Contents

Preface xvii

Chapter 1 Introduction to Chemistry 1

1.1 The Nature of Chemistry 2
1.2 Matter 5
INSIGHTS into CHEMISTRY: Science, Society, and Technology Modern Alloys are Widely Used. Techniques Evolved from the Ancients 13
1.3 The Periodic Table 14
1.4 Separation of Mixtures 19
INSIGHTS into CHEMISTRY: Science, Society, and Technology Gas Chromatography, a Modern Separation Technique 24
1.5 Measurement and Units 24
1.6 Uncertainty in Measurements 34

Chapter 2 Atoms, Molecules, and Ions 49

2.1 Dalton’s Atomic Theory 49
INSIGHTS into CHEMISTRY: Development of Chemistry Dalton’s Atomic Theory Provides Foundation for Chemistry 52
2.2 Structure of Atoms 55
INSIGHTS into CHEMISTRY: Science, Society, and Technology Mass Spectrometers Are Now Used by Scientists to Measure an Isotope’s Mass and Abundance 63
2.3 Ionic Compounds 66
## Chapter 3: Stoichiometry I: Equations, the Mole, and Chemical Formulas

3.1 Chemical Equations 81  
INSIGHTS into CHEMISTRY: Chemical Reactivity  
* Nitric and Sulfuric Acids Are Culprits in Acid Rain: No Easy Answers 88  
3.2 The Mole 91  
3.3 Empirical Formulas 98  
INSIGHTS into CHEMISTRY: Development of Chemistry  
* Richards’s Measurements Cast Doubt About Atomic Weights: New Standards Lead to Nobel Prize 106  
3.4 Mass Relationships in Equations 108  
3.5 Limiting Reactants 113

## Chapter 4: Stoichiometry II: Chemical Reactions in Solution and Thermochemistry

4.1 Solutions and Molarity 123  
INSIGHTS into CHEMISTRY: Science, Society, and Technology  
* Volumetric Glassware Available in Wide Range of Accuracy and Precision 128  
4.2 Solution Stoichiometry 130  
4.3 Chemical Analysis by Titration and Precipitation 138  
INSIGHTS into CHEMISTRY: Chemical Reactivity  
* Mysterious Liquid in Vials from Civil War Easily Identified by Precipitation Reactions 142  
4.4 Enthalpy Changes in Chemical Reactions 143  
4.5 Calorimetry 148  
4.6 Hess’s Law 151

## Chapter 5: The Gaseous State

5.1 Properties and Measurements of Gases 166  
INSIGHTS into CHEMISTRY: A Closer View  
* Plasmas—The Fourth State of Matter 168
5.2 The Ideal Gas Law  169
5.3 The Influences of Changing Conditions on Gases  173
5.4 Calculations Using the Ideal Gas Law  176
5.5 Equation Stoichiometry Involving Gases  179
5.6 Dalton's Law of Partial Pressure  182
5.7 Kinetic Molecular Theory of Gases  186
5.8 Diffusion and Effusion  189
5.9 Real Gases  192

Chapter 6  Electrons in Atoms  201

6.1 The Nature of Light  201
INSIGHTS into CHEMISTRY: A Closer View
Radiation Emitted by Heated Solids; Planck Solves “UV Catastrophe”  204
6.2 Line Spectra and the Bohr Atom  208
INSIGHTS into CHEMISTRY: Development of Chemistry
Scientists Predicted Hydrogen Spectrum; Modern Detectors Allow Its Observation  210
6.3 Matter as Waves  212
INSIGHTS into CHEMISTRY: A Closer View
Heisenberg’s Uncertainty Principle Limits Bohr’s Atomic Model  213
6.4 Quantum Numbers in the Hydrogen Atom  215
6.5 Energy Levels for Multi-Electron Atoms  221
6.6 Electrons in Multi-Electron Atoms  224
INSIGHTS into CHEMISTRY: A Closer View
Simple Methods to Help Remember Relative Energies of Sublevels  225
INSIGHTS into CHEMISTRY: A Closer View
Chemists Are Interested in Magnetism to Study Spin Quantum Numbers of Electrons  229

Chapter 7  Periodic Trends of the Elements  237

7.1 Electronic Structure and the Periodic Table  237
7.2 Sizes of Atoms and Ions  246
INSIGHTS into CHEMISTRY: A Closer View
The Lanthanide Contraction Interrupts the Periodic Table’s Orderly Progression  252
7.3 Ionization Energy  254
7.4 Electron Affinity  259
7.5 Trends in the Chemistry of Elements in Groups IA, IIA, and VIIA 261

INSIGHTS into CHEMISTRY: Chemical Reactivity
Blood Sodium and Potassium Levels are Critical; Analyses Help Doctors Diagnose Patients 263

Chapter 8 Chemical Bonds 273

8.1 Lewis Symbols 273
8.2 Ionic Bonding 274
8.3 Covalent Bonding 278
8.4 Electronegativity 286

INSIGHTS into CHEMISTRY: Development of Chemistry
Linus Pauling: Two Nobel Prizes for Work in Chemical Bonding and Nuclear Disarmament 290

8.5 Formal Charges in Lewis Structures 290
8.6 Resonance in Lewis Structures 294
8.7 Molecules That Do Not Satisfy the Octet Rule 298
8.8 Bond Energies 303

Chapter 9 Molecular Structure and Bonding Theories 313

9.1 Valence-Shell Electron-Pair Repulsion Model 313
9.2 Polarity of Molecules 323
9.3 Valence Bond Theory 328

INSIGHTS into CHEMISTRY: A Closer View
Experimental Bond Angles Explained by Hybridization Theory 338

9.4 Multiple Bonds 338
9.5 Molecular Orbitals: Homonuclear Diatomic Molecules 347
9.6 Heteronuclear Diatomic Molecules and Delocalized Molecular Orbitals 355

INSIGHTS into CHEMISTRY: A Closer View
Atomic Orbitals Overlap to Form Delocalized Molecular Orbitals 356

Chapter 10 Liquids and Solids 369

10.1 Intermolecular Attractions 370
10.2 Properties of Liquids 377
10.3 The Solid State 379
10.4 X-Ray Diffraction 389
10.5 Phase Changes 391
INSIGHTS into CHEMISTRY: Science, Society, and Technology Beyond the Critical Point: Supercritical Fluids 395
10.6 Phase Diagrams 398
INSIGHTS into CHEMISTRY: Science, Society, and Technology High Temperature and Pressure Turn Black Graphite into Sparkling Diamonds 403

Chapter 11  Solutions 411

11.1 Solution Concentration 411
11.2 Principles of Solubility 417
11.3 Effect of Temperature and Pressure on Solubility 424
11.4 Colligative Properties of Solutions 427
INSIGHTS into CHEMISTRY: A Closer View Vapor Phase Osmometry Measures Solutes. A Single Drop Yields Useful Information 434
INSIGHTS into CHEMISTRY: Science, Society, and Technology Colligative Properties Find Application: Reverse Osmosis Desalinizes Sea Water 437
11.5 Colligative Properties of Electrolyte Solutions 437
11.6 Mixtures of Volatile Substances 439
INSIGHTS into CHEMISTRY: A Closer Look Chemical Antifreeze: Surviving the Winter 442

Chapter 12  Chemical Equilibrium 451

12.1 The Equilibrium Constant 452
INSIGHTS into CHEMISTRY: A Closer View Conversion Between Pressure and Concentration: Origin Lies in the Ideal Gas Law 458
12.2 The Reaction Quotient 458
INSIGHTS into CHEMISTRY: Science, Technology, and Society Nitrogen Oxides May Help Form Smog. Solutions to Problems Are Not Clear 461
12.3 The Principle of Le Chatelier 464
Chapter 13  Solutions of Acids and Bases  501

INSIGHTS into CHEMISTRY: Development of Chemistry  Tasting Lab Chemicals Was once Routine. Now This Dangerous Practice is Obsolete  502
13.1 Brønsted-Lowry Acid-Base Systems  502
13.2 Autoionization of Water  505
13.3 Strong Acids and Bases  511
INSIGHTS into CHEMISTRY: Chemical Reactivity Hydrofluoric Acid Considered a Weak Acid, Yet Is Highly Reactive—Can Dissolve Glass  512
INSIGHTS into CHEMISTRY: Chemical Reactivity Group IA and Soluble IIA Hydroxides Are Strong Bases  514
13.4 Weak Acids and Bases: Qualitative Aspects  515
13.5 Weak Acids and Bases: Quantitative Aspects  517
INSIGHTS into CHEMISTRY: Chemical Reactivity Picric Acid is Unstable; It Can Corrode Storage Bottles and Then Explode  519
13.6 Solutions of Weak Bases and Salts  526
INSIGHTS into CHEMISTRY: Chemical Reactivity Ammonia Solutions Cut Through Grease and Rinse Clean—Shouldn't be Mixed with Bleach  529
13.7 Mixtures of Strong and Weak Acids  535
Chapter 14  Reactions Between Acids and Bases  551
14.1 Titrations of Strong Acids and Bases  551
14.2 Buffers  562
INSIGHTS into CHEMISTRY: Chemical Reactivity
Blood as an Effective Buffer System, Neutralizing Excess Acids or Bases  568
14.3 The Titration of Weak Acids or Bases  569
14.4 Indicators  577
14.5 Polyprotic Acids  580
14.6 Amphoteric Species  584
14.7 Factors That Influence Solubility  585

Chapter 15  Chemical Thermodynamics  595
15.1 Work and Heat  596
INSIGHTS into CHEMISTRY: A Closer View
Work is Performed as a Gas Expands Against External Pressure  598
15.2 The First Law of Thermodynamics  600
15.3 Entropy  608
15.4 Free Energy  615
INSIGHTS into CHEMISTRY: Science, Society, and Technology  Nitromethane, A High-Energy Race Car Fuel, Emits Too Many Pollutants for General Use  618
15.5 Concentration, Free Energy, and the Equilibrium Constant  623
INSIGHTS into CHEMISTRY: Science, Society, and Technology  Phase Changes of Glauber's Salt Can Be Used to Heat Your Home  624
INSIGHTS into CHEMISTRY: A Closer View
Free Energy Changes Are Influenced by Changes in Pressure and Concentration  629
INSIGHTS into CHEMISTRY: Development of Chemistry  Trouton's Law States Constant
Chapter 18  Metallurgy, Transition Metals, and Coordination Chemistry  777

18.1 Metallurgy  778
18.2 Properties of the Transition Elements  784
18.3 Chemistry of Selected Transition Elements  789

Chapter 19  The Chemistry of Hydrogen, Elements in Groups IIIA Through VIA, and the Noble Gases  823

19.1 General Trends  823
19.2 Hydrogen  825
19.3 The Chemistry of Group IIIA (13) Elements  827
19.4 The Chemistry of Group IVA (14) Elements  833

19.5 The Chemistry of Group VA (15) Elements  842
19.6 The Chemistry of Group VIA (16) Elements  847
19.7 The Noble Gases  853
Chapter 20  Nuclear Chemistry  861

20.1 Nuclear Stability and Radioactivity  862
20.2 Nuclear Reactions  874
INSIGHTS into CHEMISTRY: A Closer View
Quarks: These Subatomic Particles Hold the Key to Understanding Nuclear Forces  876
20.3 Nuclear Binding Energy  879
20.4 Fission and Fusion  882
20.5 Biological Effects of Radiation  887
INSIGHTS into CHEMISTRY: Science, Society, and Technology  Radiopharmaceuticals Zero in on Target Organs and Enable Images that Improve Healthcare Delivery  890

Chapter 21  Organic Chemistry and Biochemistry  899

21.1 Alkanes  900
21.2 Alkenes and Alkynes  909
21.3 Functional Groups  918
INSIGHTS into CHEMISTRY: Science, Society, and Technology  Reaction of Dichromate Ion with Alcohol is the Basis for the Breath Alcohol Test  922
INSIGHTS into CHEMISTRY: A Closer View
Soap's Unique Chemical Structure Enables it to Dissolve Oil into Water  927
21.4 Synthetic Organic Polymers  931
21.5 Proteins  935
21.6 Carbohydrates  940
21.7 Nucleic Acids  942

Appendix A  Math Procedures  A.1
Appendix B  Selected Physical Constants  A.12
Appendix C  Unit Conversion Factors  A.13
Appendix D  Names of Ions  A.16
Appendix E  Properties of Water  A.18
Appendix F  Solubility Products, Acids, and Bases  A.19
Appendix G  Thermodynamic Constants for Selected Compounds  A.24
Appendix H  Standard Reduction Potentials at 25 °C  A.33