Contents

Preface 15

For Instructors 18

1 Chemical Tools: Experimentation and Measurement 35

- The Scientific Method: Nanoparticle Catalysts for Fuel Cells 36
- **1.2** Measurements: SI Units and Scientific Notation 39
- **1.3** Mass and Its Measurement 41
- **1.4** Length and Its Measurement 42
- **1.5** Temperature and Its Measurement 43
- **1.6** Derived Units: Volume and Its Measurement 45
- **1.7** Derived Units: Density and Its Measurement 47
- **1.8** Derived Units: Energy and Its Measurement 48
- **1.9** Accuracy, Precision, and Significant Figures in Measurement 50
- **1.10** Significant Figures in Calculations 52
- **1.11** Converting from One Unit to Another 54

INQUIR What are the unique properties of nanoscale materials? 57

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

2 Atoms, Molecules, and Ions 67

- **2.1** Chemistry and the Elements 68
- **2.2** Elements and the Periodic Table 70
- **2.3** Some Common Groups of Elements and Their Properties 72
- 2.4 Observations Supporting Atomic Theory: The Conservation of Mass and the Law of Definite Proportions 75
- 2.5 The Law of Multiple Proportions and Dalton's Atomic Theory 77
- **2.6** Atomic Structure: Electrons 79
- 2.7 Atomic Structure: Protons and Neutrons 81
- 2.8 Atomic Numbers 83
- **2.9** Atomic Weights and the Mole 85
- 2.10 Measuring Atomic Weight: Mass Spectrometry 89
- 2.11 Mixtures and Chemical Compounds; Molecules and Covalent Bonds 91

- **2.12** Ions and Ionic Bonds 95
- 2.13 Naming Chemical Compounds 97

INQUIR How can measurements of oxygen and hydrogen isotopes in ice cores determine past climates? 103

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

3 Mass Relationships in Chemical Reactions 117

- **3.1** Representing Chemistry on Different Levels 118
- **3.2** Balancing Chemical Equations 119
- **3.3** Molecular Weight and Molar Mass 122
- **3.4** Stoichiometry: Relating Amounts of Reactants and Products 124
- **3.5** Yields of Chemical Reactions 126
- **3.6** Reactions with Limiting Amounts of Reactants 128
- **3.7** Percent Composition and Empirical Formulas 131
- **3.8** Determining Empirical Formulas: Elemental Analysis 134
- **3.9** Determining Molecular Weights: Mass Spectrometry 137

INQUIR How is the principle of atom economy used to minimize waste in a chemical synthesis? 139

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

4 Reactions in Aqueous Solution 150

- **4.1** Solution Concentration: Molarity 151
- **4.2** Diluting Concentrated Solutions 153
- **4.3** Electrolytes in Aqueous Solution 155
- **4.4** Types of Chemical Reactions in Aqueous Solution 157
- **4.5** Aqueous Reactions and Net Ionic Equations 158
- **4.6** Precipitation Reactions and Solubility Guidelines 159
- **4.7** Acids, Bases, and Neutralization Reactions 162
- **4.8** Solution Stoichiometry 166
- **4.9** Measuring the Concentration of a Solution: Titration 167

- **4.10** Oxidation–Reduction (Redox) Reactions 169
- **4.11** Identifying Redox Reactions 172
- **4.12** The Activity Series of the Elements 175
- **4.13** Redox Titrations 178
- 4.14 Some Applications of Redox Reactions 180

INQUIR How do sports drinks replenish the substances lost in sweat? 182

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

5 Periodicity and the Electronic Structure of Atoms 195

- 5.1 Wave Properties of Radiant Energy and the Electromagnetic Spectrum 196
- 5.2 Particlelike Properties of Radiant Energy: The Photoelectric Effect and Planck's Postulate 200
- 5.3 Atomic Line Spectra and Quantized Energy 2035.4 Wavelike Properties of Matter: de Broglie's
- Hypothesis 207**5.5** The Quantum Mechanical Model of the Atom:
- Heisenberg's Uncertainty Principle 2095.6 The Quantum Mechanical Model of the Atom: Orbitals and Quantum Numbers 210
- 5.7 The Shapes of Orbitals 213
- **5.8** Electron Spin and the Pauli Exclusion Principle 218
- **5.9** Orbital Energy Levels in Multielectron Atoms 219
- **5.10** Electron Configurations of Multielectron Atoms 221
- 5.11 Anomalous Electron Configurations 223
- **5.12** Electron Configurations and the Periodic Table 223
- **5.13** Electron Configurations and Periodic Properties: Atomic Radii 226

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

6 Ionic Compounds: Periodic Trends and Bonding Theory 242

- 6.1 Electron Configurations of Ions 243
- 6.2 Ionic Radii 246
- **6.3** Ionization Energy 248
- 6.4 Higher Ionization Energies 250

- **6.5** Electron Affinity 252
- 6.6 The Octet Rule 254
- 6.7 Ionic Bonds and the Formation of Ionic Solids 256
- **6.8** Lattice Energies in Ionic Solids 260

INQUIR How do ionic liquids lead to more environmentally friendly processes? 262

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

7 Covalent Bonding and Electron-Dot Structures 272

- 7.1 Covalent Bonding in Molecules 273
- **7.2** Strengths of Covalent Bonds 274
- 7.3 Polar Covalent Bonds: Electronegativity 276
- 7.4 A Comparison of Ionic and Covalent Compounds 280
- **7.5** Electron-Dot Structures: The Octet Rule 281
- 7.6 Procedure for Drawing Electron-Dot Structures 284
- 7.7 Drawing Electron-Dot Structures for Radicals 288
- **7.8** Electron-Dot Structures of Compounds Containing Only Hydrogen and Second-Row Elements 289
- **7.9** Electron-Dot Structures and Resonance 291
- 7.10 Formal Charges 295

INQUIR How does bond polarity affect the toxicity of organophosphate insecticides? 299

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

8 Covalent Compounds: Bonding Theories and Molecular Structure 312

- 8.1 Molecular Shapes: The VSEPR Model 313
- **8.2** Valence Bond Theory 320
- **8.3** Hybridization and sp^3 Hybrid Orbitals 321
- 8.4 Other Kinds of Hybrid Orbitals 324
- 8.5 Polar Covalent Bonds and Dipole Moments 329
- **8.6** Intermolecular Forces 332
- 8.7 Molecular Orbital Theory: The Hydrogen Molecule 340
- **8.8** Molecular Orbital Theory: Other Diatomic Molecules 342
- 8.9 Combining Valence Bond Theory and Molecular Orbital Theory 346

INQUIR⁽?) Which is better for human health, natural or synthetic vitamins? 348

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

INQUIR How does knowledge of atomic emission spectra help us build more efficient light bulbs? 229

9 Thermochemistry: Chemical Energy 361

- 9.1 Energy and Its Conservation 362
- 9.2 Internal Energy and State Functions 364
- 9.3 Expansion Work 366
- **9.4** Energy and Enthalpy 368
- **9.5** Thermochemical Equations and the Thermodynamic Standard State 370
- 9.6 Enthalpies of Chemical and Physical Changes 372
- **9.7** Calorimetry and Heat Capacity 375
- 9.8 Hess's Law 379
- 9.9 Standard Heats of Formation 382
- 9.10 Bond Dissociation Energies 384
- **9.11** An Introduction to Entropy 386
- 9.12 An Introduction to Free Energy 389

INQUIR⁽) How do we determine the energy content of biofuels? 393

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

10 Gases: Their Properties and Behavior 408

- **10.1** Gases and Gas Pressure 409
- **10.2** The Gas Laws 414
- **10.3** The Ideal Gas Law 419
- **10.4** Stoichiometric Relationships with Gases 421
- 10.5 Mixtures of Gases: Partial Pressure and Dalton's Law 424
- **10.6** The Kinetic–Molecular Theory of Gases 427
- **10.7** Gas Diffusion and Effusion: Graham's Law 429
- **10.8** The Behavior of Real Gases 431
- **10.9** The Earth's Atmosphere and the Greenhouse Effect 432
- **10.10** Greenhouse Gases 435
- **10.11** Climate Change 437

INQUIR How do inhaled anesthetics work? 441

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

11 Liquids and Phase Changes 456

- **11.1** Properties of Liquids 457
- **11.2** Vapor Pressure and Boiling Point 458
- **11.3** Phase Changes between Solids, Liquids, and Gases 462

- **11.4** Energy Changes during Phase Transitions 465
- **11.5** Phase Diagrams 467
- **11.6** Liquid Crystals 470

INQUIR How is caffeine removed from coffee? 473

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

12 Solids and Solid-State Materials 484

- **12.1** Types of Solids 485
- 12.2 Probing the Structure of Solids: X-Ray Crystallography 487
- 12.3 The Packing of Spheres in Crystalline Solids: Unit Cells 489
- **12.4** Structures of Some Ionic Solids 493
- 12.5 Structures of Some Covalent Network Solids 496
- **12.6** Bonding in Metals 498
- 12.7 Semiconductors 502
- **12.8** Semiconductor Applications 505
- 12.9 Superconductors 509
- **12.10** Ceramics and Composites 511

INQUIR What are quantum dots, and what controls their color? 516

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

13 Solutions and Their Properties 528

- **13.1** Solutions 529
- **13.2** Enthalpy Changes and the Solution Process 530
- **13.3** Predicting Solubility 532
- **13.4** Concentration Units for Solutions 535
- **13.5** Some Factors That Affect Solubility 540
- **13.6** Physical Behavior of Solutions: Colligative Properties 544
- 13.7 Vapor-Pressure Lowering of Solutions: Raoult's Law 545
- **13.8** Boiling-Point Elevation and Freezing-Point Depression of Solutions 551
- **13.9** Osmosis and Osmotic Pressure 555

INQUIR⁽?) How does hemodialysis cleanse the blood of patients with kidney failure? 559

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

14 Chemical Kinetics 572

- **14.1** Reaction Rates 573
- **14.2** Rate Laws and Reaction Order 578
- **14.3** Method of Initial Rates: Experimental Determination of a Rate Law 580
- 14.4 Integrated Rate Law: Zeroth-Order Reactions 584
- 14.5 Integrated Rate Law: First-Order Reactions 586
- **14.6** Integrated Rate Law: Second-Order Reactions 591
- 14.7 Reaction Rates and Temperature: The Arrhenius Equation 594
- 14.8 Using the Arrhenius Equation 598
- **14.9** Reaction Mechanisms 601
- **14.10** Rate Laws for Elementary Reactions 604
- **14.11** Rate Laws for Overall Reactions 607
- **14.12** Catalysis 611
- **14.13** Homogeneous and Heterogeneous Catalysts 614

INQUIR⁽) How do enzymes work? 617

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

15 Chemical Equilibrium 635

- **15.1** The Equilibrium State 637
- **15.2** The Equilibrium Constant K_c 639
- **15.3** The Equilibrium Constant $K_{\rm P}$ 644
- **15.4** Heterogeneous Equilibria 646
- **15.5** Using the Equilibrium Constant 648
- **15.6** Factors That Alter the Composition of an Equilibrium Mixture: Le Châtelier's Principle 658
- **15.7** Altering an Equilibrium Mixture: Changes in Concentration 659
- **15.8** Altering an Equilibrium Mixture: Changes in Pressure and Volume 663
- **15.9** Altering an Equilibrium Mixture: Changes in Temperature 665
- **15.10** The Link between Chemical Equilibrium and Chemical Kinetics 668

INQUIR How does high altitude affect oxygen transport in the body? 671

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

16 Aqueous Equilibria: Acids and Bases 688

- **16.1** Acid–Base Concepts: The Brønsted–Lowry Theory 689
- **16.2** Acid Strength and Base Strength 692
- **16.3** Factors That Affect Acid Strength 695

- **16.4** Dissociation of Water 698
- **16.5** The pH Scale 700
- 16.6 Measuring pH 702
- 16.7 The pH in Solutions of Strong Acids and Strong Bases 703
- **16.8** Equilibria in Solutions of Weak Acids 705
- **16.9** Calculating Equilibrium Concentrations in Solutions of Weak Acids 707
- **16.10** Percent Dissociation in Solutions of Weak Acids 711
- **16.11** Polyprotic Acids 712
- 16.12 Equilibria in Solutions of Weak Bases 716
- **16.13** Relation Between K_a and K_b 718
- 16.14 Acid–Base Properties of Salts 720
- **16.15** Lewis Acids and Bases 725

INQUIR Has the problem of acid rain been solved? 728

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

17 Applications of Aqueous Equilibria 742

- **17.1** Neutralization Reactions 743
- **17.2** The Common-Ion Effect 746
- **17.3** Buffer Solutions 750
- **17.4** The Henderson–Hasselbalch Equation 754
- **17.5** pH Titration Curves 757
- **17.6** Strong Acid–Strong Base Titrations 758
- **17.7** Weak Acid–Strong Base Titrations 761
- **17.8** Weak Base–Strong Acid Titrations 766
- **17.9** Polyprotic Acid–Strong Base Titrations 767
- **17.10** Solubility Equilibria for Ionic Compounds 772
- **17.11** Measuring K_{sp} and Calculating Solubility from K_{sp} 773
- **17.12** Factors That Affect Solubility 776
- **17.13** Precipitation of Ionic Compounds 784
- **17.14** Separation of Ions by Selective Precipitation 785
- **17.15** Qualitative Analysis 786

INQUIR What is causing ocean acidification? 788

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

18 Thermodynamics: Entropy, Free Energy, and Spontaneity 802

- **18.1** Spontaneous Processes 803
- **18.2** Enthalpy, Entropy, and Spontaneous Processes 804
- **18.3** Entropy and Probability 807

10 CONTENTS

- **18.4** Entropy and Temperature 811
- 18.5 Standard Molar Entropies and Standard Entropies of Reaction 813
- **18.6** Entropy and the Second Law of Thermodynamics 815
- 18.7 Free Energy and the Spontaneity of Chemical Reactions 818
- **18.8** Standard Free-Energy Changes for Reactions 821
- **18.9** Standard Free Energies of Formation 823
- 18.10 Free-Energy Changes for Reactions under Nonstandard-State Conditions 826
- **18.11** Free Energy and Chemical Equilibrium 828

INQUIR⁽?) Does the formation of highly ordered molecules violate the second law of thermodynamics? 832

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

19 Electrochemistry 847

- 19.1 Balancing Redox Reactions by the Half-Reaction Method 848
- 19.2 Galvanic Cells 853
- **19.3** Shorthand Notation for Galvanic Cells 858
- 19.4 Cell Potentials and Free-Energy Changes for Cell Reactions 859
- 19.5 Standard Reduction Potentials 861
- 19.6 Using Standard Reduction Potentials 864
- 19.7 Cell Potentials under Nonstandard-State Conditions: The Nernst Equation 867
- **19.8** Electrochemical Determination of pH 870
- **19.9** Standard Cell Potentials and Equilibrium Constants 872
- **19.10** Batteries 874
- 19.11 Corrosion 877
- 19.12 Electrolysis and Electrolytic Cells 880
- **19.13** Commercial Applications of Electrolysis 883
- 19.14 Quantitative Aspects of Electrolysis 886

INQUIR How do hydrogen fuel cells work? 888

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

20 Nuclear Chemistry 904

- 20.1 Nuclear Reactions and Their Characteristics 905
- 20.2 Radioactivity 906
- 20.3 Nuclear Stability 909
- **20.4** Radioactive Decay Rates 911
- **20.5** Dating with Radioisotopes 915

- 20.6 Energy Changes during Nuclear Reactions 916
- 20.7 Nuclear Fission and Fusion 920
- 20.8 Nuclear Transmutation 924
- **20.9** Detecting and Measuring Radioactivity 925

INQUIR How are radioisotopes used in medicine? 928

Study Guide • Key Terms • Key Equations • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

21 Transition Elements and Coordination Chemistry 938

- **21.1** Electron Configurations 940
- **21.2** Properties of Transition Elements 942
- **21.3** Oxidation States of Transition Elements 946
- 21.4 Coordination Compounds 947
- 21.5 Ligands 949
- **21.6** Naming Coordination Compounds 952
- **21.7** Isomers 955
- 21.8 Enantiomers and Molecular Handedness 960
- **21.9** Color of Transition Metal Complexes 963
- **21.10** Crystal Field Theory 964
- **21.11** Bonding in Complexes: Valence Bond Theory 970

INQUIR How does cisplatin kill cancer cells? 974

Study Guide • Key Terms • Key Equation • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

22 The Main-Group Elements 988

- 22.1 A Review of General Properties and Periodic Trends 989
- **22.2** Distinctive Properties of the Second-Row Elements 991
- 22.3 Group 1A: Hydrogen 993
- **22.4** Group 1A: Alkali Metals and Group 2A: Alkaline Earth Metals 996
- **22.5** Group 3A Elements 999
- 22.6 Group 4A Elements 1001
- 22.7 Group 5A Elements 1008
- **22.8** Group 6A Elements 1014
- 22.9 Group 7A: The Halogens 1021
- **22.10** Group 8A: Noble Gases 1023

INQUIR⁽?) What are the barriers to a hydrogen economy? 1024

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

23 Organic and Biological Chemistry 1037

- 23.1 Organic Molecules and Their Structures: Consitutional Isomers 1038
- 23.2 Stereoisomers: Chiral Molecules 1042
- **23.3** Families of Organic Compounds: Functional Groups 1045
- **23.4** Carbohydrates: A Biological Example of Isomers 1048
- **23.5** Valence Bond Theory and Orbital Overlap Pictures 1051
- **23.6** Lipids: A Biological Example of Cis–Trans Isomerism 1055
- **23.7** Formal Charge and Resonance in Organic Compounds 1059
- 23.8 Conjugated Systems 1064
- 23.9 Proteins: A Biological Example of Conjugation 1068
- **23.10** Aromatic Compounds and Molecular Orbital Theory 1072
- **23.11** Nucleic Acids: A Biological Example of Aromaticity 1075

INQUIR Why do enantiomers have different biological responses? 1079

Study Guide • Key Terms • Practice Test • Conceptual Problems • Section Problems • Multiconcept Problems

Appendix A: Mathematical Operations A-1

- A.1 Scientific Notation A-1
- A.2 Logarithms A-4
- A.3 Straight-Line Graphs and Linear Equations A-6
- A.4 Quadratic Equations A-7
- A.5 Calculus Derivations of Integrated Rate Laws A-7

Appendix B: Thermodynamic Properties at 25 °C A-9

Appendix C: Equilibrium Constants at 25 °C A-14

Appendix D: Standard Reduction Potentials at 25 °C A-18

Appendix E: Properties of Water A-20

Answers to Selected Problems A-21

Glossary G-1

Index I-1

Photo/Text Credits C-1