

Contents

Preface 12
For Instructors 14

1 Chemical Tools: Experimentation and Measurement 29

- 1.1 The Scientific Method in a Chemical Context: Improved Pharmaceutical Insulin 30
- 1.2 Experimentation and Measurement 34
- 1.3 Mass and Its Measurement 36
- 1.4 Length and Its Measurement 36
- 1.5 Temperature and Its Measurement 37
- 1.6 Derived Units: Volume and Its Measurement 39
- 1.7 Derived Units: Density and Its Measurement 40
- 1.8 Derived Units: Energy and Its Measurement 42
- 1.9 Accuracy, Precision, and Significant Figures in Measurement 44
- 1.10 Rounding Numbers 46
- 1.11 Calculations: Converting from One Unit to Another 48

INQUIRY >>> What are the unique properties of nanoscale materials? 51

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems

2 Atoms, Molecules, and Ions 61

- 2.1 Chemistry and the Elements 62
- 2.2 Elements and the Periodic Table 63
- 2.3 Some Common Groups of Elements and Their Properties 66
- 2.4 Observations Supporting Atomic Theory: The Conservation of Mass and the Law of Definite Proportions 69
- 2.5 The Law of Multiple Proportions and Dalton's Atomic Theory 71
- 2.6 Atomic Structure: Electrons 73
- 2.7 Atomic Structure: Protons and Neutrons 75
- 2.8 Atomic Numbers 77
- 2.9 Atomic Weights and the Mole 79
- 2.10 Mixtures and Chemical Compounds; Molecules and Covalent Bonds 82
- 2.11 Ions and Ionic Bonds 86
- 2.12 Naming Chemical Compounds 88

4

INQUIRY >>> How is the principle of atom economy used to minimize waste in a chemical synthesis? 94

Study Guide • Key Terms • Conceptual Problems • Section Problems • Chapter Problems

3 Mass Relationships in Chemical Reactions 105

- 3.1 Representing Chemistry on Different Levels 106
- 3.2 Balancing Chemical Equations 107
- 3.3 Chemical Arithmetic: Stoichiometry 110
- 3.4 Yields of Chemical Reactions 114
- 3.5 Reactions with Limiting Amounts of Reactants 116
- 3.6 Percent Composition and Empirical Formulas 119
- 3.7 Determining Empirical Formulas: Elemental Analysis 122
- 3.8 Determining Molecular Weights: Mass Spectrometry 125

INQUIRY >>> Can alternative fuels decrease CO₂ emissions? 129

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems

4 Reactions in Aqueous Solution 139

- 4.1 Solution Concentration: Molarity 140
- 4.2 Diluting Concentrated Solutions 142
- 4.3 Electrolytes in Aqueous Solution 144
- 4.4 Types of Chemical Reactions in Aqueous Solution 146
- 4.5 Aqueous Reactions and Net Ionic Equations 147
- 4.6 Precipitation Reactions and Solubility Guidelines 148
- 4.7 Acids, Bases, and Neutralization Reactions 151
- 4.8 Solution Stoichiometry 155
- 4.9 Measuring the Concentration of a Solution: Titration 156
- 4.10 Oxidation–Reduction (Redox) Reactions 158
- 4.11 Identifying Redox Reactions 161
- 4.12 The Activity Series of the Elements 163
- 4.13 Redox Titrations 166
- 4.14 Some Applications of Redox Reactions 169

INQUIRY >>> How do sports drinks replenish the chemicals lost in sweat? 170

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

5 Periodicity and the Electronic Structure of Atoms 182

- 5.1 The Nature of Radiant Energy and the Electromagnetic Spectrum 183
- 5.2 Particlelike Properties of Radiant Energy: The Photoelectric Effect and Planck's Postulate 186
- 5.3 The Interaction of Radiant Energy with Atoms: Line Spectra 188
- 5.4 The Bohr Model of the Atom: Quantized Energy 191
- 5.5 Wavelike Properties of Matter: de Broglie's Hypothesis 193
- 5.6 The Quantum Mechanical Model of the Atom: Heisenberg's Uncertainty Principle 195
- 5.7 The Quantum Mechanical Model of the Atom: Orbitals and Quantum Numbers 196
- 5.8 The Shapes of Orbitals 198
- 5.9 Electron Spin and the Pauli Exclusion Principle 202
- 5.10 Orbital Energy Levels in Multielectron Atoms 203
- 5.11 Electron Configurations of Multielectron Atoms 204
- 5.12 Anomalous Electron Configurations 206
- 5.13 Electron Configurations and the Periodic Table 206
- 5.14 Electron Configurations and Periodic Properties: Atomic Radii 209

INQUIRY >>> How does knowledge of atomic emission spectra help us build more efficient light bulbs? 212

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

6 Ionic Compounds: Periodic Trends and Bonding Theory 223

- 6.1 Electron Configurations of Ions 224
- 6.2 Ionic Radii 226
- 6.3 Ionization Energy 228
- 6.4 Higher Ionization Energies 230
- 6.5 Electron Affinity 232
- 6.6 The Octet Rule 234
- 6.7 Ionic Bonds and the Formation of Ionic Solids 236
- 6.8 Lattice Energies in Ionic Solids 239

INQUIRY >>> How has an understanding of ionic compounds led to the production of safer solvents? 242

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

7 Covalent Bonding and Electron-Dot Structures 250

- 7.1 Covalent Bonding in Molecules 251
- 7.2 Strengths of Covalent Bonds 253
- 7.3 Polar Covalent Bonds: Electronegativity 254
- 7.4 A Comparison of Ionic and Covalent Compounds 257
- 7.5 Electron-Dot Structures: The Octet Rule 259
- 7.6 Procedure for Drawing Electron-Dot Structures 262
- 7.7 Drawing Electron-Dot Structures for Radicals 266
- 7.8 Electron-Dot Structures of Compounds Containing Only Hydrogen and Second-Row Elements 268
- 7.9 Electron-Dot Structures and Resonance 270
- 7.10 Formal Charges 274

INQUIRY >>> How do we make organophosphate insecticides less toxic to humans? 278

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

8 Covalent Compounds: Bonding Theories and Molecular Structure 289

- 8.1 Molecular Shapes: The VSEPR Model 290
- 8.2 Valence Bond Theory 298
- 8.3 Hybridization and sp^3 Hybrid Orbitals 299
- 8.4 Other Kinds of Hybrid Orbitals 301
- 8.5 Polar Covalent Bonds and Dipole Moments 306
- 8.6 Intermolecular Forces 310
- 8.7 Molecular Orbital Theory: The Hydrogen Molecule 319
- 8.8 Molecular Orbital Theory: Other Diatomic Molecules 322
- 8.9 Combining Valence Bond Theory and Molecular Orbital Theory 325

INQUIRY >>> Why do different drugs have different physiological responses? 327

Study Guide • Key Terms • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

9 Thermochemistry: Chemical Energy 339

- 9.1 Energy and Its Conservation 340
- 9.2 Internal Energy and State Functions 342
- 9.3 Expansion Work 344
- 9.4 Energy and Enthalpy 346
- 9.5 Thermochemical Equations and the Thermodynamic Standard State 349
- 9.6 Enthalpies of Chemical and Physical Changes 351
- 9.7 Calorimetry and Heat Capacity 353
- 9.8 Hess's Law 357
- 9.9 Standard Heats of Formation 359
- 9.10 Bond Dissociation Energies 362
- 9.11 Fossil Fuels, Fuel Efficiency, and Heats of Combustion 363
- 9.12 An Introduction to Entropy 365
- 9.13 An Introduction to Free Energy 368

INQUIRY >>> How is the energy content of new fuels determined? 372

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

10 Gases: Their Properties and Behavior 386

- 10.1 Gases and Gas Pressure 387
- 10.2 The Gas Laws 392
- 10.3 The Ideal Gas Law 397
- 10.4 Stoichiometric Relationships with Gases 400
- 10.5 Mixtures of Gases: Partial Pressure and Dalton's Law 403
- 10.6 The Kinetic-Molecular Theory of Gases 406
- 10.7 Gas Diffusion and Effusion: Graham's Law 408
- 10.8 The Behavior of Real Gases 411
- 10.9 The Earth's Atmosphere and Air Pollution 412
- 10.10 The Greenhouse Effect 417
- 10.11 Climate Change 422

INQUIRY >>> Which gases are greenhouse gases? 420

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

11 Liquids, Solids, and Phase Changes 438

- 11.1 Properties of Liquids 439
- 11.2 Phase Changes between Solids, Liquids, and Gases 440

- 11.3 Evaporation, Vapor Pressure, and Boiling Point 445
- 11.4 Kinds of Solids 448
- 11.5 Probing the Structure of Solids: X-Ray Crystallography 450
- 11.6 The Packing of Spheres in Crystalline Solids: Unit Cells 453
- 11.7 Structures of Some Ionic Solids 458
- 11.8 Structures of Some Covalent Network Solids 460
- 11.9 Phase Diagrams 463

INQUIRY >>> How is caffeine removed from coffee? 465

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

12 Solutions and Their Properties 475

- 12.1 Solutions 476
- 12.2 Energy Changes and the Solution Process 477
- 12.3 Concentration Units for Solutions 482
- 12.4 Some Factors That Affect Solubility 486
- 12.5 Physical Behavior of Solutions: Colligative Properties 490
- 12.6 Vapor-Pressure Lowering of Solutions: Raoult's Law 490
- 12.7 Boiling-Point Elevation and Freezing-Point Depression of Solutions 497
- 12.8 Osmosis and Osmotic Pressure 501
- 12.9 Fractional Distillation of Liquid Mixtures 505

INQUIRY >>> How does hemodialysis cleanse the blood of patients with kidney failure? 507

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

13 Chemical Kinetics 519

- 13.1 Reaction Rates 520
- 13.2 Rate Laws and Reaction Order 525
- 13.3 Method of Initial Rates: Experimental Determination of a Rate Law 528
- 13.4 Integrated Rate Law: Zeroth-Order Reactions 531
- 13.5 Integrated Rate Law: First-Order Reactions 533
- 13.6 Integrated Rate Law: Second-Order Reactions 538
- 13.7 Reaction Rates and Temperature: The Arrhenius Equation 542
- 13.8 Using the Arrhenius Equation 546
- 13.9 Reaction Mechanisms 548
- 13.10 Rate Laws for Elementary Reactions 552
- 13.11 Rate Laws for Overall Reactions 554

- 13.12 Catalysis 558
 13.13 Homogeneous and Heterogeneous Catalysts 561
 13.14 Enzyme Catalysis 564

INQUIRY >>> What causes the ozone hole? 565

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

14 Chemical Equilibrium 581

- 14.1 The Equilibrium State 582
 14.2 The Equilibrium Constant K_c 584
 14.3 The Equilibrium Constant K_p 589
 14.4 Heterogeneous Equilibria 592
 14.5 Using the Equilibrium Constant 593
 14.6 Factors that Alter the Composition of an Equilibrium Mixture: Le Châtelier's Principle 602
 14.7 Altering an Equilibrium Mixture: Changes in Concentration 603
 14.8 Altering an Equilibrium Mixture: Changes in Pressure and Volume 607
 14.9 Altering an Equilibrium Mixture: Changes in Temperature 609
 14.10 The Link between Chemical Equilibrium and Chemical Kinetics 612

INQUIRY >>> How does equilibrium affect oxygen transport in the bloodstream? 616

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

15 Aqueous Equilibria: Acids and Bases 631

- 15.1 Acid–Base Concepts: The Brønsted–Lowry Theory 632
 15.2 Acid Strength and Base Strength 636
 15.3 Factors That Affect Acid Strength 638
 15.4 Dissociation of Water 641
 15.5 The pH Scale 644
 15.6 Measuring pH 646
 15.7 The pH in Solutions of Strong Acids and Strong Bases 647
 15.8 Equilibria in Solutions of Weak Acids 649
 15.9 Calculating Equilibrium Concentrations in Solutions of Weak Acids 651
 15.10 Percent Dissociation in Solutions of Weak Acids 655
 15.11 Polyprotic Acids 656
 15.12 Equilibria in Solutions of Weak Bases 660
 15.13 Relation between K_a and K_b 662

- 15.14 Acid–Base Properties of Salts 664
 15.15 Lewis Acids and Bases 668

INQUIRY >>> What is acid rain and what are its effects? 671

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

16 Applications of Aqueous Equilibria 684

- 16.1 Neutralization Reactions 685
 16.2 The Common-Ion Effect 688
 16.3 Buffer Solutions 692
 16.4 The Henderson–Hasselbalch Equation 697
 16.5 pH Titration Curves 700
 16.6 Strong Acid–Strong Base Titrations 701
 16.7 Weak Acid–Strong Base Titrations 704
 16.8 Weak Base–Strong Acid Titrations 709
 16.9 Polyprotic Acid–Strong Base Titrations 710
 16.10 Solubility Equilibria for Ionic Compounds 714
 16.11 Measuring K_{sp} and Calculating Solubility from K_{sp} 716
 16.12 Factors That Affect Solubility 718
 16.13 Precipitation of Ionic Compounds 726
 16.14 Separation of Ions by Selective Precipitation 728
 16.15 Qualitative Analysis 728

INQUIRY >>> What is causing a decrease in the pH of the oceans? 731

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

17 Thermodynamics: Entropy, Free Energy, and Equilibrium 743

- 17.1 Spontaneous Processes 744
 17.2 Enthalpy, Entropy, and Spontaneous Processes: A Brief Review 745
 17.3 Entropy and Probability 748
 17.4 Entropy and Temperature 752
 17.5 Standard Molar Entropies and Standard Entropies of Reaction 754
 17.6 Entropy and the Second Law of Thermodynamics 756
 17.7 Free Energy and the Spontaneity of Chemical Reactions 758
 17.8 Standard Free-Energy Changes for Reactions 761
 17.9 Standard Free Energies of Formation 764

- 17.10** Free-Energy Changes for Reactions under Nonstandard-State Conditions 766
- 17.11** Free Energy and Chemical Equilibrium 768

INQUIRY >>> Does entropy prevent the evolution of biological complexity? 772

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

18 Electrochemistry 784

- 18.1** Balancing Redox Reactions by the Half-Reaction Method 785
- 18.2** Galvanic Cells 789
- 18.3** Shorthand Notation for Galvanic Cells 794
- 18.4** Cell Potentials and Free-Energy Changes for Cell Reactions 795
- 18.5** Standard Reduction Potentials 797
- 18.6** Using Standard Reduction Potentials 801
- 18.7** Cell Potentials under Nonstandard-State Conditions: The Nernst Equation 803
- 18.8** Electrochemical Determination of pH 805
- 18.9** Standard Cell Potentials and Equilibrium Constants 807
- 18.10** Batteries 810
- 18.11** Corrosion 813
- 18.12** Electrolysis and Electrolytic Cells 815
- 18.13** Commercial Applications of Electrolysis 818
- 18.14** Quantitative Aspects of Electrolysis 821

INQUIRY >>> How do hydrogen fuel cells work? 823

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

19 Nuclear Chemistry 836

- 19.1** Nuclear Reactions and Their Characteristics 837
- 19.2** Radioactivity 838
- 19.3** Nuclear Stability 841
- 19.4** Radioactive Decay Rates 844
- 19.5** Energy Changes during Nuclear Reactions 847
- 19.6** Nuclear Fission and Fusion 850
- 19.7** Nuclear Transmutation 855
- 19.8** Detecting and Measuring Radioactivity 856
- 19.9** Some Applications of Nuclear Chemistry 858

INQUIRY >>> Are there any naturally occurring nuclear reactors? 861

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

20 Transition Elements and Coordination Chemistry 868

- 20.1** Electron Configurations 870
- 20.2** Properties of Transition Elements 872
- 20.3** Oxidation States of Transition Elements 875
- 20.4** Chemistry of Selected Transition Elements 877
- 20.5** Coordination Compounds 882
- 20.6** Ligands 884
- 20.7** Naming Coordination Compounds 886
- 20.8** Isomers 890
- 20.9** Enantiomers and Molecular Handedness 895
- 20.10** Color of Transition Metal Complexes 897
- 20.11** Bonding in Complexes: Valence Bond Theory 898
- 20.12** Crystal Field Theory 902

INQUIRY >>> How does cisplatin kill cancer cells? 908

Study Guide • Key Terms • Key Equations • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

21 Metals and Solid-State Materials 920

- 21.1** Sources of the Metallic Elements 921
- 21.2** Metallurgy 922
- 21.3** Iron and Steel 925
- 21.4** Bonding in Metals 927
- 21.5** Semiconductors 930
- 21.6** Semiconductor Applications 933
- 21.7** Superconductors 937
- 21.8** Ceramics 940
- 21.9** Composites 943

INQUIRY >>> What are quantum dots and what controls their color? 944

Study Guide • Key Terms • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

22 The Main-Group Elements 955

- 22.1** A Review of General Properties and Periodic Trends 956
- 22.2** Distinctive Properties of the Second-Row Elements 958
- 22.3** Group 1A: Hydrogen 960
- 22.4** Group 1A: Alkali Metals 965
- 22.5** Group 2A: Alkaline-Earth Metals 967

- 22.6 Group 3A: Elements 968
- 22.7 Group 4A: Carbon 970
- 22.8 Group 4A: Silicon 974
- 22.9 Group 5A: Nitrogen 978
- 22.10 Group 5A: Phosphorus 982
- 22.11 Group 6A: Oxygen 985
- 22.12 Group 6A: Sulfur 989
- 22.13 Group 7A: The Halogens 992
- 22.14 Group 8A: Noble Gases 994

INQUIRY >>> What are the barriers to a hydrogen economy? 995

Study Guide • Key Terms • Conceptual Problems • Section Problems • Chapter Problems • Multiconcept Problems

23 Organic and Biological Chemistry 1006

- 23.1 Organic Molecules and Their Structures: Alkanes 1007
- 23.2 Families of Organic Compounds: Functional Groups 1011
- 23.3 Naming Organic Compounds 1013
- 23.4 Carbohydrates: A Biological Example of Isomers 1018
- 23.5 Valence Bond Theory and Orbital Overlap Pictures 1021
- 23.6 Lipids: A Biological Example of Cis-Trans Isomerism 1025

- 23.7 Formal Charge and Resonance in Organic Compounds 1029
- 23.8 Conjugated Systems 1034
- 23.9 Proteins: A Biological Example of Conjugation 1037
- 23.10 Aromatic Compounds and Molecular Orbital Theory 1042
- 23.11 Nucleic Acids: A Biological Example of Aromaticity 1045

INQUIRY >>> Which is better, natural or synthetic? 1049

Study Guide • Key Terms • Conceptual Problems • Section Problems • Chapter 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

Appendix B: Thermodynamic Properties at 25 °C A-8

Appendix C: Equilibrium Constants at 25 °C A-13

Appendix D: Standard Reduction Potentials at 25 °C A-17

Appendix E: Properties of Water A-19

Answers to Selected Problems A-21

Glossary G-1

Index I-1

Photo/Text Credits C-1