

## DETAILED CONTENTS

## CHAPTER

## 1

## 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  
 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

## CHAPTER

## 3

## 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

## 4

## 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  $\text{H}_2\text{O}$  from  $\text{H}^+$  and  $\text{OH}^-$  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

## 5

## 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

## CHAPTER

## 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 Change 256

**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

**6.4 Stoichiometry of Thermochemical Equations 266****6.5 Hess's Law: Finding  $\Delta H$  of Any Reaction 267****6.6 Standard Enthalpies of Reaction ( $\Delta H_{\text{rxn}}^\circ$ ) 270**

Formation Equations and Their Standard Enthalpy Changes 270  
 Determining  $\Delta H_{\text{rxn}}^\circ$  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

## 7

## Quantum Theory and Atomic Structure 286

**7.1 The Nature of Light 287**

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

**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

## 8

## 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 Ions 346

CHAPTER REVIEW GUIDE 352

PROBLEMS 354

## CHAPTER

## 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  $\Delta H_{\text{rxn}}^{\circ}$  Come From? 376  
Using Bond Energies to Calculate  $\Delta H_{\text{rxn}}^{\circ}$  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 Ions 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 the Octet Rule 402

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

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

Bond Polarity, Bond Angle, and Dipole Moment 417  
 The Effect of Molecular Polarity on Behavior 419

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

CHAPTER REVIEW GUIDE 421

PROBLEMS 424

## CHAPTER 11 *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

Orbital Overlap in Single and Multiple Bonds 436  
 Orbital Overlap and Rotation Within a Molecule 439

### 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 12 *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

## CHAPTER

## 13

**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

## 14

**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

**14.10 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

## CHAPTER 15 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

## CHAPTER 17 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 Various Forms 735
- 17.3 Expressing Equilibria with Pressure Terms: Relation Between  $K_c$  and  $K_p$  740**
- 17.4 Comparing  $Q$  and  $K$  to Determine Reaction Direction 742**
- 17.5 How to Solve Equilibrium Problems 744**  
 Using Quantities to Find the Equilibrium Constant 745  
 Using the Equilibrium Constant to Find Quantities 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

## 18

## Acid-Base Equilibria 776

**18.1 Acids and Bases in Water 778**

Release of  $H^+$  or  $OH^-$  and the Arrhenius Acid-Base Definition 778  
 Variation in Acid Strength: The Acid-Dissociation Constant ( $K_a$ ) 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  $K_a$  Given Concentrations 793  
 Finding Concentrations Given  $K_a$  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

## CHAPTER

## 19

## 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

**19.3 Equilibria of Slightly Soluble Ionic Compounds 846**

The Ion-Product Expression ( $Q_{sp}$ ) and the 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 Ions 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  $\Delta H$  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 Law 883  
 Predicting Relative  $S^\circ$  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

## CHAPTER

## 21

**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 ( $E_{\text{cell}}^{\circ}$ ) 930  
 Relative Strengths of Oxidizing and Reducing Agents 933

Using  $E_{\text{half-cell}}^{\circ}$  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

## CHAPTER

## 23

**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 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