 

CHAPTER REVIEW GUIDE 964 PROBLEMS 967

# CHAPTER 22

### The Elements in Nature and Industry 976

#### 22.1 How the Elements Occur in Nature 977

Earth's Structure and the Abundance of the Elements 977 Sources of the Elements 981

## 22.2 The Cycling of Elements Through the Environment 982

The Carbon Cycle 982 The Nitrogen Cycle 984 The Phosphorus Cycle 986

## 22.3 Metallurgy: Extracting a Metal from Its Ore 988

Pretreating the Ore 989 Converting Mineral to Element 990 Refining and Alloying the Element 992

## **22.4** Tapping the Crust: Isolation and Uses of Selected Elements 994

Producing the Alkali Metals: Sodium and Potassium 994

The Indispensable Three: Iron, Copper, and Aluminum 996

Mining the Sea for Magnesium 1002 The Sources and Uses of Hydrogen 1003

#### 22.5 Chemical Manufacturing: Two Case Studies 1006

Sulfuric Acid, the Most Important Chemical 1006 The Chlor-Alkali Process 1008

CHAPTER REVIEW GUIDE 1009 PROBLEMS 1010



#### **Transition Elements and Their Coordination Compounds 1016**

## **23.1** Properties of the Transition Elements 1017

Electron Configurations of the Transition Metals and Their Ions 1018 Atomic and Physical Properties of the Transition Elements 1020 Chemical Properties of the Transition Elements 1022

#### 23.2 The Inner Transition Elements 1024

The Lanthanides 1024
The Actinides 1025

#### 23.3 Coordination Compounds 1026

Complex Ions: Coordination Numbers, Geometries, and Ligands 1026 Formulas and Names of Coordination Compounds 1028 Isomerism in Coordination Compounds 1031

## 23.4 Theoretical Basis for the Bonding and Properties of Complexes 1034

Applying Valence Bond Theory to Complex Ions 1034 Crystal Field Theory 1036 CHEMICAL CONNECTIONS TO NUTRITIONAL SCIENCE: TRANSITION METALS AS ESSENTIAL DIETARY TRACE ELEMENTS 1043

CHAPTER REVIEW GUIDE 1045 PROBLEMS 1046

# CHAPTER 24

### **Nuclear Reactions and Their Applications 1052**

## 24.1 Radioactive Decay and Nuclear Stability 1053

Comparing Chemical and Nuclear Change 1054
The Components of the Nucleus: Terms and Notation 1054
The Discovery of Radioactivity and the Types of Emissions 1055
Modes of Radioactive Decay; Balancing Nuclear Equations 1055
Nuclear Stability and the Mode of Decay 1058

#### **24.2** The Kinetics of Radioactive Decay 1062

Detection and Measurement of Radioactivity 1063 The Rate of Radioactive Decay 1064 Radioisotopic Dating 1067

## 24.3 Nuclear Transmutation: Induced Changes in Nuclei 1069

Early Transmutation Experiments; Nuclear Shorthand Notation 1070 Particle Accelerators and the Transuranium Elements 1070

## 24.4 Effects of Nuclear Radiation on Matter 1072

Effects of Ionizing Radiation on Living Tissue 1073 Background Sources of Ionizing Radiation 1075 Assessing the Risk from Ionizing Radiation 1076

#### 24.5 Applications of Radioisotopes 1077

Radioactive Tracers 1077 Additional Applications of Ionizing Radiation 1080

## 24.6 The Interconversion of Mass and Energy 1081

The Mass Difference Between a Nucleus and Its Nucleons 1081 Nuclear Binding Energy and Binding Energy per Nucleon 1082

#### 24.7 Applications of Fission and Fusion 1084

The Process of Nuclear Fission 1084 The Promise of Nuclear Fusion 1088

CHEMICAL CONNECTIONS TO
COSMOLOGY: ORIGIN OF THE ELEMENTS
IN THE STARS 1090

CHAPTER REVIEW GUIDE 1092 PROBLEMS 1094

Appendix A Common Mathematical
Operations in Chemistry A-1
Appendix B Standard Thermodynamic Values

**Appendix B** Standard Thermodynamic Values for Selected Substances A-5

**Appendix C** Equilibrium Constants for Selected Substances A-8

Appendix D Standard Electrode (Half-Cell) Potentials A-14 Appendix E Answers to Selected Problems A-15 Glossary G-1 Credits C-1 Index I-1

#### LIST OF SAMPLE PROBLEMS (Molecular-scene problems are shown in color.)

#### **Chapter 1**

- 1.1 Visualizing Change on the Atomic Scale 6
- 1.2 Distinguishing Between Physical and Chemical Change 7
- 1.3 Converting Units of Length 20
- 1.4 Converting Units of Volume 21
- 1.5 Converting Units of Mass 21
- 1.6 Converting Units Raised to a Power 22
- 1.7 Calculating Density from Mass and Volume 24
- 1.8 Converting Units of Temperature 26
- 1.9 Determining the Number of Significant Figures 28
- 1.10 Significant Figures and Rounding 30

#### **Chapter 2**

- 2.1 Distinguishing Elements, Compounds, and Mixtures at the Atomic Scale 43
- 2.2 Calculating the Mass of an Element in a Compound 46
- 2.3 Visualizing the Mass Laws 48
- 2.4 Determining the Number of Subatomic Particles in the Isotopes of an Element 54
- 2.5 Calculating the Atomic Mass of an Element 55
- 2.6 Identifying an Element from Its Z Value 60
- 2.7 Predicting the Ion an Element Forms 63
- 2.8 Naming Binary Ionic Compounds 66
- 2.9 Determining Formulas of Binary Ionic Compounds 67
- 2.10 Determining Names and Formulas of Ionic Compounds of Metals That Form More Than One Ion 68
- 2.11 Determining Names and Formulas of Ionic Compounds Containing Polyatomic Ions 69
- 2.12 Recognizing Incorrect Names and Formulas of Ionic Compounds 69
- 2.13 Determining Names and Formulas of Anions and Acids 70
- 2.14 Determining Names and Formulas of Binary Covalent Compounds 71
- 2.15 Recognizing Incorrect Names and Formulas of Binary Covalent Compounds 72
- 2.16 Calculating the Molecular Mass of a Compound 73
- 2.17 Using Molecular Depictions to Determine Formula, Name, and Mass 74

#### Chapter 3

- 3.1 Converting Between Mass and Amount of an Element 94
- 3.2 Converting Between Number of Entities and Amount of an Element 95
- 3.3 Converting Between Number of Entities and Mass of an Element 95
- 3.4 Converting Between Number of Entities and Mass of a Compound I 96
- 3.5 Converting Between Number of Entities and Mass of a Compound II 97
- 3.6 Calculating the Mass Percent of Each Element in a Compound from the Formula 98
- 3.7 Calculating the Mass of an Element in a Compound 100
- 3.8 Determining an Empirical Formula from Amounts of Elements 101
- 3.9 Determining an Empirical Formula from Masses of Elements 102
- 3.10 Determining a Molecular Formula from Elemental Analysis and Molar Mass 103
- 3.11 Determining a Molecular Formula from Combustion Analysis 104
- 3.12 Balancing Chemical Equations 110
- 3.13 Balancing an Equation from a Molecular Scene 111
- 3.14 Calculating Quantities of Reactants and Products: Amount (mol) to Amount (mol) 114

- 3.15 Calculating Quantities of Reactants and Products: Amount (mol) to Mass (g) 114
- 3.16 Calculating Quantities of Reactants and Products: Mass to Mass 115
- 3.17 Writing an Overall Equation for a Reaction Sequence 116
- 3.18 Using Molecular Depictions in a Limiting-Reactant Problem 119
- 3.19 Calculating Quantities in a Limiting-Reactant Problem: Amount to Amount 120
- 3.20 Calculating Quantities in a Limiting-Reactant Problem: Mass to Mass 121
- 3.21 Calculating Percent Yield 123

#### **Chapter 4**

- 4.1 Using Molecular Scenes to Depict an Ionic Compound in Aqueous Solution 142
- 4.2 Determining Amount (mol) of lons in Solution 143
- 4.3 Calculating the Molarity of a Solution 144
- 4.4 Calculating Mass of Solute in a Given Volume of Solution 145
- 4.5 Determining Amount (mol) of lons in a Solution 145
- 4.6 Preparing a Dilute Solution from a Concentrated Solution 147
- 1.7 Visualizing Changes in Concentration 148
- 4.8 Predicting Whether a Precipitation Reaction Occurs: Writing Ionic Equations 153
- 4.9 Using Molecular Depictions in Precipitation Reactions 154
- 4.10 Calculating Amounts of Reactants and Products in a Precipitation Reaction 156
- 4.11 Solving a Limiting-Reactant Problem for a Precipitation Reaction 157
- 4.12 Determining the Number of H<sup>+</sup> (or OH<sup>-</sup>) lons in Solution 160
- 4.13 Writing Ionic Equations for Acid-Base Reactions 161
- 4.14 Writing Proton-Transfer Equations for Acid-Base Reactions 165
- 4.15 Calculating the Amounts of Reactants and Products in an Acid-Base Reaction 165
- 4.16 Finding the Concentration of an Acid from a Titration 167
- 4.17 Determining the Oxidation Number of Each Element in a Compound (or lon) 170
- 4.18 Identifying Redox Reactions and Oxidizing and Reducing Agents 171
- 4.19 Finding the Amount of Reducing Agent by Titration 173
- 4.20 Identifying the Type of Redox Reaction 180

#### **Chapter 5**

- 5.1 Converting Units of Pressure 203
- 5.2 Applying the Volume-Pressure Relationship 211
- 5.3 Applying the Volume-Temperature and Pressure-Temperature Relationships 211
- 5.4 Applying the Volume-Amount and Pressure-Amount Relationships 212
- 5.5 Applying the Volume-Pressure-Temperature Relationship 213
- 5.6 Solving for an Unknown Gas Variable at Fixed Conditions 214
- 5.7 Using Gas Laws to Determine a Balanced Equation 214
- 5.8 Calculating Gas Density 216
- 5.9 Finding the Molar Mass of a Volatile Liquid 218
- 5.10 Applying Dalton's Law of Partial Pressures 220
- 5.11 Calculating the Amount of Gas Collected over Water 221
- 5.12 Using Gas Variables to Find Amounts of Reactants or Products I 222
- 5.13 Using Gas Variables to Find Amounts of Reactants or Products II 223
- 5.14 Applying Graham's Law of Effusion 230

#### **Chapter 6**

- 6.1 Determining the Change in Internal Energy of a System 256
- 6.2 Calculating Pressure-Volume Work Done by or on a System 258
- 6.3 Drawing Enthalpy Diagrams and Determining the Sign of  $\Delta H~260$
- 6.4 Finding the Quantity of Heat from a Temperature Change 262
- 6.5 Determining the Specific Heat Capacity of a Solid 263
- 6.6 Determining the Enthalpy Change of an Aqueous Reaction 263
- 6.7 Calculating the Heat of a Combustion Reaction 265
- 6.8 Using the Enthalpy Change of a Reaction ( $\Delta H$ ) to Find the Amount of a Substance 267
- 6.9 Using Hess's Law to Calculate an Unknown  $\Delta H$  269
- 6.10 Writing Formation Equations 270
- 6.11 Calculating  $\Delta H_{\rm rxn}^{\circ}$  from  $\Delta H_{\rm f}^{\circ}$  Values 272

#### **Chapter 7**

- 7.1 Interconverting Wavelength and Frequency 289
- 7.2 Interconverting Energy, Wavelength, and Frequency 293
- 7.3 Determining  $\Delta E$  and  $\lambda$  of an Electron Transition 298
- 7.4 Calculating the de Broglie Wavelength of an Electron 303
- 7.5 Applying the Uncertainty Principle 305
- 7.6 Determining Quantum Numbers for an Energy Level 309
- 7.7 Determining Sublevel Names and Orbital Quantum Numbers 310
- 7.8 Identifying Incorrect Quantum Numbers 310

#### **Chapter 8**

- 8.1 Correlating Quantum Numbers and Orbital Diagrams 329
- 8.2 Determining Electron Configurations 335
- 8.3 Ranking Elements by Atomic Size 338
- 8.4 Ranking Elements by First Ionization Energy 341
- 8.5 Identifying an Element from Its Ionization Energies 342
- 8.6 Writing Electron Configurations of Main-Group Ions 347
- 8.7 Writing Electron Configurations and Predicting Magnetic Behavior of Transition Metal lons 350
- 8.8 Ranking lons by Size 351

#### **Chapter 9**

- 9.1 Depicting Ion Formation 362
- 9.2 Predicting Relative Lattice Energy from Ionic Properties 366
- $9.3 \;\; \text{Comparing Bond Length and Bond Strength} \;\; 372$
- 9.4 Using Bond Energies to Calculate  $\Delta H_{rxn}^{\circ}$  378
- 9.5 Determining Bond Polarity from EN Values 383

#### Chapter 10

- 10.1 Writing Lewis Structures for Species with One Central Atom 397
- 10.2 Writing Lewis Structures for Molecules with More Than One Central Atom 398
- 10.3 Writing Lewis Structures for Molecules with Multiple Bonds 398
- 10.4 Writing Resonance Structures 400
- 10.5 Writing Lewis Structures for Octet-Rule Exceptions 405
- 10.6 Examining Shapes with Two, Three, or Four Electron Groups 414
- 10.7 Examining Shapes with Five or Six Electron Groups 414
- 10.8 Predicting Molecular Shapes with More Than One Central Atom 416
- 10.9 Predicting the Polarity of Molecules 418

#### **Chapter 11**

- 11.1 Postulating Hybrid Orbitals in a Molecule 435
- 11.2 Describing the Types of Bonds in Molecules 438
- 11.3 Predicting Stability of Species Using MO Diagrams 442
- 11.4 Using MO Theory to Explain Bond Properties 446

#### **Chapter 12**

- 12.1 Finding the Heat of a Phase Change Depicted by Molecular Scenes 461
- 12.2 Applying the Clausius-Clapeyron Equation 464
- 12.3 Using a Phase Diagram to Predict Phase Changes 467
- 12.4 Drawing Hydrogen Bonds Between Molecules of a Substance 471
- 12.5 Identifying the Types of Intermolecular Forces 473
- 12.6 Determining the Number of Particles per Unit Cell and the Coordination Number 480
- 12.7 Determining Atomic Radius 484
- 12.8 Determining Atomic Radius from the Unit Cell 485

#### **Chapter 13**

- 13.1 Predicting Relative Solubilities 521
- 13.2 Calculating an Aqueous Ionic Heat of Solution 531
- 13.3 Using Henry's Law to Calculate Gas Solubility 536
- 13.4 Calculating Molality 537
- 13.5 Expressing Concentrations in Parts by Mass, Parts by Volume, and Mole Fraction 539
- 13.6 Interconverting Concentration Terms 540
- 13.7 Using Raoult's Law to Find  $\Delta P$  543
- 13.8 Determining Boiling and Freezing Points of a Solution 545
- 13.9 Determining Molar Mass from Osmotic Pressure 547
- 13.10 Depicting Strong Electrolyte Solutions 549

#### **Chapter 15**

- 15.1 Drawing Hydrocarbons 621
- 15.2 Naming Alkanes, Alkenes, and Alkynes 630
- 15.3 Recognizing the Type of Organic Reaction 636
- 15.4 Predicting the Reactions of Alcohols, Alkyl Halides, and Amines 642
- 15.5 Predicting the Steps in a Reaction Sequence 645
- 15.6 Predicting Reactions of the Carboxylic Acid Family 649
- 15.7 Recognizing Functional Groups 651

#### **Chapter 16**

- 16.1 Expressing Rate in Terms of Changes in Concentration with Time 681
- 16.2 Determining Reaction Orders from Rate Laws 685
- 16.3 Determining Reaction Orders and Rate Constants from Rate Data 689
- 16.4 Determining Reaction Orders from Molecular Scenes 690
- 16.5 Determining the Reactant Concentration after a Given Time 692
- 16.6 Using Molecular Scenes to Find Quantities at Various Times 696
- 16.7 Determining the Half-Life of a First-Order Reaction 697
- 16.8 Determining the Energy of Activation 702
- 16.9 Drawing Reaction Energy Diagrams and Transition States 705
- 16.10 Determining Molecularities and Rate Laws for Elementary Steps 707
- 16.11 Identifying Intermediates and Correlating Rate Laws and Reaction Mechanisms 710

#### **Chapter 17**

- 17.1 Writing the Reaction Quotient from the Balanced Equation 736
- 17.2 Writing the Reaction Quotient and Finding K for an Overall Reaction 737
- 17.3 Finding the Equilibrium Constant for an Equation Multiplied by a Common Factor 739
- 17.4 Converting Between  $K_c$  and  $K_p$  741
- 17.5 Using Molecular Scenes to Determine Reaction Direction 743
- 17.6 Using Concentrations to Determine Reaction Direction 744

- 17.7 Calculating K<sub>c</sub> from Concentration Data 746
- 17.8 Determining Equilibrium Concentrations from K<sub>c</sub> 747
- 17.9 Determining Equilibrium Concentrations from Initial Concentrations and  $K_c$  748
- 17.10 Making a Simplifying Assumption to Calculate Equilibrium Concentrations 750
- 17.11 Predicting Reaction Direction and Calculating Equilibrium Concentrations 752
- 17.12 Predicting the Effect of a Change in Concentration on the Equilibrium Position 756
- 17.13 Predicting the Effect of a Change in Volume (Pressure) on the Equilibrium Position 758
- 17.14 Predicting the Effect of a Change in Temperature on the Equilibrium Position 760
- 17.15 Determining Equilibrium Parameters from Molecular Scenes 762

#### **Chapter 18**

- 18.1 Classifying Acid and Base Strength from the Chemical Formula 782
- 18.2 Calculating  $[H_3O^+]$  or  $[OH^-]$  in Aqueous Solution 784
- 18.3 Calculating  $[H_3O^+]$ , pH,  $[OH^-]$ , and pOH for Strong Acids and Bases 786
- 18.4 Identifying Conjugate Acid-Base Pairs 789
- 18.5 Predicting the Net Direction of an Acid-Base Reaction 790
- 18.6 Using Molecular Scenes to Predict the Net Direction of an Acid-Base Reaction 791
- 18.7 Finding  $K_a$  of a Weak Acid from the Solution pH 793
- 18.8 Determining Concentration and pH from K<sub>a</sub> and Initial [HA] 794
- 18.9 Finding the Percent Dissociation of a Weak Acid 796
- 18.10 Calculating Equilibrium Concentrations for a Polyprotic Acid 798
- 18.11 Determining pH from K<sub>b</sub> and Initial [B] 803
- 18.12 Determining the pH of a Solution of A<sup>-</sup> 805
- 18.13 Predicting Relative Acidity of Salt Solutions from Reactions of the lons with Water 808
- 18.14 Predicting the Relative Acidity of a Salt Solution from  $K_{\rm a}$  and  $K_{\rm b}$  of the lons 810
- 18.15 Identifying Lewis Acids and Bases 813

#### **Chapter 19**

- 19.1 Calculating the Effect of Added H<sub>3</sub>O<sup>+</sup> or OH<sup>-</sup> on Buffer pH 830
- 19.2 Using Molecular Scenes to Examine Buffers 834
- 19.3 Preparing a Buffer 835
- 19.4 Finding the pH During a Weak Acid-Strong Base Titration 842
- 19.5 Writing Ion-Product Expressions 847
- 19.6 Determining  $K_{sp}$  from Solubility 848
- 19.7 Determining Solubility from  $K_{sp}$  849
- 19.8 Calculating the Effect of a Common Ion on Solubility 851
- 19.9 Predicting the Effect on Solubility of Adding Strong Acid 852
- 19.10 Predicting Whether a Precipitate Will Form 854
- 19.11 Using Molecular Scenes to Predict Whether a Precipitate Will Form 854
- 19.12 Separating lons by Selective Precipitation 856
- 19.13 Calculating the Concentration of a Complex Ion 860
- 19.14 Calculating the Effect of Complex-Ion Formation on Solubility 862

#### **Chapter 20**

- 20.1 Predicting Relative Entropy Values 887
- 20.2 Calculating the Standard Entropy of Reaction,  $\Delta S_{rxn}^{\circ}$  889
- 20.3 Determining Reaction Spontaneity 890
- 20.4 Calculating  $\Delta G_{rxn}^{\circ}$  from Enthalpy and Entropy Values 894
- 20.5 Calculating  $\Delta G_{\rm rxn}^{\circ}$  from  $\Delta G_{\rm f}^{\circ}$  Values 896
- 20.6 Using Molecular Scenes to Determine the Signs of  $\Delta H, \Delta S,$  and  $\Delta G$  898
- 20.7 Determining the Effect of Temperature on  $\Delta G$  899
- 20.8 Finding the Temperature at Which a Reaction Becomes Spontaneous 900
- 20.9 Exploring the Relationship Between  $\Delta G^{\circ}$  and K 904
- 20.10 Using Molecular Scenes to Find  $\Delta G$  for a Reaction at Nonstandard Conditions 905
- 20.11 Calculating  $\Delta G$  at Nonstandard Conditions 907

#### **Chapter 21**

- 21.1 Balancing a Redox Reaction in Basic Solution 922
- 21.2 Describing a Voltaic Cell with Diagram and Notation 928
- 21.3 Using  $E_{\text{half-cell}}^{\circ}$  to Find  $E_{\text{cell}}^{\circ}$  931
- 21.4 Calculating an Unknown  $E_{\text{half-cell}}^{\circ}$  from  $E_{\text{cell}}^{\circ}$  933
- 21.5 Writing Spontaneous Redox Reactions and Ranking Oxidizing and Reducing Agents by Strength 936
- 21.6 Calculating K and  $\Delta G^{\circ}$  from  $E_{\text{cell}}^{\circ}$  940
- 21.7 Using the Nernst Equation to Calculate  $E_{cell}$  942
- 21.8 Calculating the Potential of a Concentration Cell 945
- 21.9 Predicting the Electrolysis Products of a Molten Salt Mixture 956
- 21.10 Predicting the Electrolysis Products of Aqueous Salt Solutions 958
- 21.11 Applying the Relationship Among Current, Time, and Amount of Substance 960

#### Chapter 23

- 23.1 Writing Electron Configurations of Transition Metal Atoms and Ions 1020
- 23.2 Finding the Number of Unpaired Electrons 1025
- 23.3 Finding the Coordination Number and Charge of the Central Metal Ion in a Coordination Compound 1029
- 23.4 Writing Names and Formulas of Coordination Compounds 1030
- 23.5 Determining the Type of Stereoisomerism 1034
- 23.6 Ranking Crystal Field Splitting Energies ( $\Delta$ ) for Complex lons of a Metal 1040
- 23.7 Identifying High-Spin and Low-Spin Complex Ions 1041

#### **Chapter 24**

- 24.1 Writing Equations for Nuclear Reactions 1058
- 24.2 Predicting Nuclear Stability 1060
- 24.3 Predicting the Mode of Nuclear Decay 1061
- 24.4 Calculating the Specific Activity and the Decay Constant of a Radionuclide 1064
- 24.5 Finding the Number of Radioactive Nuclei 1066
- 24.6 Applying Radiocarbon Dating 1069
- 24.7 Calculating the Binding Energy per Nucleon 1083