

# Chemistry Principles and Reactions

William L. Masterton Cecile N. Hurley Edward J. Neth

International Edition

# Contents

Matter and Measurements 1

	1.1 1.2	Measurements 7					
	The Human Side: Antoine Lavoisier 15						
	1.3 Properties of Substances 15  Beyond the Classroom: Arsenic 21						
	Chapter Highlights 22						
	_	mary Problem 23					
		stions and Problems 23					
2	Atoms, Molecules, and Ions 27						
	2.1	Atoms and the Atomic Theory 28					
	2.2	Components of the Atom 28					
	The Human Side: John Dalton 29						
	2.3	Quantitative Properties of the Atom 31					
	2.4	Introduction to the Periodic Table 37					
	2.5	Molecules and lons 40	:				
	2.6	Formulas of Ionic Compounds 45	:				
	2.7	Names of Compounds 47					
	Beyond the Classroom: Ethyl Alcohol and the Law 53						
	Chapter Highlights 54 Summary Problem 54						
	Que	stions and Problems 55					
3	Mai	ss Relations in Chemistry; Stoichiometry	60				
3	3.1	The Mole 61	60				
	3.2						
	3.2						
	Beyond the Classroom: Hydrates 82						
	Chapter Highlights 83						
	Summary Problem 84  Questions and Problems 84						
	Que	Stions and Problems 84					
4	Reactions in Aqueous Solution 90						
	4.1	Precipitation Reactions 91					
	4.2	Acid-Base Reactions 96					
	4.3	Oxidation-Reduction Reactions 103					
	The Human Side: Svante August Arrhenius 104						
		and the Classroom: Reversible Color Changes 112					
	Chapter Highlights 113						

Summary Problem 114

Questions and Problems 114

 Gas	Gases 120		
5.1	Measurements on Gases 1		
5.2	The Ideal Gas Law 123		
5.3	Gas Law Calculations 125		

Stoichiometry of Gaseous Reactions 131

The Human Side: Amadeo Avogadro 135 Gas Mixtures: Partial Pressures and Mole Fractions 137

21

5.6 Kinetic Theory of Gases 140

5.7 Real Gases 146 Beyond the Classroom: Measurement of Blood Pressure 148 Chapter Highlights 149

Summary Problem 149 Questions and Problems 150

6.2

6.6

6 Electronic Structure and the Periodic Table 155

- Light, Photon Energies, and Atomic Spectra 156
- 6.3 Quantum Numbers 165

The Hydrogen Atom 161

- 6.4 Atomic Orbitals; Shapes and Sizes 168
- 6.5 Electron Configurations in Atoms 169
- The Human Side: Glenn Theodore Seaborg 173
- Orbital Diagrams of Atoms 174 6.7 Electron Arrangements in Monatomic Ions 176
- 6.8 Periodic Trends in the Properties of Atoms 179

Beyond the Classroom: Why Do Lobsters Turn Red When Cooked? 184 Chapter Highlights 185

Summary Problem 186

Questions and Problems 186

# 7 Covalent Bonding 190

Lewis Structures: The Octet Rule 191

The Human Side: Gilbert Newton Lewis 200

- Molecular Geometry 202 Polarity of Molecules 209 7.3

Atomic Orbitals; Hybridization 213 7.4

Beyond the Classroom: The Noble Gases 219

Chapter Highlights 220

Summary Problem 221

Questions and Problems 221

## 8 Thermochemistry 225

- Principles of Heat Flow 226 8.1
- Measurement of Heat Flow; Calorimetry 230 8.2

8.3 Enthalpy <b>233</b>	
8.4 Thermochemical Equations 234	
8.5 Enthalpies of Formation 240	
8.6 Bond Enthalpy 246	
8.7 The First Law of Thermodynamics 248	
Beyond the Classroom: Energy Balance in the Human Body 252	
Chapter Highlights 253	
Summary Problem 254	
Questions and Problems 254	
Liquids and Solids 259	
9.1 Comparing Solids, Liquids, and Gases 260	
9.2 Liquid-Vapor Equilibrium 260	
9.3 Phase Diagrams 267	
9.4 Molecular Substances; Intermolecular Forces 270	
9.5 Network Covalent, Ionic, and Metallic Solids 277	
9.6 Crystal Structures 282	
The Human Side: Dorothy Crowfoot Hodgkin 286	
Beyond the Classroom: Supercritical Carbon Dioxide 288	
Chapter Highlights 289	
Summary Problem 289	
Questions and Problems 290	
Solutions 295	
10.1 Concentration Units 296	
10.2 Principles of Solubility 304	
10.3 Colligative Properties of Nonelectrolytes 308	
10.4 Colligative Properties of Electrolytes 318	
Beyond the Classroom: Maple Syrup 321	
Chapter Highlights 322	
Summary Problem 322	
Questions and Problems 323	
Rate of Reaction 328	
11.1 Meaning of Reaction Rate 329	
11.2 Reaction Rate and Concentration 332	
11.3 Reactant Concentration and Time 338	
11.4 Models for Reaction Rate 345	
The Human Side: Henry Eyring 348	
11.5 Reaction Rate and Temperature 348	
11.6 Catalysis 352	
11.7 Reaction Mechanisms 355	

Beyond the Classroom: The Ozone Story 359

Chapter Highlights 360
Summary Problem 360
Questions and Problems 361

- 12 Gaseous Chemical Equilibrium 370
  - 12.1 The N<sub>2</sub>O<sub>4</sub>–NO<sub>2</sub> Equilibrium System 371
  - 12.2 The Equilibrium Constant Expression 374
  - 12.3 Determination of K 379
  - 12.3 Determination of K 3/9
  - 12.4 Applications of the Equilibrium Constant 382

12.5 Effect of Changes in Conditions on an Equilibrium System 387

Beyond the Classroom: An Industrial Application of Gaseous Equilibrium 393

Chapter Highlights 394

Summary Problem 395

Questions and Problems 395

- 13 Acids and Bases 401
  - 13.1 Brønsted-Lowry Acid-Base Model 402
    13.2 The lon Product of Water 403
  - 13.3 pH and pOH 404
  - 13.4 Weak Acids and Their Equilibrium Constants 410
  - 13.5 Weak Bases and Their Equilibrium Constants 419
  - 13.6 Acid-Base Properties of Salt Solutions 424
  - 13.7 Extending the Concept of Acids and Bases: The Lewis Model 426

Beyond the Classroom: Organic Acids and Bases 428

Chapter Highlights 429

Summary Problem 430

Questions and Problems 430

- 14 Equilibria in Acid-Base Solutions 435
  - 14.1 Buffers 436
    - 14.2 Acid-Base Indicators 44714.3 Acid-Base Titrations 450

Beyond the Classroom: Acid Rain 460

Chapter Highlights 461

Summary Problem 461

Questions and Problems 462

- Complex Ion and Precipitation Equilibria 467
  15.1 Complex Ion Equilibria; Formation Constant (K<sub>f</sub>) 467
  - 15.2 Solubility; Solubility Product Constant ( $K_{sp}$ ) 471
    - 15.3 Precipitate Formation 479
    - 15.4 Dissolving Precipitates 483

	Sum	mary Problem 491				
	Que	stions and Problems 491				
16	Spc	Spontaneity of Reaction 496				
	16.1	Spontaneous Processes 497				
	16.2	Entropy, S 499				
	16.3	Free Energy, G 503				
	The H	The Human Side: J. Willard Gibbs 505				
	16.4	Standard Free Energy Change, $\Delta G^{\circ}$ 505				
	16.5	Effect of Temperature, Pressure, and Concentration on Reaction Spontaneity 510				
	16.6	The Free Energy Change and the Equilibrium Constant 514				
	16.7	Additivity of Free Energy Changes; Coupled Reactions 516				
	Beyo	Beyond the Classroom: Rubber Elasticity: An Entropic Phenomenon 518				
	Chap	Chapter Highlights 519				
	Sum	Summary Problem 520				
	Que	Questions and Problems 520				
17	Flee	ctrochemistry 526				
.,		Voltaic Cells 527				
		Standard Voltages 531				
		Relations Between $E^{\circ}$ , $\Delta G^{\circ}$ , and $K$ 538				
		Effect of Concentration on Voltage 540				
		Electrolytic Cells 544				
		Commercial Cells 549				
	The H	Human Side: Michael Faraday 551				
		Beyond the Classroom: Fuel Cells: The Next Step in Chemical-to-Electrical-Energy Conversion? 554				
	Chap	Chapter Highlights 556				
	Sum	Summary Problem 556				
	Que	stions and Problems 557				
18	Nuc	clear Reactions 563				
	18.1	Nuclear Stability 564				
	18.2	Radioactivity 565				

Beyond the Classroom: Qualitative Analysis 489

Chapter Highlights 490

The Human Side: Marie Curie 571

18.5 Nuclear Fission 57918.6 Nuclear Fusion 582

18.3 Rate of Radioactive Decay 57118.4 Mass-Energy Relations 575

Beyond the Classroom: Biological Effects of Radiation 584

Chapter Highlights	585	
Summary Problem	585	
Questions and Prol	olems	586

### 19 Complex Ions 590

- 19.1 Composition of Complex Ions 591
- 19.2 Naming Complex Ions and Coordination Compounds 595
- 19.3 Geometry of Complex Ions 597
- 19.4 Electronic Structure of Complex Ions 601

The Human Side: Alfred Werner 602

Beyond the Classroom: Chelates: Natural and Synthetic 607

Chapter Highlights 609

Summary Problem 609

Questions and Problems 609

# 20 Chemistry of the Metals 612

- 20.1 Metallurgy 613
- 20.2 Reactions of the Alkali and Alkaline Earth Metals 619
- 20.3 Redox Chemistry of the Transition Metals 623

Beyond the Classroom: Essential Metals in Nutrition 629

Chapter Highlights 630

Summary Problem 631

Questions and Problems 631

### 21 Chemistry of the Nonmetals 633

- 21.1 The Elements and Their Preparation 634
  - 21.2 Hydrogen Compounds of Nonmetals 638
  - 21.3 Oxygen Compounds of Nonmetals 642
  - 21.4 Oxoacids and Oxoanions 646

Beyond the Classroom: Arsenic and Selenium 653

Chapter Highlights 654

Summary Problem 654

Questions and Problems 655

22.4 Functional Groups 670

### 22 Organic Chemistry 658

- 22.1 Saturated Hydrocarbons: Alkanes 659
- 22.2 Unsaturated Hydrocarbons: Alkenes and Alkynes 665
- 22.3 Aromatic Hydrocarbons and Their Derivatives 667
- 22.5 Isomerism in Organic Compounds 678
- 22.6 Organic Reactions 683

Beyond the Classroom: Cholesterol 685

Chapter Highlights 687
Summary Problem 687
Questions and Problems 688

# 23 Organic Polymers, Natural and Synthetic 691

- 23.1 Synthetic Addition Polymers 692
- 23.2 Synthetic Condensation Polymers 695
- 23.3 Carbohydrates 698
- 23.4 Proteins 702

Beyond the Classroom: DNA Fingerprinting 710

Chapter Highlights 711

Summary Problem 712

Questions and Problems 712

# **Appendices**

- 1 Units, Constants, and Reference Data 715
- 2 Properties of the Elements 721
- 3 Exponents and Logarithms 723
- 4 Molecular Orbitals 728
- 5 Answers to Even-Numbered and Challenge Questions and Problems 734