

Contents

List of Applications vi

Preface vii

1 CHEMISTRY: THE SCIENCE OF CHANGE 2

1.1 The Study of Chemistry 3

• Chemistry You May Already Know 3 • The Scientific Method 3

1.2 Classification of Matter 5

• States of Matter 5 • Mixtures 5

1.3 The Properties of Matter 7

• Physical Properties 7 • Chemical Properties 7 • Extensive and Intensive Properties 7

1.4 Scientific Measurement 8

• SI Base Units 9 • Mass 9 • Temperature 10 • Derived Units: Volume and Density 12

1.5 Uncertainty in Measurement 14

• Significant Figures 14 • Calculations with Measured Numbers 15
• Accuracy and Precision 18 • Thinking Outside the Box: Tips for Success in Chemistry Class 19

1.6 Using Units and Solving Problems 20

• Conversion Factors 20 • Dimensional Analysis—Tracking Units 20

2 ATOMS AND THE PERIODIC TABLE 32

2.1 Atoms First 33

2.2 Subatomic Particles and Atomic Structure 34

• Discovery of the Electron 34 • Radioactivity 36 • The Proton and the Nuclear Model of the Atom 37 • The Neutron 38

2.3 Atomic Number, Mass Number, and Isotopes 39

2.4 Nuclear Stability 41

• Patterns of Nuclear Stability 41

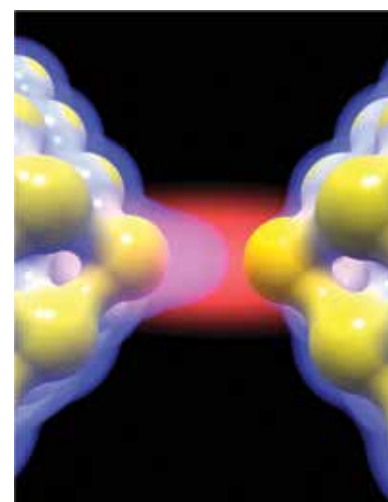
2.5 Average Atomic Mass 43

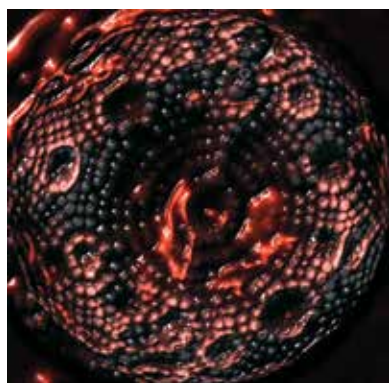
• Thinking Outside the Box: Measuring Atomic Mass 44

2.6 The Periodic Table 45

2.7 The Mole and Molar Mass 46

• The Mole 47 • Molar Mass 48 • Interconverting Mass, Moles, and Numbers of Atoms 49





3 QUANTUM THEORY AND THE ELECTRONIC STRUCTURE OF ATOMS 58

3.1 Energy and Energy Changes 59

- Forms of Energy 59 • Units of Energy 60

3.2 The Nature of Light 62

- Properties of Waves 62 • The Electromagnetic Spectrum 63
- The Double-Slit Experiment 63

3.3 Quantum Theory 65

- Quantization of Energy 66 • Photons and the Photoelectric Effect 66
- Thinking Outside the Box: Everyday Occurrences of the Photoelectric Effect 67

3.4 Bohr's Theory of the Hydrogen Atom 70

- Atomic Line Spectra 70 • The Line Spectrum of Hydrogen 72

3.5 Wave Properties of Matter 77

- The de Broglie Hypothesis 77 • Diffraction of Electrons 79

3.6 Quantum Mechanics 79

- The Uncertainty Principle 80 • The Schrödinger Equation 81 • The Quantum Mechanical Description of the Hydrogen Atom 81

3.7 Quantum Numbers 82

- Principal Quantum Number (n) 82 • Angular Momentum Quantum Number (ℓ) 82 • Magnetic Quantum Number (m_ℓ) 83 • Electron Spin Quantum Number (m_s) 84

3.8 Atomic Orbitals 85

- s Orbitals 86 • p Orbitals 87 • d Orbitals and Other Higher-Energy Orbitals 87 • Energies of Orbitals 88

3.9 Electron Configurations 89

- Energies of Atomic Orbitals in Many-Electron Systems 89
- The Pauli Exclusion Principle 90 • The Aufbau Principle 91 • Hund's Rule 91
- General Rules for Writing Electron Configurations 92

3.10 Electron Configurations and the Periodic Table 93



4 PERIODIC TRENDS OF THE ELEMENTS 110

4.1 Development of the Periodic Table 111

4.2 The Modern Periodic Table 114

- Classification of Elements 114

4.3 Effective Nuclear Charge 117

4.4 Periodic Trends in Properties of Elements 118

- Atomic Radius 118 • Ionization Energy 120 • Electron Affinity 122
- Metallic Character 125

4.5 Electron Configuration of Ions 127

- Ions of Main Group Elements 127 • Ions of d-Block Elements 129

4.6 Ionic Radius 130

- Thinking Outside the Box: Mistaking Strontium for Calcium 130 • Comparing Ionic Radius with Atomic Radius 131 • Isoelectronic Series 131

5 IONIC AND COVALENT COMPOUNDS 144

- 5.1 **Compounds 145**
- 5.2 **Lewis Dot Symbols 145**
- 5.3 **Ionic Compounds and Bonding 147**
- 5.4 **Naming Ions and Ionic Compounds 151**
 - Formulas of Ionic Compounds 152 • Naming Ionic Compounds 152
- 5.5 **Covalent Bonding and Molecules 154**
 - Molecules 154 • Molecular Formulas 156 • Empirical Formulas 157
- 5.6 **Naming Molecular Compounds 160**
 - Specifying Numbers of Atoms 160 • Compounds Containing Hydrogen 162
 - Organic Compounds 162 • Thinking Outside the Box: Functional Groups 164
- 5.7 **Covalent Bonding in Ionic Species 164**
 - Polyatomic Ions 164 • Oxoacids 166 • Hydrates 168 • Familiar Inorganic Compounds 169
- 5.8 **Molecular and Formula Masses 169**
- 5.9 **Percent Composition of Compounds 171**
- 5.10 **Molar Mass 173**
 - Interconverting Mass, Moles, and Numbers of Particles 173 • Determination of Empirical Formula and Molecular Formula from Percent Composition 175



6 REPRESENTING MOLECULES 188

- 6.1 **The Octet Rule 189**
 - Lewis Structures 189 • Multiple Bonds 192
- 6.2 **Electronegativity and Polarity 193**
 - Electronegativity 193 • Dipole Moment, Partial Charges, and Percent Ionic Character 196
- 6.3 **Drawing Lewis Structures 199**
- 6.4 **Lewis Structures and Formal Charge 201**
- 6.5 **Resonance 204**
- 6.6 **Exceptions to the Octet Rule 206**
 - Incomplete Octets 206 • Thinking Outside the Box: Species with Unpaired Electrons 206 • Odd Numbers of Electrons 207 • Expanded Octets 208



7 MOLECULAR GEOMETRY, INTERMOLECULAR FORCES, AND BONDING THEORIES 220

- 7.1 **Molecular Geometry 221**
 - The VSEPR Model 222 • Electron-Domain Geometry and Molecular Geometry 223 • Deviation from Ideal Bond Angles 227 • Geometry of Molecules with More Than One Central Atom 227
- 7.2 **Molecular Geometry and Polarity 229**
- 7.3 **Intermolecular Forces 232**
 - Dipole-Dipole Interactions 233 • Hydrogen Bonding 233 • Dispersion Forces 234 • Ion-Dipole Interactions 236
- 7.4 **Valence Bond Theory 237**

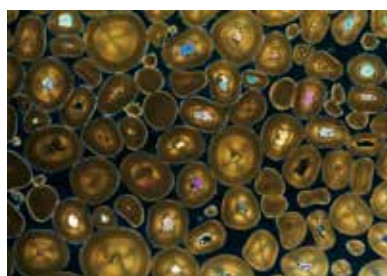


- 7.5 Hybridization of Atomic Orbitals 240**
 • Hybridization of s and p Orbitals 241 • Hybridization of s , p , and d Orbitals 243
- 7.6 Hybridization in Molecules Containing Multiple Bonds 247**
- 7.7 Molecular Orbital Theory 254**
 • Bonding and Antibonding Molecular Orbitals 254 • σ Molecular Orbitals 255
 • Thinking Outside the Box: Phases 256 • Bond Order 256 • π Molecular Orbitals 257 • Molecular Orbital Diagrams 259 • Thinking Outside the Box: Molecular Orbitals in Heteronuclear Diatomic Species 260
- 7.8 Bonding Theories and Descriptions of Molecules with Delocalized Bonding 261**



8 CHEMICAL REACTIONS 278

- 8.1 Chemical Equations 279**
 • Interpreting and Writing Chemical Equations 279 • Balancing Chemical Equations 281 • Patterns of Chemical Reactivity 285
- 8.2 Combustion Analysis 287**
 • Determination of Empirical Formula 288
- 8.3 Calculations with Balanced Chemical Equations 290**
 • Moles of Reactants and Products 290 • Mass of Reactants and Products 292
- 8.4 Limiting Reactants 293**
 • Determining the Limiting Reactant 294 • Reaction Yield 298
- 8.5 Periodic Trends in Reactivity of the Main Group Elements 300**
 • General Trends in Reactivity 300 • Thinking Outside the Box: Atom Economy 301 • Hydrogen ($1s^1$) 302 • Reactions of the Active Metals 302
 • Reactions of Other Main Group Elements 303 • Comparison of Group 1A and Group 1B Elements 306



9 CHEMICAL REACTIONS IN AQUEOUS SOLUTIONS 318

- 9.1 General Properties of Aqueous Solutions 319**
 • Electrolytes and Nonelectrolytes 319 • Strong Electrolytes and Weak Electrolytes 320
- 9.2 Precipitation Reactions 324**
 • Solubility Guidelines for Ionic Compounds in Water 325 • Molecular Equations 326 • Ionic Equations 327 • Net Ionic Equations 327
- 9.3 Acid-Base Reactions 329**
 • Strong Acids and Bases 330 • Brønsted Acids and Bases 330 • Acid-Base Neutralization 332
- 9.4 Oxidation-Reduction Reactions 334**
 • Oxidation Numbers 335 • Oxidation of Metals in Aqueous Solutions 338
 • Balancing Simple Redox Equations 338 • Other Types of Redox Reactions 342

9.5 Concentration of Solutions 344

• Molarity 344 • Dilution 348 • Serial Dilution 349 • Thinking Outside the Box: Visible Spectrophotometry 351 • The pH Scale 353 • Solution Stoichiometry 355

9.6 Aqueous Reactions and Chemical Analysis 357

• Gravimetric Analysis 357 • Acid-Base Titrations 358

10 ENERGY CHANGES IN CHEMICAL REACTIONS 378**10.1 Energy and Energy Changes 379****10.2 Introduction to Thermodynamics 381**

• States and State Functions 381 • The First Law of Thermodynamics 382
• Work and Heat 383

10.3 Enthalpy 384

• Reactions Carried Out at Constant Volume or at Constant Pressure 385
• Enthalpy and Enthalpy Changes 387 • Thermochemical Equations 388

10.4 Calorimetry 390

• Specific Heat and Heat Capacity 390 • Constant-Pressure Calorimetry 392
• Constant-Volume Calorimetry 393 • Thinking Outside the Box: Heat Capacity of Calorimeters 398

10.5 Hess's Law 400**10.6 Standard Enthalpies of Formation 402****10.7 Bond Enthalpy and the Stability of Covalent Molecules 405****10.8 Lattice Energy and the Stability of Ionic Solids 409**

• The Born-Haber Cycle 409 • Comparison of Ionic and Covalent Compounds 411

**11 GASES 430****11.1 Properties of Gases 431****11.2 The Kinetic Molecular Theory of Gases 432**

• Molecular Speed 433 • Diffusion and Effusion 435

11.3 Gas Pressure 436

• Definition and Units of Pressure 437 • Calculation of Pressure 437
• Measurement of Pressure 438

11.4 The Gas Laws 440

• Boyle's Law: The Pressure-Volume Relationship 440 • Charles's and Gay-Lussac's Law: The Temperature-Volume Relationship 442 • Avogadro's Law: The Amount-Volume Relationship 445 • The Gas Laws and Kinetic Molecular Theory 446 • The Combined Gas Law: The Pressure-Temperature-Amount-Volume Relationship 447

11.5 The Ideal Gas Equation 449

• Applications of the Ideal Gas Equation 451

11.6 Real Gases 453

• Factors That Cause Deviation from Ideal Behavior 454 • The van der Waals Equation 454 • van der Waals Constants 456



11.7 Gas Mixtures 458

• Dalton's Law of Partial Pressures 458 • Mole Fractions 459 • Thinking Outside the Box: Decompression Injury 461

11.8 Reactions with Gaseous Reactants and Products 462

• Calculating the Required Volume of a Gaseous Reactant 462 • Determining the Amount of Reactant Consumed Using Change in Pressure 464
• Using Partial Pressures to Solve Problems 465

**12 LIQUIDS AND SOLIDS 484****12.1 The Condensed Phases 485****12.2 Properties of Liquids 486**

• Surface Tension 486 • Viscosity 486 • Vapor Pressure of Liquids 487
• Boiling Point 491

12.3 The Properties of Solids 491

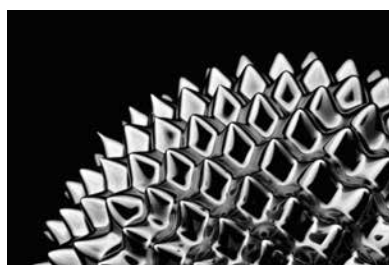
• Melting Point 491 • Vapor Pressure of Solids 492 • Amorphous Solids 493
• Crystalline Solids 494 • Thinking Outside the Box: X-ray Diffraction 498

12.4 Types of Crystalline Solids 501

• Ionic Crystals 501 • Covalent Crystals 503 • Molecular Crystals 504
• Metallic Crystals 505

12.5 Phase Changes 506

• Liquid-Vapor 507 • Solid-Liquid 508 • Solid-Vapor 510

12.6 Phase Diagrams 512**13 PHYSICAL PROPERTIES OF SOLUTIONS 528****13.1 Types of Solutions 529****13.2 A Molecular View of the Solution Process 530**

• The Importance of Intermolecular Forces 530 • Energy and Entropy in Solution Formation 531

13.3 Concentration Units 534

• Molality 534 • Percent by Mass 534 • Comparison of Concentration Units 536

13.4 Factors That Affect Solubility 537

• Temperature 538 • Pressure 538

13.5 Colligative Properties 540

• Vapor-Pressure Lowering 540 • Boiling-Point Elevation 543 • Freezing-Point Depression 544 • Osmotic Pressure 546 • Electrolyte Solutions 546 • Thinking Outside the Box: Intravenous Fluids 549 • Thinking Outside the Box: Fluoride Poisoning 550

13.6 Calculations Using Colligative Properties 551**13.7 Colloids 554**

14 ENTROPY AND FREE ENERGY 570

14.1 Spontaneous Processes 571

14.2 Entropy 572

• A Qualitative Description of Entropy 572 • A Quantitative Definition of Entropy 572

14.3 Entropy Changes in a System 574

• Calculating ΔS_{sys} 574 • Standard Entropy, S° 575 • Qualitatively Predicting the Sign of $\Delta S_{\text{sys}}^\circ$ 578

14.4 Entropy Changes in the Universe 582

• Calculating ΔS_{surr} 583 • The Second Law of Thermodynamics 583 • Thinking Outside the Box: Thermodynamics and Living Systems 586 • The Third Law of Thermodynamics 586

14.5 Predicting Spontaneity 588

• Gibbs Free-Energy Change, ΔG 588 • Standard Free-Energy Changes, ΔG° 590 • Using ΔG and ΔG° to Solve Problems 591

14.6 Thermodynamics in Living Systems 594



15 CHEMICAL EQUILIBRIUM 604

15.1 The Concept of Equilibrium 605

15.2 The Equilibrium Constant 607

• Calculating Equilibrium Constants 608 • Magnitude of the Equilibrium Constant 610

15.3 Equilibrium Expressions 611

• Heterogeneous Equilibria 611 • Manipulating Equilibrium Expressions 613 • Gaseous Equilibria 616

15.4 Chemical Equilibrium and Free Energy 619

• Using Q and K to Predict the Direction of Reaction 619 • Relationship Between ΔG and ΔG° 620 • Relationship Between ΔG° and K 622

15.5 Calculating Equilibrium Concentrations 626

15.6 Le Châtelier's Principle: Factors That Affect Equilibrium 635

• Addition or Removal of a Substance 635 • Changes in Volume and Pressure 638 • Changes in Temperature 640 • Thinking Outside the Box: Biological Equilibria 646



16 ACIDS, BASES, AND SALTS 664

16.1 Brønsted Acids and Bases 665

16.2 Molecular Structure and Acid Strength 667

• Hydrohalic Acids 667 • Oxoacids 668 • Carboxylic Acids 669

16.3 The Acid-Base Properties of Water 670

16.4 The pH and pOH Scales 672

16.5 Strong Acids and Bases 674

• Strong Acids 674 • Strong Bases 676

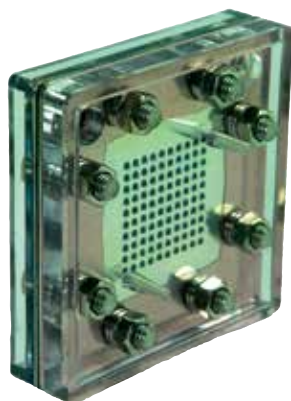


- 16.6 Weak Acids and Acid Ionization Constants 678**
 • The Ionization Constant, K_a 679 • Calculating pH from K_a 679 • Percent Ionization 684 • Thinking Outside the Box: Acid Rain 684 • Using pH to Determine K_a 686
- 16.7 Weak Bases and Base Ionization Constants 688**
 The Ionization Constant, K_b 688 • Calculating pH from K_b 689
 • Using pH to Determine K_b 690
- 16.8 Conjugate Acid-Base Pairs 691**
 • The Strength of a Conjugate Acid or Base 691 • The Relationship Between K_a and K_b of a Conjugate Acid-Base Pair 692
- 16.9 Diprotic and Polyprotic Acids 694**
- 16.10 Acid-Base Properties of Salt Solutions 697**
 • Basic Salt Solutions 697 • Acidic Salt Solutions 698 • Neutral Salt Solutions 700 • Salts in Which Both the Cation and the Anion Hydrolyze 702
- 16.11 Acid-Base Properties of Oxides and Hydroxides 702**
 • Oxides of Metals and Nonmetals 702 • Basic and Amphoteric Hydroxides 704
- 16.12 Lewis Acids and Bases 704**



17 ACID-BASE EQUILIBRIA AND SOLUBILITY EQUILIBRIA 718

- 17.1 The Common Ion Effect 719**
- 17.2 Buffer Solutions 721**
 • Calculating the pH of a Buffer 721 • Preparing a Buffer Solution with a Specific pH 726
- 17.3 Acid-Base Titrations 728**
 • Strong Acid–Strong Base Titrations 728 • Weak Acid–Strong Base Titrations 729 • Strong Acid–Weak Base Titrations 733 • Acid-Base Indicators 735
- 17.4 Solubility Equilibria 738**
 • Solubility Product Expression and K_{sp} 738 • Calculations Involving K_{sp} and Solubility 738 • Predicting Precipitation Reactions 742
- 17.5 Factors Affecting Solubility 744**
 • The Common Ion Effect 744 • pH 745 • Complex Ion Formation 749
 • Thinking Outside the Box: Equilibrium and Tooth Decay 750
- 17.6 Separation of Ions Using Differences in Solubility 754**
 • Fractional Precipitation 754 • Qualitative Analysis of Metal Ions in Solution 755



18 ELECTROCHEMISTRY 768

- 18.1 Balancing Redox Reactions 769**
- 18.2 Galvanic Cells 773**
- 18.3 Standard Reduction Potentials 776**
- 18.4 Spontaneity of Redox Reactions Under Standard-State Conditions 783**
 • Thinking Outside the Box: Amalgam Fillings and Dental Pain 787

18.5 Spontaneity of Redox Reactions Under Conditions Other Than Standard State 787

• The Nernst Equation 787 • Concentration Cells 789

18.6 Batteries 792

• Dry Cells and Alkaline Batteries 792 • Lead Storage Batteries 793
• Lithium-Ion Batteries 793 • Fuel Cells 793

18.7 Electrolysis 795

• Electrolysis of Molten Sodium Chloride 795 • Electrolysis of Water 796
• Electrolysis of an Aqueous Sodium Chloride Solution 796 • Quantitative Applications of Electrolysis 797

18.8 Corrosion 800**19 CHEMICAL KINETICS 814****Reaction Rates 815****Collision Theory of Chemical Reactions 815****Measuring Reaction Progress and Expressing Reaction Rate 817**

• Average Reaction Rate 817 • Instantaneous Rate 821 • Stoichiometry and Reaction Rate 824

19.4 Dependence of Reaction Rate on Reactant Concentration 827

• The Rate Law 827 • Experimental Determination of the Rate Law 828

19.5 Dependence of Reactant Concentration on Time 832

• First-Order Reactions 832 • Second-Order Reactions 838

19.6 Dependence of Reaction Rate on Temperature 841

• The Arrhenius Equation 841 • Thinking Outside the Box: Surface Area 846

19.7 Reaction Mechanisms 847

• Elementary Reactions 847 • Rate-Determining Step 848 • Mechanisms with a Fast First Step 852 • Experimental Support for Reaction Mechanisms 854

19.8 Catalysis 855

• Heterogeneous Catalysis 856 • Homogeneous Catalysis 856
• Enzymes: Biological Catalysts 857

**20 NUCLEAR CHEMISTRY 874****20.1 Nuclei and Nuclear Reactions 875****20.2 Nuclear Stability 877**

• Types of Nuclear Decay 877 • Nuclear Binding Energy 878

20.3 Natural Radioactivity 881

• Kinetics of Radioactive Decay 881 • Dating Based on Radioactive Decay 882

20.4 Nuclear Transmutation 885**20.5 Nuclear Fission 887****20.6 Nuclear Fusion 893****20.7 Uses of Isotopes 895**

• Chemical Analysis 895 • Thinking Outside the Box: Nuclear Medicine 896
• Isotopes in Medicine 896

20.8 Biological Effects of Radiation 897



21 METALLURGY AND THE CHEMISTRY OF METALS 906

21.1 Occurrence of Metals 907

21.2 Metallurgical Processes 908

• Preparation of the Ore 908 • Production of Metals 908 • The Metallurgy of Iron 909 • Steelmaking 910 • Purification of Metals 912 • Thinking Outside the Box: Copper 913

21.3 Band Theory of Conductivity 914

• Conductors 914 • Semiconductors 914

21.4 Periodic Trends in Metallic Properties 916

21.5 The Alkali Metals 916

21.6 The Alkaline Earth Metals 919

• Magnesium 919 • Calcium 920

21.7 Aluminum 920



22 COORDINATION CHEMISTRY 928

22.1 Coordination Compounds 929

• Properties of Transition Metals 929 • Ligands 931 • Nomenclature of Coordination Compounds 933 • Thinking Outside the Box: Chelation Therapy 935

22.2 Structure of Coordination Compounds 936

22.3 Bonding in Coordination Compounds: Crystal Field Theory 938

• Crystal Field Splitting in Octahedral Complexes 939 • Color 940 • Magnetic Properties 941 • Tetrahedral and Square-Planar Complexes 943

22.4 Reactions of Coordination Compounds 944

22.5 Applications of Coordination Compounds 944



23 ORGANIC CHEMISTRY 952

23.1 Why Carbon Is Different 953

23.2 Classes of Organic Compounds 955

• Basic Nomenclature 959 • Molecules with Multiple Substituents 962 • Molecules with Specific Functional Groups 963

23.3 Representing Organic Molecules 965

• Condensed Structural Formulas 966 • Kekulé Structures 966 • Skeletal Structures 966 • Resonance 968

23.4 Isomerism 971

• Constitutional Isomerism 971 • Stereoisomerism 971 • Thinking Outside the Box: Thalidomide Analogues 975

23.5 Organic Reactions 976

• Addition Reactions 976 • Substitution Reactions 978 • Other Types of Organic Reactions 982

23.6 Organic Polymers 984

• Addition Polymers 984 • Condensation Polymers 985 • Biological Polymers 987

24 MODERN MATERIALS 1002

24.1 Polymers 1003

• Addition Polymers 1003 • Condensation Polymers 1009 • Thinking Outside the Box: Electrically Conducting Polymers 1011

24.2 Ceramics and Composite Materials 1012

• Ceramics 1012 • Composite Materials 1013

24.3 Liquid Crystals 1013

24.4 Biomedical Materials 1016

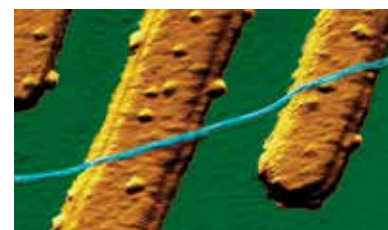
• Dental Implants 1017 • Soft Tissue Materials 1017 • Artificial Joints 1018

24.5 Nanotechnology 1019

• Graphite, Buckyballs, and Nanotubes 1019

24.6 Semiconductors 1021

24.7 Superconductors 1023



25 NONMETALLIC ELEMENTS AND THEIR COMPOUNDS (ONLINE ONLY)

25.1 General Properties of Nonmetals 1031

25.2 Hydrogen 1032

• Binary Hydrides 1033 • Isotopes of Hydrogen 1034 • Hydrogenation 1034
The Hydrogen Economy 1035

25.3 Carbon 1035

25.4 Nitrogen and Phosphorus 1037

• Nitrogen 1037 • Phosphorus 1039

25.5 Oxygen and Sulfur 1042

• Oxygen 1042 • Sulfur 1044 • Thinking Outside the Box: Arsenic 1048

25.6 The Halogens 1048

• Preparation and General Properties of the Halogens 1049
• Compounds of the Halogens 1051 • Uses of the Halogens 1053



Glossary G-1

Answers to Odd-Numbered Problems AP-1

Credits C-1

Index I-1