

GLOBAL
EDITION

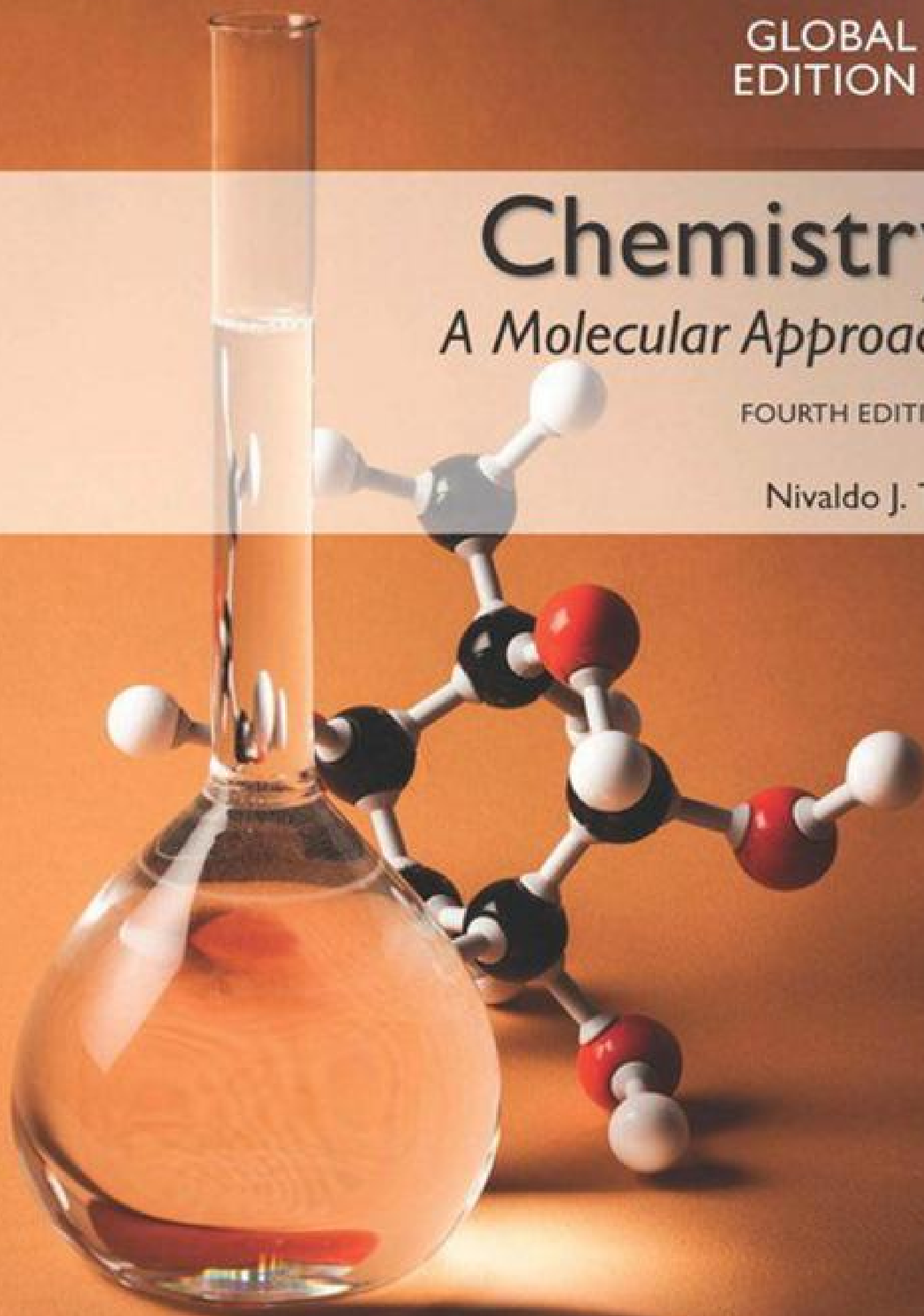


Chemistry

A Molecular Approach

FOURTH EDITION

Nivaldo J. Tro

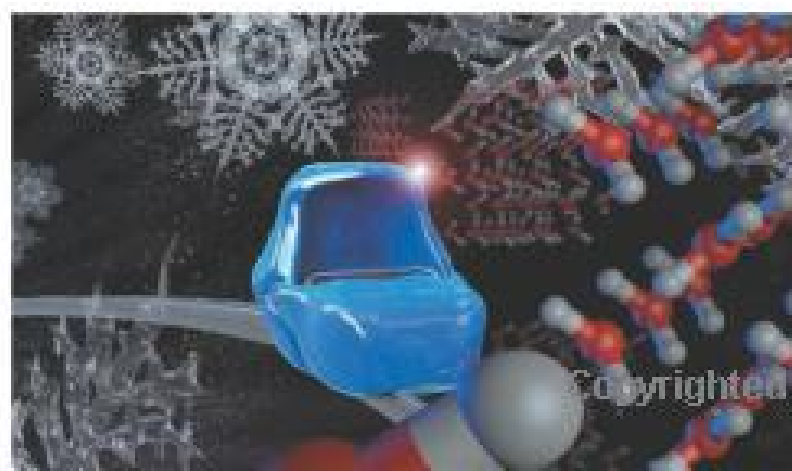


CONTENTS

PREFACE 20

1 Matter, Measurement, and Problem Solving 38

- 1.1 Atoms and Molecules** 39
- 1.2 The Scientific Approach to Knowledge** 41
 - The Nature of Science** Thomas S. Kuhn and Scientific Revolutions 43
- 1.3 The Classification of Matter** 43
 - The States of Matter: Solid, Liquid, and Gas 44
 - Classifying Matter according to Its Composition: Elements, Compounds, and Mixtures 45
 - Separating Mixtures 46
- 1.4 Physical and Chemical Changes and Physical and Chemical Properties** 47
- 1.5 Energy: A Fundamental Part of Physical and Chemical Change** 50
- 1.6 The Units of Measurement** 51
 - Standard Units 51 The Meter: A Measure of Length 52 The Kilogram: A Measure of Mass 52 The Second: A Measure of Time 52
 - The Kelvin: A Measure of Temperature 53
 - Prefix Multipliers 55 Derived Units: Volume and Density 55 Calculating Density 57
 - Chemistry and Medicine** Bone Density 58
- 1.7 The Reliability of a Measurement** 58
 - Counting Significant Figures 60 Exact Numbers 60 Significant Figures in Calculations 61 Precision and Accuracy 63
 - Chemistry in Your Day** Integrity in Data Gathering 64
- 1.8 Solving Chemical Problems** 64
 - Converting from One Unit to Another 64 General Problem-Solving Strategy 66 Units Raised to a Power 68 Order-of-Magnitude Estimations 69
 - Problems Involving an Equation 70
- CHAPTER IN REVIEW** Self-Assessment Quiz 71 Key Terms 72 Key Concepts 73 Key Equations and Relationships 73 Key Learning Outcomes 74
- EXERCISES** Review Questions 74 Problems by Topic 74 Cumulative Problems 78 Challenge Problems 79 Conceptual Problems 80 Questions for Group Work 80 Data Interpretation and Analysis 81 Answers to Conceptual Connections 81



2 Atoms and Elements 82

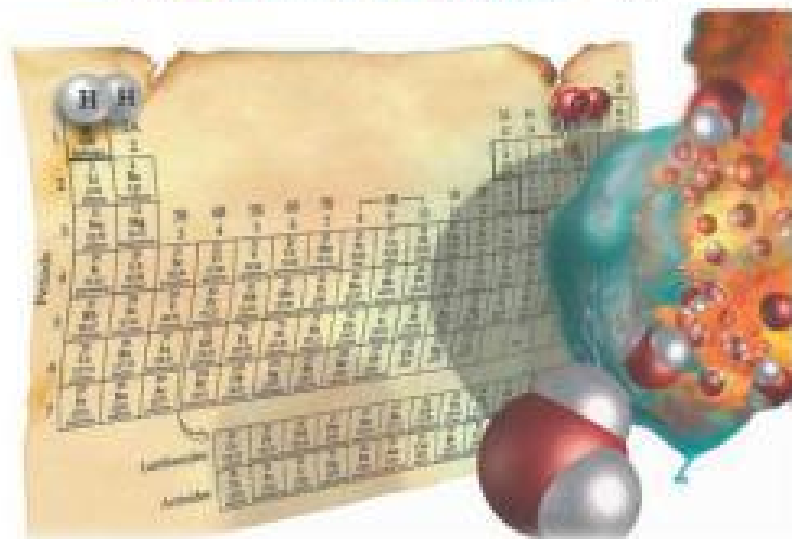


- 2.1 Brownian Motion: Atoms Confirmed** 83
- 2.2 Early Ideas about the Building Blocks of Matter** 85
- 2.3 Modern Atomic Theory and the Laws That Led to It** 85
 - The Law of Conservation of Mass 85 The Law of Definite Proportions 86 The Law of Multiple Proportions 87 John Dalton and the Atomic Theory 88
 - Chemistry in Your Day** Atoms and Humans 89
- 2.4 The Discovery of the Electron** 89
 - Cathode Rays 89 Millikan's Oil Drop Experiment: The Charge of the Electron 90
- 2.5 The Structure of the Atom** 91
- 2.6 Subatomic Particles: Protons, Neutrons, and Electrons in Atoms** 93
 - Elements: Defined by Their Numbers of Protons 94
 - Isotopes: When the Number of Neutrons Varies 95
 - Ions: Losing and Gaining Electrons 97
 - Chemistry in Your Day** Where Did Elements Come From? 98
- 2.7 Finding Patterns: The Periodic Law and the Periodic Table** 98
 - Modern Periodic Table Organization 100 Ions and the Periodic Table 102
 - Chemistry and Medicine** The Elements of Life 103
- 2.8 Atomic Mass: The Average Mass of an Element's Atoms** 103
 - Mass Spectrometry: Measuring the Mass of Atoms and Molecules 104
 - Chemistry in Your Day** Evolving Atomic Masses 106
- 2.9 Molar Mass: Counting Atoms by Weighing Them** 107
 - The Mole: A Chemist's "Dozen" 107 Converting between Number of Moles and Number of Atoms 108 Converting between Mass and Amount (Number of Moles) 109

CHAPTER IN REVIEW Self-Assessment Quiz 112
Key Terms 113 Key Concepts 114 Key Equations
and Relationships 114 Key Learning Outcomes 115

EXERCISES Review Questions 115 Problems by Topic 116
Cumulative Problems 119 Challenge Problems 120
Conceptual Problems 121 Questions for Group
Work 121 Data Interpretation and Analysis 122
Answers to Conceptual Connections 123

3 Molecules, Compounds, and Chemical Equations 124



- 3.1 Hydrogen, Oxygen, and Water 125**
- 3.2 Chemical Bonds 127**
Ionic Bonds 127 Covalent Bonds 128
- 3.3 Representing Compounds: Chemical Formulas
and Molecular Models 128**
Types of Chemical Formulas 128 Molecular
Models 130
- 3.4 An Atomic-Level View of Elements and
Compounds 130**
- 3.5 Ionic Compounds: Formulas and Names 134**
Writing Formulas for Ionic Compounds 134
Naming Ionic Compounds 135 Naming Binary
Ionic Compounds Containing a Metal That Forms
Only One Type of Cation 136 Naming Binary
Ionic Compounds Containing a Metal That Forms
More Than One Kind of Cation 137 Naming Ionic
Compounds Containing Polyatomic Ions 138
Hydrated Ionic Compounds 139
- 3.6 Molecular Compounds: Formulas and
Names 139**
Naming Molecular Compounds 140 Naming
Acids 141 Naming Binary Acids 141 Naming
Oxyacids 142
Chemistry in the Environment Acid Rain 142
- 3.7 Summary of Inorganic Nomenclature 143**
- 3.8 Formula Mass and the Mole Concept for
Compounds 145**
Molar Mass of a Compound 145 Using Molar Mass
to Count Molecules by Weighing 145
- 3.9 Composition of Compounds 147**
Mass Percent Composition as a Conversion
Factor 148 Conversion Factors from Chemical
Formulas 150
Chemistry and Medicine Methylmercury in Fish 152

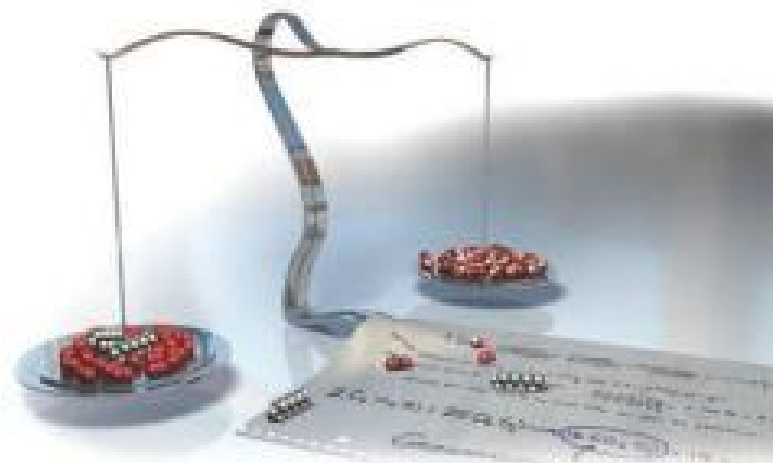
- 3.10 Determining a Chemical Formula from
Experimental Data 152**
Determining Molecular Formulas for
Compounds 154 Combustion Analysis 155
- 3.11 Writing and Balancing Chemical Equations 157**
- 3.12 Organic Compounds 161**
Hydrocarbons 162 Functionalized
Hydrocarbons 163

CHAPTER IN REVIEW Self-Assessment Quiz 165
Key Terms 165 Key Concepts 166 Key Equations
and Relationships 166 Key Learning Outcomes 167

EXERCISES Review Questions 167 Problems by Topic 168
Cumulative Problems 172 Challenge Problems 173
Conceptual Problems 173 Questions for Group
Work 173 Data Interpretation and Analysis 174
Answers to Conceptual Connections 174

4 Chemical Quantities and Aqueous Reactions 176

- 4.1 Climate Change and the Combustion of Fossil
Fuels 177**
- 4.2 Reaction Stoichiometry: How Much Carbon
Dioxide? 179**
Making Pizza: The Relationships among
Ingredients 179 Making Molecules: Mole-to-Mole
Conversions 179 Making Molecules: Mass-to-Mass
Conversions 180
- 4.3 Limiting Reactant, Theoretical Yield, and
Percent Yield 183**
Calculating Limiting Reactant, Theoretical Yield, and
Percent Yield 184 Calculating Limiting Reactant,
Theoretical Yield, and Percent Yield from Initial
Reactant Masses 185
- 4.4 Solution Concentration and Solution
Stoichiometry 189**
Solution Concentration 189 Using Molarity in
Calculations 191 Solution Dilution 192
Solution Stoichiometry 194
- 4.5 Types of Aqueous Solutions and Solubility 196**
Electrolyte and Nonelectrolyte Solutions 196
The Solubility of Ionic Compounds 198



- 4.6 Precipitation Reactions** 200
- 4.7 Representing Aqueous Reactions: Molecular, Ionic, and Complete Ionic Equations** 204
- 4.8 Acid–Base and Gas-Evolution Reactions** 205
Acid–Base Reactions 206 Gas-Evolution Reactions 211
- 4.9 Oxidation–Reduction Reactions** 213
Oxidation States 214 Identifying Redox Reactions 216
Chemistry in Your Day Bleached Blonde 219
Combustion Reactions 219
- CHAPTER IN REVIEW** Self-Assessment Quiz 220
Key Terms 221 Key Concepts 222 Key Equations and Relationships 223 Key Learning Outcomes 223
- EXERCISES** Review Questions 224 Problems by Topic 224
Cumulative Problems 228 Challenge Problems 230
Conceptual Problems 230 Questions for Group Work 231 Data Interpretation and Analysis 232
Answers to Conceptual Connections 233

5 Gases 234



- 5.1 Supersonic Skydiving and the Risk of Decompression** 235
- 5.2 Pressure: The Result of Molecular Collisions** 236
Pressure Units 237 The Manometer: A Way to Measure Pressure in the Laboratory 238
Chemistry and Medicine Blood Pressure 239
- 5.3 The Simple Gas Laws: Boyle's Law, Charles's Law, and Avogadro's Law** 239
Boyle's Law: Volume and Pressure 240 Charles's Law: Volume and Temperature 242
Chemistry in Your Day Extra-Long Snorkels 243
Avogadro's Law: Volume and Amount (in Moles) 245
- 5.4 The Ideal Gas Law** 246
- 5.5 Applications of the Ideal Gas Law: Molar Volume, Density, and Molar Mass of a Gas** 249
Molar Volume at Standard Temperature and Pressure 249 Density of a Gas 250 Molar Mass of a Gas 251
- 5.6 Mixtures of Gases and Partial Pressures** 252
Deep-Sea Diving and Partial Pressures 255
Collecting Gases over Water 257

- 5.7 Gases in Chemical Reactions: Stoichiometry Revisited** 259
Molar Volume and Stoichiometry 260
- 5.8 Kinetic Molecular Theory: A Model for Gases** 262
How Kinetic Molecular Theory Explains Pressure and the Simple Gas Laws 263 Kinetic Molecular Theory and the Ideal Gas Law 264 Temperature and Molecular Velocities 265
- 5.9 Mean Free Path, Diffusion, and Effusion of Gases** 268
- 5.10 Real Gases: The Effects of Size and Intermolecular Forces** 270
The Effect of the Finite Volume of Gas Particles 271
The Effect of Intermolecular Forces 272 Van der Waals Equation 273 Real Gases 273
- CHAPTER IN REVIEW** Self-Assessment Quiz 274
Key Terms 275 Key Concepts 275 Key Equations and Relationships 276 Key Learning Outcomes 276
- EXERCISES** Review Questions 277 Problems by Topic 278
Cumulative Problems 281 Challenge Problems 283
Conceptual Problems 283 Questions for Group Work 284 Data Interpretation and Analysis 284
Answers to Conceptual Connections 285

6 Thermochemistry 286

- 6.1 Chemical Hand Warmers** 287
- 6.2 The Nature of Energy: Key Definitions** 288
Types of Energy 288 Energy Conservation and Energy Transfer 289 Units of Energy 289
- 6.3 The First Law of Thermodynamics: There Is No Free Lunch** 291
Internal Energy 291
Chemistry in Your Day Redheffer's Perpetual Motion Machine 291
Heat and Work 294
- 6.4 Quantifying Heat and Work** 296
Heat 296 Work: Pressure–Volume Work 300
- 6.5 Measuring ΔE for Chemical Reactions: Constant-Volume Calorimetry** 302
- 6.6 Enthalpy: The Heat Evolved in a Chemical Reaction at Constant Pressure** 305
Exothermic and Endothermic Processes: A Molecular View 307 Stoichiometry Involving ΔH : Thermochemical Equations 307



- 6.7 Constant-Pressure Calorimetry: Measuring ΔH_{rxn}** 308
- 6.8 Relationships Involving ΔH_{rxn}** 310
- 6.9 Determining Enthalpies of Reaction from Standard Enthalpies of Formation** 313
Standard States and Standard Enthalpy Changes 313 Calculating the Standard Enthalpy Change for a Reaction 315
- 6.10 Energy Use and the Environment** 318
Energy Consumption 318 Environmental Problems Associated with Fossil Fuel Use 319 Air Pollution 319 Global Climate Change 320
Chemistry in the Environment Renewable Energy 322

CHAPTER IN REVIEW Self-Assessment Quiz 323
Key Terms 324 Key Concepts 324 Key Equations and Relationships 325 Key Learning Outcomes 325

EXERCISES Review Questions 326 Problems by Topic 327 Cumulative Problems 330 Challenge Problems 331 Conceptual Problems 331 Questions for Group Work 332 Data Interpretation and Analysis 332 Answers to Conceptual Connections 333

7 The Quantum-Mechanical Model of the Atom 334

- 7.1 Schrödinger's Cat** 335
- 7.2 The Nature of Light** 336
The Wave Nature of Light 337
The Electromagnetic Spectrum 339
Chemistry and Medicine Radiation Treatment for Cancer 341
Interference and Diffraction 341
The Particle Nature of Light 343
- 7.3 Atomic Spectroscopy and the Bohr Model** 346
Chemistry in Your Day Atomic Spectroscopy, a Bar Code for Atoms 348
- 7.4 The Wave Nature of Matter: The de Broglie Wavelength, the Uncertainty Principle, and Indeterminacy** 349
The de Broglie Wavelength 351 The Uncertainty Principle 352 Indeterminacy and Probability Distribution Maps 353

7.5 Quantum Mechanics and the Atom 355

Solutions to the Schrödinger Equation for the Hydrogen Atom 355 Atomic Spectroscopy Explained 358

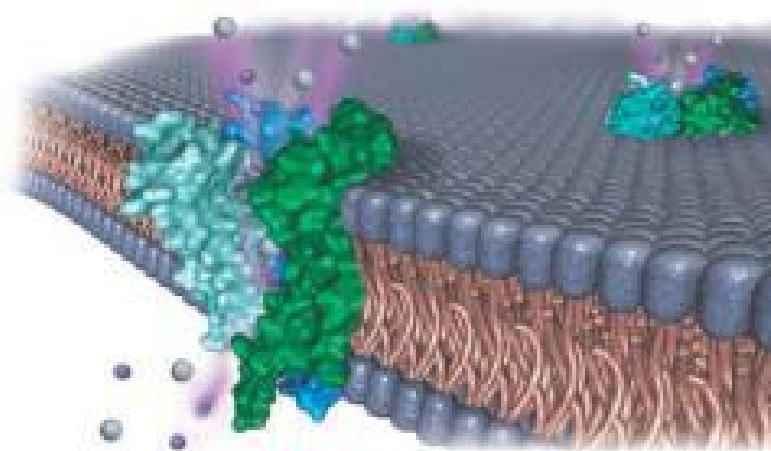
7.6 The Shapes of Atomic Orbitals 361

s Orbitals ($l=0$) 361 *p* Orbitals ($l=1$) 364
d Orbitals ($l=2$) 364 *f* Orbitals ($l=3$) 364
The Phase of Orbitals 365 The Shape of Atoms 366

CHAPTER IN REVIEW Self-Assessment Quiz 368
Key Terms 367 Key Concepts 367 Key Equations and Relationships 368 Key Learning Outcomes 368

EXERCISES Review Questions 368 Problems by Topic 369 Cumulative Problems 370 Challenge Problems 371 Conceptual Problems 372 Questions for Group Work 372 Data Interpretation and Analysis 372 Answers to Conceptual Connections 373

8 Periodic Properties of the Elements 374



- 8.1 Nerve Signal Transmission** 375
- 8.2 The Development of the Periodic Table** 376
- 8.3 Electron Configurations: How Electrons Occupy Orbitals** 377
Electron Spin and the Pauli Exclusion Principle 378 Sublevel Energy Splitting in Multielectron Atoms 379 Electron Configurations for Multielectron Atoms 382
- 8.4 Electron Configurations, Valence Electrons, and the Periodic Table** 385
Orbital Blocks in the Periodic Table 386 Writing an Electron Configuration for an Element from Its Position in the Periodic Table 387 The Transition and Inner Transition Elements 388
- 8.5 The Explanatory Power of the Quantum-Mechanical Model** 389
- 8.6 Periodic Trends in the Size of Atoms and Effective Nuclear Charge** 390
Effective Nuclear Charge 391 Atomic Radii and the Transition Elements 393
- 8.7 Ions: Electron Configurations, Magnetic Properties, Ionic Radii, and Ionization Energy** 395
Electron Configurations and Magnetic Properties of Ions 395 Ionic Radii 397 Ionization Energy 399 Trends in First Ionization Energy 399



Exceptions to Trends in First Ionization Energy 401
Trends in Second and Successive Ionization Energies 402

8.8 Electron Affinities and Metallic Character 403

Electron Affinity 403 Metallic Character 404

8.9 Some Examples of Periodic Chemical Behavior: The Alkali Metals, the Halogens, and the Noble Gases 407

The Alkali Metals (Group 1A) 407 The Halogens (Group 7A) 408 The Noble Gases (Group 8A) 409

CHAPTER IN REVIEW Self-Assessment Quiz 410

Key Terms 411 Key Concepts 412 Key Equations and Relationships 412 Key Learning Outcomes 413

EXERCISES Review Questions 413 Problems by Topic 414 Cumulative Problems 416 Challenge Problems 417 Conceptual Problems 417 Questions for Group Work 418 Data Interpretation and Analysis 418 Answers to Conceptual Connections 419

9 Chemical Bonding I: The Lewis Model 420

9.1 Bonding Models and AIDS Drugs 421

9.2 Types of Chemical Bonds 422

9.3 Representing Valence Electrons with Dots 424

9.4 Ionic Bonding: Lewis Symbols and Lattice Energies 425

Ionic Bonding and Electron Transfer 425 Lattice Energy: The Rest of the Story 426 The Born-Haber Cycle 426 Trends in Lattice Energies: Ion Size 429 Trends in Lattice Energies: Ion Charge 429 Ionic Bonding: Models and Reality 430

Chemistry and Medicine Ionic Compounds in Medicine 431

9.5 Covalent Bonding: Lewis Structures 432

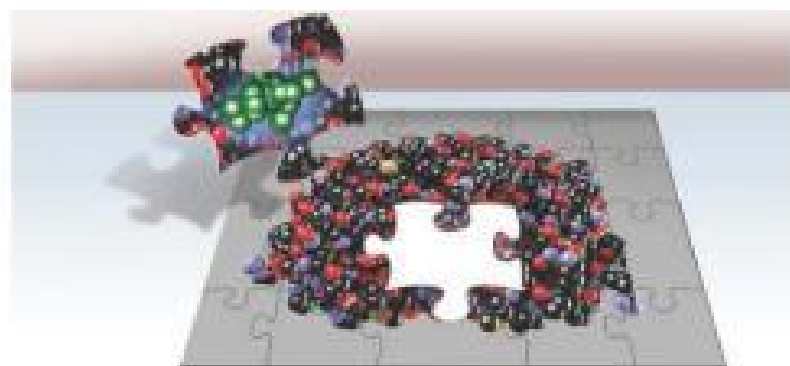
Single Covalent Bonds 432 Double and Triple Covalent Bonds 432 Covalent Bonding: Models and Reality 433

9.6 Electronegativity and Bond Polarity 434

Electronegativity 435 Bond Polarity, Dipole Moment, and Percent Ionic Character 436

9.7 Lewis Structures of Molecular Compounds and Polyatomic Ions 438

Writing Lewis Structures for Molecular Compounds 438 Writing Lewis Structures for Polyatomic Ions 440



9.8 Resonance and Formal Charge 440

Resonance 440 Formal Charge 442

9.9 Exceptions to the Octet Rule: Odd-Electron Species, Incomplete Octets, and Expanded Octets 445

Odd-Electron Species 446 Incomplete Octets 446

Chemistry in the Environment Free Radicals and the Atmospheric Vacuum Cleaner 447

Expanded Octets 448

9.10 Bond Energies and Bond Lengths 449

Bond Energy 450 Using Average Bond Energies to Estimate Enthalpy Changes for Reactions 451 Bond Lengths 452

9.11 Bonding in Metals: The Electron Sea Model 453

Chemistry in the Environment The Lewis Structure of Ozone 454

CHAPTER IN REVIEW Self-Assessment Quiz 455

Key Terms 456 Key Concepts 456 Key Equations and Relationships 457 Key Learning Outcomes 457

EXERCISES Review Questions 458 Problems by Topic 459 Cumulative Problems 460 Challenge Problems 462 Conceptual Problems 462 Questions for Group Work 462 Data Interpretation and Analysis 463 Answers to Conceptual Connections 463

10 Chemical Bonding II: Molecular Shapes, Valence Bond Theory, and Molecular Orbital Theory 464



10.1 Artificial Sweeteners: Fooled by Molecular Shape 465

10.2 VSEPR Theory: The Five Basic Shapes 466

Two Electron Groups: Linear Geometry 467 Three Electron Groups: Trigonal Planar Geometry 467 Four Electron Groups: Tetrahedral Geometry 467 Five Electron Groups: Trigonal Bipyramidal Geometry 469 Six Electron Groups: Octahedral Geometry 469

10.3 VSEPR Theory: The Effect of Lone Pairs 470

Four Electron Groups with Lone Pairs 470 Five Electron Groups with Lone Pairs 472 Six Electron Groups with Lone Pairs 473

10.4 VSEPR Theory: Predicting Molecular Geometries 475

Representing Molecular Geometries on Paper 477
Predicting the Shapes of Larger Molecules 477

10.5 Molecular Shape and Polarity 478

Vector Addition 480

Chemistry in Your Day How Soap Works 482

10.6 Valence Bond Theory: Orbital Overlap as a Chemical Bond 483**10.7 Valence Bond Theory: Hybridization of Atomic Orbitals** 485

sp^3 Hybridization 486 sp^2 Hybridization and Double Bonds 488

Chemistry in Your Day The Chemistry of Vision 492

sp Hybridization and Triple Bonds 492 sp^3d and sp^3d^2 Hybridization 494 Writing Hybridization and Bonding Schemes 495

10.8 Molecular Orbital Theory: Electron Delocalization 498

Linear Combination of Atomic Orbitals (LCAOs) 499 Period Two Homonuclear Diatomic Molecules 503 Second-Period Heteronuclear Diatomic Molecules 508 Polyatomic Molecules 510

CHAPTER IN REVIEW Self-Assessment Quiz 511

Key Terms 512 Key Concepts 512 Key Equations and Relationships 512 Key Learning Outcomes 513

EXERCISES Review Questions 513 Problems by Topic 514 Cumulative Problems 516 Challenge Problems 518 Conceptual Problems 519 Questions for Group Work 519 Data Interpretation and Analysis 520 Answers to Conceptual Connections 520

11 Liquids, Solids, and Intermolecular Forces 522**11.1 Water, No Gravity** 523**11.2 Solids, Liquids, and Gases: A Molecular Comparison** 524

Differences between States of Matter 524 Changes between States 526

11.3 Intermolecular Forces: The Forces That Hold Condensed States Together 527

Dispersion Force 528 Dipole–Dipole Force 530 Hydrogen Bonding 533 Ion–Dipole Force 535

Chemistry and Medicine Hydrogen Bonding in DNA 536

**11.4 Intermolecular Forces in Action: Surface Tension, Viscosity, and Capillary Action** 537

Surface Tension 537 Viscosity 539

Chemistry in Your Day Viscosity and Motor Oil 539

Capillary Action 539

11.5 Vaporization and Vapor Pressure 540

The Process of Vaporization 540 The Energetics of Vaporization 541 Vapor Pressure and Dynamic Equilibrium 543 The Critical Point: The Transition to an Unusual State of Matter 549

11.6 Sublimation and Fusion 550

Sublimation 550 Fusion 551 Energetics of Melting and Freezing 551

11.7 Heating Curve for Water 552**11.8 Phase Diagrams** 555

The Major Features of a Phase Diagram 555 Navigation within a Phase Diagram 556 The Phase Diagrams of Other Substances 557

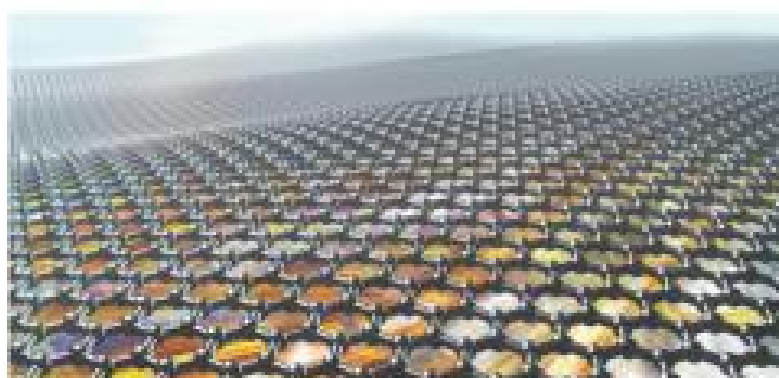
11.9 Water: An Extraordinary Substance 558

Chemistry in the Environment Water Pollution 559

CHAPTER IN REVIEW Self-Assessment Quiz 560

Key Terms 561 Key Concepts 561 Key Equations and Relationships 562 Key Learning Outcomes 562

EXERCISES Review Questions 562 Problems by Topic 563 Cumulative Problems 566 Challenge Problems 566 Conceptual Problems 567 Questions for Group Work 567 Data Interpretation and Analysis 568 Answers to Conceptual Connections 569

12 Solids and Modern Materials 570**12.1 Friday Night Experiments: The Discovery of Graphene** 571**12.2 X-Ray Crystallography** 572**12.3 Unit Cells and Basic Structures** 575

Cubic Unit Cells 575 Closest-Packed Structures 581

12.4 The Fundamental Types of Crystalline Solids 582

Molecular Solids 583

Chemistry in Your Day Chocolate, An Edible Material 584

Ionic Solids 585 Atomic Solids 585

12.5 The Structures of Ionic Solids 586**12.6 Network Covalent Atomic Solids: Carbon and Silicates** 588

Carbon 588 Silicates 591

- 12.7 Ceramics, Cement, and Glass** 591
 Ceramics 591 Cement 592 Glass 593
- 12.8 Semiconductors and Band Theory** 593
 Molecular Orbitals and Energy Bands 593 Doping:
 Controlling the Conductivity of
 Semiconductors 595
- 12.9 Polymers and Plastics** 595
Chemistry in Your Day Kevlar 598
- CHAPTER IN REVIEW** Self-Assessment Quiz 598
 Key Terms 599 Key Concepts 600 Key Equations
 and Relationships 600 Key Learning Outcomes 600
- EXERCISES** Review Questions 601 Problems by Topic 601
 Cumulative Problems 604 Challenge Problems 605
 Conceptual Problems 605 Questions for Group
 Work 608 Data Interpretation and Analysis 606
 Answers to Conceptual Connections 607

13 Solutions 608

- 13.1 Thirsty Solutions: Why You Shouldn't Drink Seawater** 609



- 13.2 Types of Solutions and Solubility** 611
 Nature's Tendency toward Mixing: Entropy 612
 The Effect of Intermolecular Forces 612
- 13.3 Energetics of Solution Formation** 615
 Energy Changes in Solution
 Formation 616 Aqueous Solutions and Heats of
 Hydration 617
- 13.4 Solution Equilibrium and Factors Affecting Solubility** 619
 The Temperature Dependence of the Solubility of
 Solids 620 Factors Affecting the Solubility of
 Gases in Water 621
- 13.5 Expressing Solution Concentration** 623
Chemistry in the Environment Lake Nyos 624
 Molarity 624 Molality 626 Parts by Mass and
 Parts by Volume 626 Using Parts by Mass (or Parts
 by Volume) in Calculations 626 Mole Fraction
 and Mole Percent 627
Chemistry in the Environment The Dirty Dozen 628
- 13.6 Colligative Properties: Vapor Pressure Lowering, Freezing Point Depression, Boiling Point Elevation, and Osmotic Pressure** 631

Vapor Pressure Lowering 631 Vapor Pressures of
 Solutions Containing a Volatile (Nonelectrolyte)
 Solute 635 Freezing Point Depression and Boiling
 Point Elevation 638

Chemistry in Your Day Antifreeze in Frogs 641
 Osmotic Pressure 641

- 13.7 Colligative Properties of Strong Electrolyte Solutions** 643
 Strong Electrolytes and Vapor Pressure 644
 Colligative Properties and Medical Solutions 645
- 13.8 Colloids** 646

CHAPTER IN REVIEW Self-Assessment Quiz 649
 Key Terms 650 Key Concepts 650 Key Equations
 and Relationships 651 Key Learning Outcomes 651

EXERCISES Review Questions 652 Problems by Topic 652
 Cumulative Problems 656 Challenge Problems 657
 Conceptual Problems 657 Questions for Group
 Work 658 Data Interpretation and Analysis 658
 Answers to Conceptual Connections 659

14 Chemical Kinetics 660

- 14.1 Catching Lizards** 661
- 14.2 The Rate of a Chemical Reaction** 662
 Definition of Reaction Rate 662 Measuring
 Reaction Rates 665
- 14.3 The Rate Law: The Effect of Concentration on Reaction Rate** 667
 The Three Common Reaction Orders ($n=0, 1$, and
 2) 667 Determining the Order of a Reaction 668
 Reaction Order for Multiple Reactants 670
- 14.4 The Integrated Rate Law: The Dependence of Concentration on Time** 672
 The Integrated Rate Law 672 The Half-Life of a
 Reaction 676
- 14.5 The Effect of Temperature on Reaction Rate** 680
 The Arrhenius Equation 680 The Activation
 Energy, Frequency Factor, and Exponential
 Factor 681 Arrhenius Plots: Experimental
 Measurements of the Frequency Factor and the
 Activation Energy 682 The Collision Model: A
 Closer Look at the Frequency Factor 685



14.6 Reaction Mechanisms 686

Rate Laws for Elementary Steps 687 Rate-Determining Steps and Overall Reaction Rate Laws 688 Mechanisms with a Fast Initial Step 689

14.7 Catalysis 691

Homogeneous and Heterogeneous Catalysis 693 Enzymes: Biological Catalysts 694
Chemistry and Medicine Enzyme Catalysis and the Role of Chymotrypsin in Digestion 695

CHAPTER IN REVIEW Self-Assessment Quiz 697

Key Terms 699 Key Concepts 699 Key Equations and Relationships 700 Key Learning Outcomes 700

EXERCISES Review Questions 701 Problems by Topic 701 Cumulative Problems 706 Challenge Problems 708 Conceptual Problems 709 Questions for Group Work 710 Data Interpretation and Analysis 710 Answers to Conceptual Connections 711

15 Chemical Equilibrium 712**15.1 Fetal Hemoglobin and Equilibrium** 713**15.2 The Concept of Dynamic Equilibrium** 715**15.3 The Equilibrium Constant (K)** 718

Expressing Equilibrium Constants for Chemical Reactions 718 The Significance of the Equilibrium Constant 719

Chemistry and Medicine Life and Equilibrium 720 Relationships between the Equilibrium Constant and the Chemical Equation 721

15.4 Expressing the Equilibrium Constant in Terms of Pressure 722

Relationship Between K_p and K_c 723 Units of K 724

15.5 Heterogeneous Equilibria: Reactions Involving Solids and Liquids 725**15.6 Calculating the Equilibrium Constant from Measured Equilibrium Concentrations** 726**15.7 The Reaction Quotient: Predicting the Direction of Change** 729**15.8 Finding Equilibrium Concentrations** 731

Finding Equilibrium Concentrations from the Equilibrium Constant and All but One of the Equilibrium Concentrations of the Reactants and Products 732 Finding Equilibrium Concentrations

from the Equilibrium Constant and Initial Concentrations or Pressures 733 Simplifying Approximations in Working Equilibrium Problems 737

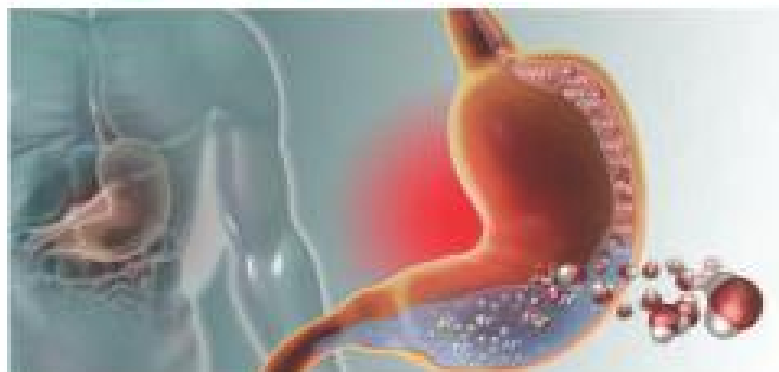
15.9 Le Châtelier's Principle: How a System at Equilibrium Responds to Disturbances 741

The Effect of a Concentration Change on Equilibrium 742 The Effect of a Volume (or Pressure) Change on Equilibrium 744 The Effect of a Temperature Change on Equilibrium 746

CHAPTER IN REVIEW Self-Assessment Quiz 748

Key Terms 749 Key Concepts 749 Key Equations and Relationships 750 Key Learning Outcomes 750

EXERCISES Review Questions 751 Problems by Topic 752 Cumulative Problems 755 Challenge Problems 758 Conceptual Problems 757 Questions for Group Work 757 Data Interpretation and Analysis 758 Answers to Conceptual Connections 759

16 Acids and Bases 760**16.1 Heartburn** 761**16.2 The Nature of Acids and Bases** 762**16.3 Definitions of Acids and Bases** 764

The Arrhenius Definition 764 The Brønsted-Lowry Definition 765

16.4 Acid Strength and the Acid Ionization Constant (K_a) 767

Strong Acids 767 Weak Acids 768 The Acid Ionization Constant (K_a) 769

16.5 Autolization of Water and pH 770

The pH Scale: A Way to Quantify Acidity and Basicity 772 pOH and Other p Scales 773

Chemistry and Medicine Ulcers 774

16.6 Finding the $[H_3O^+]$ and pH of Strong and Weak Acid Solutions 775

Strong Acids 775 Weak Acids 775 Percent Ionization of a Weak Acid 780 Mixtures of Acids 781

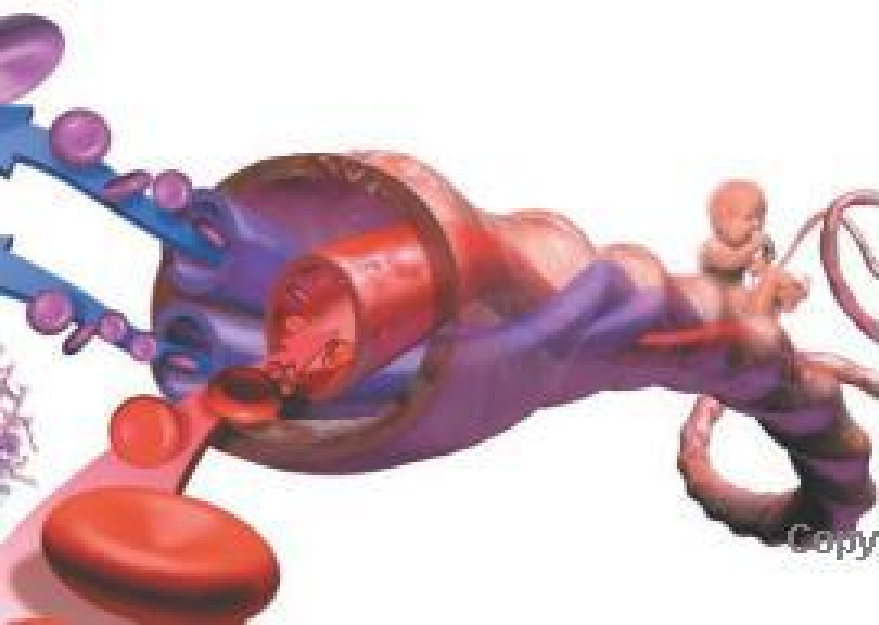
16.7 Base Solutions 784

Strong Bases 784 Weak Bases 784 Finding the $[OH^-]$ and pH of Basic Solutions 786

Chemistry and Medicine What's in My Antacid? 788

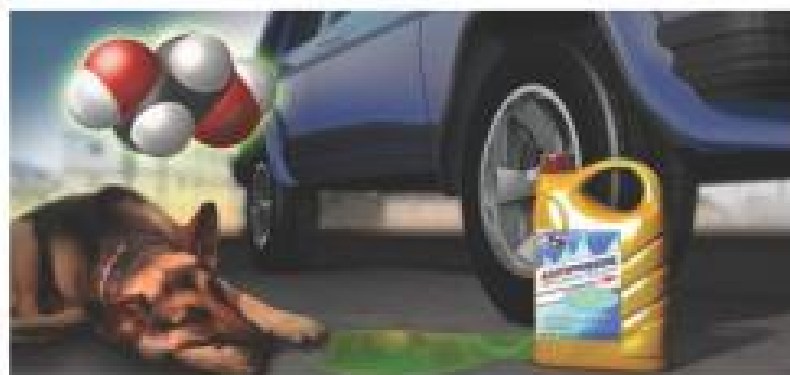
16.8 The Acid-Base Properties of Ions and Salts 788

Anions as Weak Bases 789 Cations as Weak Acids 792 Classifying Salt Solutions as Acidic, Basic, or Neutral 793



- 16.9 Polyprotic Acids** 795
 Finding the pH of Polyprotic Acid Solutions 796 Finding the Concentration of the Anions for a Weak Diprotic Acid Solution 798
- 16.10 Acid Strength and Molecular Structure** 800
 Binary Acids 800 Oxyacids 801
- 16.11 Lewis Acids and Bases** 802
 Molecules That Act as Lewis Acids 802 Cations That Act as Lewis Acids 803
- 16.12 Acid Rain** 803
 Effects of Acid Rain 804 Acid Rain Legislation 805
- CHAPTER IN REVIEW** Self-Assessment Quiz 805
 Key Terms 806 Key Concepts 808 Key Equations and Relationships 807 Key Learning Outcomes 808
- EXERCISES** Review Questions 808 Problems by Topic 809 Cumulative Problems 812 Challenge Problems 813 Conceptual Problems 814 Questions for Group Work 814 Data Interpretation and Analysis 814 Answers to Conceptual Connections 815

17 Aqueous Ionic Equilibrium 816



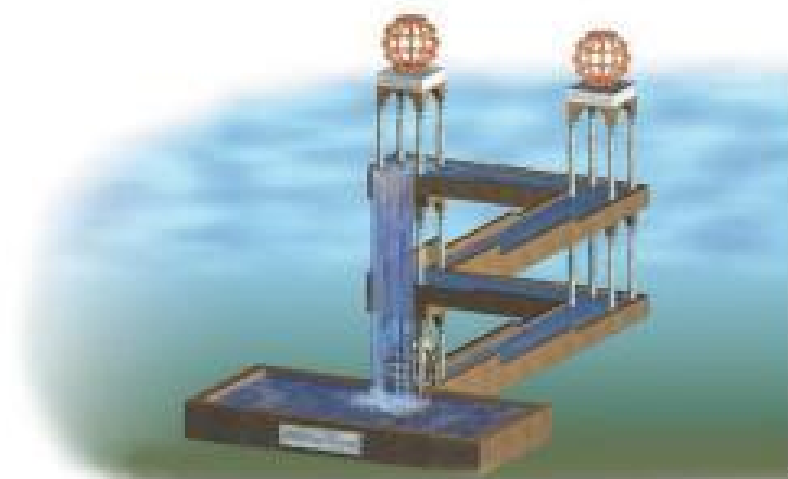
- 17.1 The Danger of Antifreeze** 817
- 17.2 Buffers: Solutions That Resist pH Change** 818
 Calculating the pH of a Buffer Solution 820 The Henderson-Hasselbalch Equation 821 Calculating pH Changes in a Buffer Solution 824 Buffers Containing a Base and Its Conjugate Acid 828
- 17.3 Buffer Effectiveness: Buffer Range and Buffer Capacity** 829
 Relative Amounts of Acid and Base 829 Absolute Concentrations of the Acid and Conjugate Base 830 Buffer Range 831
Chemistry and Medicine Buffer Effectiveness in Human Blood 832 Buffer Capacity 832
- 17.4 Titrations and pH Curves** 833
 The Titration of a Strong Acid with a Strong Base 834 The Titration of a Weak Acid with a Strong Base 838 The Titration of a Weak Base with a Strong Acid 843 The Titration of a Polyprotic Acid 843 Indicators: pH-Dependent Colors 844
- 17.5 Solubility Equilibria and the Solubility Product Constant** 847
 K_{sp} and Molar Solubility 847
Chemistry in Your Day Hard Water 849

K_{sp} and Relative Solubility 850 The Effect of a Common Ion on Solubility 850 The Effect of pH on Solubility 852

- 17.6 Precipitation** 853
 Selective Precipitation 854
- 17.7 Qualitative Chemical Analysis** 856
 Group 1: Insoluble Chlorides 857 Group 2: Acid-Insoluble Sulfides 857 Group 3: Base-Insoluble Sulfides and Hydroxides 858 Group 4: Insoluble Phosphates 858 Group 5: Alkali Metals and NH_4^+ 858
- 17.8 Complex Ion Equilibria** 859
 The Effect of Complex Ion Equilibria on Solubility 861 The Solubility of Amphoteric Metal Hydroxides 862
- CHAPTER IN REVIEW** Self-Assessment Quiz 863
 Key Terms 864 Key Concepts 864 Key Equations and Relationships 865 Key Learning Outcomes 865
- EXERCISES** Review Questions 866 Problems by Topic 867 Cumulative Problems 872 Challenge Problems 873 Conceptual Problems 873 Questions for Group Work 874 Data Interpretation and Analysis 874 Answers to Conceptual Connections 875

18 Free Energy and Thermodynamics 876

- 18.1 Nature's Heat Tax: You Can't Win and You Can't Break Even** 877
- 18.2 Spontaneous and Nonspontaneous Processes** 879
- 18.3 Entropy and the Second Law of Thermodynamics** 881
 Entropy 882 The Entropy Change upon the Expansion of an Ideal Gas 884
- 18.4 Entropy Changes Associated with State Changes** 886
 Entropy and State Change: The Concept 887 Entropy and State Changes: The Calculation 888
- 18.5 Heat Transfer and Changes in the Entropy of the Surroundings** 890
 The Temperature Dependence of ΔS_{sur} 891 Quantifying Entropy Changes in the Surroundings 892



- 18.6 Gibbs Free Energy** 893
The Effect of ΔH , ΔS , and T on Spontaneity 894
- 18.7 Entropy Changes in Chemical Reactions: Calculating $\Delta S^\circ_{\text{rxn}}$** 897
Defining Standard States and Standard Entropy Changes 897 Standard Molar Entropies (S°) and the Third Law of Thermodynamics 897
Calculating the Standard Entropy Change ($\Delta S^\circ_{\text{rxn}}$) for a Reaction 901
- 18.8 Free Energy Changes in Chemical Reactions: Calculating $\Delta G^\circ_{\text{rxn}}$** 901
Calculating Standard Free Energy Changes with $\Delta G^\circ_{\text{rxn}} = \Delta H^\circ_{\text{rxn}} - T\Delta S^\circ_{\text{rxn}}$ 902 Calculating $\Delta G^\circ_{\text{rxn}}$ with Tabulated Values of Free Energies of Formation 903
Chemistry in Your Day Making a Nonspontaneous Process Spontaneous 905
Calculating $\Delta G^\circ_{\text{rxn}}$ for a Stepwise Reaction from the Changes in Free Energy for Each of the Steps 905 Why Free Energy Is “Free” 906
- 18.9 Free Energy Changes for Nonstandard States: The Relationship between $\Delta G^\circ_{\text{rxn}}$ and ΔG_{rxn}** 908
Standard versus Nonstandard States 908 The Free Energy Change of a Reaction under Nonstandard Conditions 908
- 18.10 Free Energy and Equilibrium: Relating $\Delta G^\circ_{\text{rxn}}$ to the Equilibrium Constant (K)** 911
The Relationship between $\Delta G^\circ_{\text{rxn}}$ and K 911 The Temperature Dependence of the Equilibrium Constant 913
- CHAPTER IN REVIEW** Self-Assessment Quiz 914
Key Terms 915 Key Concepts 915 Key Equations and Relationships 916 Key Learning Outcomes 916
- EXERCISES** Review Questions 917 Problems by Topic 918
Cumulative Problems 921 Challenge Problems 922
Conceptual Problems 923 Questions for Group Work 923 Data Interpretation and Analysis 924
Answers to Conceptual Connections 925

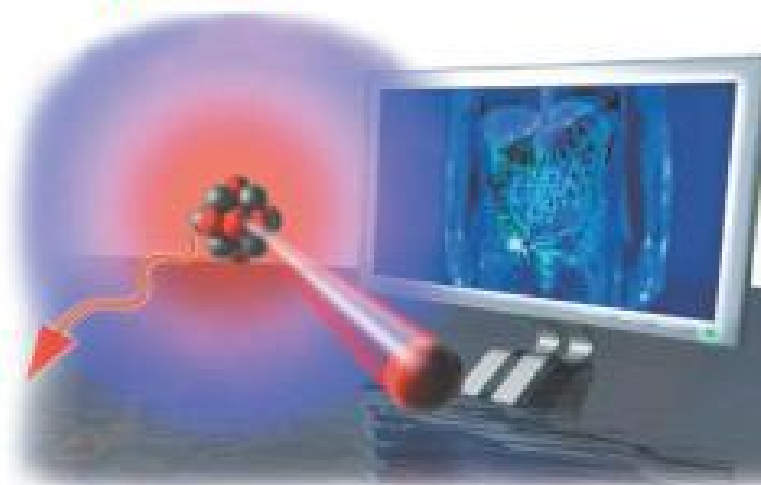
19 Electrochemistry 926

- 19.1 Pulling the Plug on the Power Grid** 927
- 19.2 Balancing Oxidation–Reduction Equations** 928
- 19.3 Voltaic (or Galvanic) Cells: Generating Electricity from Spontaneous Chemical Reactions** 931
The Voltaic Cell 932 Current and Potential Difference 933 Anode, Cathode, and Salt Bridge 934 Electrochemical Cell Notation 935



- 19.4 Standard Electrode Potentials** 936
Predicting the Spontaneous Direction of an Oxidation–Reduction Reaction 940 Predicting Whether a Metal Will Dissolve in Acid 943
- 19.5 Cell Potential, Free Energy, and the Equilibrium Constant** 943
The Relationship between ΔG° and E°_{cell} 944 The Relationship between E°_{cell} and K 946
- 19.6 Cell Potential and Concentration** 947
Cell Potential under Nonstandard Conditions: The Nernst Equation 947 Concentration Cells 950
Chemistry and Medicine Concentration Cells in Human Nerve Cells 952
- 19.7 Batteries: Using Chemistry to Generate Electricity** 952
Dry-Cell Batteries 952 Lead–Acid Storage Batteries 953 Other Rechargeable Batteries 954 Fuel Cells 955
Chemistry in Your Day The Fuel-Cell Breathalyzer 956
- 19.8 Electrolysis: Driving Nonspontaneous Chemical Reactions with Electricity** 956
Predicting the Products of Electrolysis 959 Stoichiometry of Electrolysis 962
- 19.9 Corrosion: Undesirable Redox Reactions** 963
Corrosion of Iron 964 Preventing the Corrosion of Iron 965
- CHAPTER IN REVIEW** Self-Assessment Quiz 965
Key Terms 966 Key Concepts 967 Key Equations and Relationships 967 Key Learning Outcomes 968
- EXERCISES** Review Questions 968 Problems by Topic 969
Cumulative Problems 972 Challenge Problems 974
Conceptual Problems 974 Questions for Group Work 974 Data Interpretation and Analysis 975
Answers to Conceptual Connections 975

20 Radioactivity and Nuclear Chemistry 976

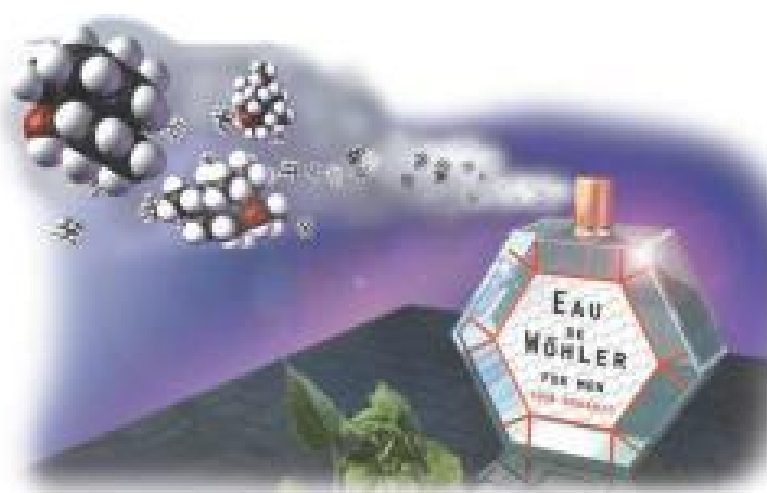


- 20.1 Diagnosing Appendicitis** 977
- 20.2 The Discovery of Radioactivity** 978
- 20.3 Types of Radioactivity** 979
Alpha (α) Decay 980 Beta (β) Decay 981
Gamma (γ) Ray Emission 981 Positron Emission 982 Electron Capture 982

- 20.4 The Valley of Stability: Predicting the Type of Radioactivity** 984
 Magic Numbers 985 Radioactive Decay Series 986
- 20.5 Detecting Radioactivity** 986
- 20.6 The Kinetics of Radioactive Decay and Radiometric Dating** 987
 The Integrated Rate Law 989 Radiocarbon Dating: Using Radioactivity to Measure the Age of Fossils and Artifacts 990
Chemistry in Your Day Radiocarbon Dating and the Shroud of Turin 992
 Uranium/Lead Dating 992
- 20.7 The Discovery of Fission: The Atomic Bomb and Nuclear Power** 994
 The Manhattan Project 994 Nuclear Power: Using Fission to Generate Electricity 996 Problems with Nuclear Power 997
- 20.8 Converting Mass to Energy: Mass Defect and Nuclear Binding Energy** 998
 Mass Defect and Nuclear Binding Energy 998 The Nuclear Binding Energy Curve 1000
- 20.9 Nuclear Fusion: The Power of the Sun** 1000
- 20.10 Nuclear Transmutation and Transuranium Elements** 1001
- 20.11 The Effects of Radiation on Life** 1002
 Acute Radiation Damage 1003 Increased Cancer Risk 1003 Genetic Defects 1003 Measuring Radiation Exposure and Dose 1003
- 20.12 Radioactivity in Medicine and Other Applications** 1005
 Diagnosis in Medicine 1005 Radiotherapy in Medicine 1006 Other Applications 1007
- CHAPTER IN REVIEW** Self-Assessment Quiz 1007 Key Terms 1008 Key Concepts 1008 Key Equations and Relationships 1009 Key Learning Outcomes 1010
- EXERCISES** Review Questions 1010 Problems by Topic 1011 Cumulative Problems 1012 Challenge Problems 1013 Conceptual Problems 1014 Questions for Group Work 1014 Data Interpretation and Analysis 1015 Answers to Conceptual Connections 1015

21 Organic Chemistry 1016

- 21.1 Fragrances and Odors** 1017
- 21.2 Carbon: Why It Is Unique** 1018
Chemistry in Your Day Vitalism and the Perceived Differences between Organic and Inorganic Compounds 1019
- 21.3 Hydrocarbons: Compounds Containing Only Carbon and Hydrogen** 1020
 Drawing Hydrocarbon Structures 1021 Stereoisomerism and Optical Isomerism 1023
- 21.4 Alkanes: Saturated Hydrocarbons** 1026
 Naming Alkanes 1027
- 21.5 Alkenes and Alkynes** 1030
 Naming Alkenes and Alkynes 1031 Geometric (Cis-Trans) Isomerism in Alkenes 1034



- 21.6 Hydrocarbon Reactions** 1035
 Reactions of Alkanes 1035 Reactions of Alkenes and Alkynes 1036
- 21.7 Aromatic Hydrocarbons** 1038
 Naming Aromatic Hydrocarbons 1038 Reactions of Aromatic Compounds 1040
- 21.8 Functional Groups** 1041
- 21.9 Alcohols** 1042
 Naming Alcohols 1042 About Alcohols 1042 Alcohol Reactions 1042
- 21.10 Aldehydes and Ketones** 1044
 Naming Aldehydes and Ketones 1045 About Aldehydes and Ketones 1045 Aldehyde and Ketone Reactions 1046
- 21.11 Carboxylic Acids and Esters** 1047
 Naming Carboxylic Acids and Esters 1047 About Carboxylic Acids and Esters 1047 Carboxylic Acid and Ester Reactions 1048
- 21.12 Ethers** 1049
 Naming Ethers 1049 About Ethers 1050
- 21.13 Amines** 1050
 Amine Reactions 1050
- CHAPTER IN REVIEW** Self-Assessment Quiz 1051 Key Terms 1052 Key Concepts 1052 Key Equations and Relationships 1053 Key Learning Outcomes 1054
- EXERCISES** Review Questions 1055 Problems by Topic 1055 Cumulative Problems 1061 Challenge Problems 1063 Conceptual Problems 1064 Questions for Group Work 1064 Data Interpretation and Analysis 1064 Answers to Conceptual Connections 1065

22 Biochemistry 1066

- 22.1 Diabetes and the Synthesis of Human Insulin** 1067
- 22.2 Lipids** 1068
 Fatty Acids 1068 Fats and Oils 1070 Other Lipids 1071
- 22.3 Carbohydrates** 1073
 Simple Carbohydrates: Monosaccharides and Disaccharides 1073 Complex Carbohydrates 1075

**22.4 Proteins and Amino Acids** 1076

Amino Acids: The Building Blocks of Proteins 1077 Peptide Bonding between Amino Acids 1079

22.5 Protein Structure 1080

Primary Structure 1082 Secondary Structure 1082 Tertiary Structure 1083 Quaternary Structure 1084

22.6 Nucleic Acids: Blueprints for Proteins 1084

The Basic Structure of Nucleic Acids 1084 The Genetic Code 1086

22.7 DNA Replication, the Double Helix, and Protein Synthesis 1088

DNA Replication and the Double Helix 1088 Protein Synthesis 1089

Chemistry and Medicine The Human Genome Project 1090

CHAPTER IN REVIEW Self-Assessment Quiz 1091

Key Terms 1092 Key Concepts 1092 Key Learning Outcomes 1093

EXERCISES Review Questions 1094 Problems by Topic 1094 Cumulative Problems 1097 Challenge Problems 1098 Conceptual Problems 1098 Questions for Group Work 1099 Data Interpretation and Analysis 1099 Answers to Conceptual Connections 1099

23 Chemistry of the Nonmetals 1100**23.1 Insulated Nanowires** 1101**23.2 The Main-Group Elements: Bonding and Properties** 1102**23.3 Silicates: The Most Abundant Matter in Earth's Crust** 1104

Quartz 1104 Aluminosilicates 1104 Individual Silicate Units, Silicate Chains, and Silicate Sheets 1105

23.4 Boron and Its Remarkable Structures 1108

Elemental Boron 1108 Boron-Halogen Compounds: Trihalides 1108 Boron-Oxygen Compounds 1109 Boron-Hydrogen Compounds: Boranes 1109

23.5 Carbon, Carbides, and Carbonates 1110

Amorphous Carbon 1110 Carbides 1111 Carbon Oxides 1113 Carbonates 1113

23.6 Nitrogen and Phosphorus: Essential Elements for Life 1114

Elemental Nitrogen and Phosphorus 1114 Nitrogen Compounds 1116 Phosphorus Compounds 1119

23.7 Oxygen 1121

Elemental Oxygen 1121 Uses for Oxygen 1122 Oxides 1122 Ozone 1122

23.8 Sulfur: A Dangerous but Useful Element 1123

Elemental Sulfur 1123 Hydrogen Sulfide and Metal Sulfides 1125 Sulfur Dioxide 1126 Sulfuric Acid 1126

23.9 Halogens: Reactive Elements with High Electronegativity 1127

Elemental Fluorine and Hydrofluoric Acid 1128 Elemental Chlorine 1129 Halogen Compounds 1129

CHAPTER IN REVIEW Self-Assessment Quiz 1131

Key Terms 1132 Key Concepts 1132 Key Learning Outcomes 1133

EXERCISES Review Questions 1133 Problems by Topic 1133 Cumulative Problems 1135 Challenge Problems 1136 Conceptual Problems 1136 Questions for Group Work 1136 Data Interpretation and Analysis 1137 Answers to Conceptual Connections 1137

24 Metals and Metallurgy 1138**24.1 Vanadium: A Problem and an Opportunity** 1139**24.2 The General Properties and Natural Distribution of Metals** 1140**24.3 Metallurgical Processes** 1142

Separation 1142 Pyrometallurgy 1142 Hydrometallurgy 1143 Electrometallurgy 1144 Powder Metallurgy 1145

24.4 Metal Structures and Alloys 1146

Alloys 1146 Substitutional Alloys 1146 Alloys with Limited Solubility 1148 Interstitial Alloys 1149

24.5 Sources, Properties, and Products of Some of the 3d Transition Metals 1151

Titanium 1151 Chromium 1152 Manganese 1153 Cobalt 1154 Copper 1155 Nickel 1155 Zinc 1156

CHAPTER IN REVIEW Self-Assessment Quiz 1158 Key Terms 1158 Key Concepts 1158 Key Equations and Relationships 1158 Key Learning Outcomes 1159

EXERCISES Review Questions 1159 Problems by Topic 1159 Cumulative Problems 1161 Challenge Problems 1161 Conceptual Problems 1161 Questions for Group Work 1162 Data Interpretation and Analysis 1162 Answers to Conceptual Connections 1163

25 Transition Metals and Coordination Compounds 1164



25.1 The Colors of Rubies and Emeralds 1165

25.2 Properties of Transition Metals 1166
 Electron Configurations 1166 Atomic Size 1168
 Ionization Energy 1168 Electronegativity 1169
 Oxidation States 1169

25.3 Coordination Compounds 1170
 Naming Coordination Compounds 1173

25.4 Structure and Isomerization 1175
 Structural Isomerism 1175 Stereoisomerism 1177

25.5 Bonding in Coordination Compounds 1180
 Valence Bond Theory 1180 Crystal Field Theory 1181

25.6 Applications of Coordination Compounds 1185
 Chelating Agents 1186 Chemical Analysis 1186
 Coloring Agents 1186 Biomolecules 1186

CHAPTER IN REVIEW Self-Assessment Quiz 1189
 Key Terms 1189 Key Concepts 1190 Key Equations and Relationships 1190 Key Learning Outcomes 1190

EXERCISES Review Questions 1191 Problems by Topic 1191 Cumulative Problems 1193 Challenge Problems 1193 Conceptual Problems 1194 Questions for Group Work 1194 Data Interpretation and Analysis 1194 Answers to Conceptual Connections 1195

Appendix I Common Mathematical Operations in Chemistry A-1

Appendix II Useful Data A-5

Appendix III Answers to Selected Exercises A-15

Appendix IV Answers to In-Chapter Practice Problems A-54

Glossary G-1

Photo and Text Credits C-1

Index I-1