

时代教育·国外高校优秀教材精选

# 化学—中心科学

Chemistry—The Central Science

(英文版·原书第8版)

狄奥多尔 L. 布朗(Theodore L. Brown)  
(美) 小 H. 尤金·勒梅(H. Eugene LeMay, Jr.) 著  
布鲁斯 E. 伯斯坦(Bruce E. Bursten)



机械工业出版社

English reprint copyright © 2002 by Pearson Education North Asia Limited and China Machine Press.  
Original English Language title: Chemistry the Central Science by Theodore L. Brown, H. Eugene LeMay, Jr and Bruce E. Bursten

Copyright © 2000, 1997, 1994, 1991, 1988, 1985, 1981, 1977 by Prentice-Hall, Inc.

All Right Reserved.

Published by arrangement with the original publisher, Pearson Education, Inc., publishing as Prentice-Hall, Inc.

This edition is authorized for sale only in the People's Republic of China(excluding the Special Administrative Region of Hong Kong and Macau).

本书封面贴有 Pearson Education 培生教育出版集团激光防伪标签,无标签者不得销售。

北京市版权局著作权合同登记号:图字:01-2002-4804

### 图书在版编目(CIP)数据

化学:中心科学:第8版/(美)布朗(Brown, T. L.)

等著. —北京:机械工业出版社, 2003. 2

(时代教育:国外高校优秀教材精选)

ISBN 7-111-11493-0

I. 化... II. 布... III. 化学—理论—高等学校—  
教材—英文 IV. 06-0

中国版本图书馆 CIP 数据核字(2003)第 004877 号

机械工业出版社(北京市百万庄大街 22 号 邮政编码 100037)

责任编辑:刘小慧

封面设计:鞠 杨 责任印制:付方敏

北京铭成印刷有限公司印刷·新华书店北京发行所发行

2003 年 3 月第 1 版第 1 次印刷

850mm×1168mm 1/16·70 印张·2 插页·1145 千字

定价:80.00 元(含 1CD)

凡购本书,如有缺页、倒页、脱页,由本社发行部调换

本社购书热线电话(010)68993821、88379646

封面无防伪标均为盗版

# 国外高校优秀教材审定委员会

主任委员：

杨叔子

委员（按姓氏笔画为序）：

王先逵	王大康	白峰杉	史荣昌	朱孝禄
陆启韶	张润琦	张 策	张三慧	张福润
张延华	吴宗泽	吴 麒	宋心琦	李俊峰
余远斌	陈文楷	陈立周	单辉祖	俞正光
赵汝嘉	郭可谦	翁海珊	龚光鲁	章栋恩
黄永畅	谭泽光			

# 出版说明

随着我国加入 WTO，国际间的竞争越来越激烈，而国际间的竞争实际上也就是人才的竞争、教育的竞争。为了加快培养具有国际竞争力的高水平技术人才，加快我国教育改革的步伐，国家教育部近来出台了一系列倡导高校开展双语教学、引进原版教材的政策。以此为契机，机械工业出版社拟于近期推出一系列国外影印版教材，其内容涉及高等学校公共基础课，以及机、电、信息领域的专业基础课和专业课。

引进国外优秀原版教材，在有条件的学校推动开展英语授课或双语教学，自然也引进了先进的教学思想和教学方法，这对提高我国自编教材的水平，加强学生的英语实际应用能力，使我国的高等教育尽快与国际接轨，必将起到积极的推动作用。

为了做好教材的引进工作，机械工业出版社特别成立了由著名专家组成的国外高校优秀教材审定委员会。这些专家对实施双语教学做了深入细致的调查研究，对引进原版教材提出许多建设性意见，并慎重地对每一本将要引进的原版教材一审再审，精选再精选，确认教材本身的质量水平，以及权威性和先进性，以期所引进的原版教材能适应我国学生的外语水平和学习特点。在引进工作中，审定委员会还结合我国高校教学课程体系的设置和要求，对原版教材的教学思想和方法的先进性、科学性严格把关。同时尽量考虑原版教材的系统性和经济性。

这套教材出版后，我们将根据各高校的双语教学计划，举办原版教材的教师培训，及时地将其推荐给各高校选用。希望高校师生在使用教材后及时反馈意见和建议，使我们更好地为教学改革服务。

机械工业出版社

2002 年 3 月

# 序

该书是一本已经再版 7 次的普通化学教材，三位作者都曾经多次获得过不同层次的教学奖。其中 Brown 在学术上造诣较深，曾获 Guggenheim 学者奖，美国化学会无机化学研究奖和无机化学进步服务优异奖等。现为 Illinois 大学 (Urbana Champaign) 资深化学教授。LeMay 教授有近 30 年的教学经验，并因此多次获得国家级教学奖。Bursten 教授是 Ohio 大学杰出化学教授，在过渡金属和铜系元素化合物研究方面有较高的水平。从作者水平和该书的再版次数来看，这本书应当是质量比较好的。

该书图文并茂，插图精美。全书共分为 25 章，其内容安排和理论深度与国内现有的普通化学或大学一年级化学相近。应当认为，这类教材是 20 世纪 70 年代以来对我国普通化学或大学一年级化学影响最大的一类国外教材，比较重视化学基础理论的完整性和系统性。该书的初等量子力学和化学热力学部分写得比较适合大学一年级学生的水平。作为化学学科的学习，该书有较好的实用性。

该书设计了一些新的栏目，如关于解题 (Problem Solving) 设有：化学中实用的策略、例题、章后练习题 (包括所附光盘上的 e-媒体练习题)、中心科学演示 (学生用 CD-ROM 和网站 <http://www.prenhall.com/brown>)；形象化 (Visualization) 设有：分子结构模型、化合物演示、分子运动三维动画以及中心科学演示；应用 (Application) 设有：生活和实际应用中的化学、化学新闻、有趣的阅读材料和中心科学演示。从而使教学内容可以方便地扩展到与生活和社会相关的其它方面。

该书可以用作双语基础化学教材。

宋心琦  
清华大学化学系  
2002 年 10 月

# Contents

出版说明 iv

序 v

Preface xx

A Student's Guide to Using this Text xxviii

About the Authors xxxiii

## 1 Introduction: Matter and Measurement 1

- 1.1 The Study of Chemistry 1  
The Molecular Perspective of Chemistry 1 Why Study Chemistry? 3
- 1.2 Classifications of Matter 5  
States of Matter 5 Pure Substances and Mixtures 6 Separation of  
Mixtures 7 Elements 9 Compounds 10
- 1.3 Properties of Matter 11  
Physical and Chemical Changes 11
- 1.4 Units of Measurement 12  
SI Units 13 Length and Mass 14 Temperature 15 Derived SI Units 16  
Volume 16 Density 17
- 1.5 Uncertainty in Measurement 20  
Precision and Accuracy 20 Significant Figures 21 Significant Figures in  
Calculations 22
- 1.6 Dimensional Analysis 24  
Using Two or More Conversion Factors 25 Conversions Involving  
Volume 25 Summary of Dimensional Analysis 26  
*Summary and Key Terms* 28 *Exercises* 29 *eMedia Exercises* 33

Chemistry at Work Chemistry and the Chemical Industry 4

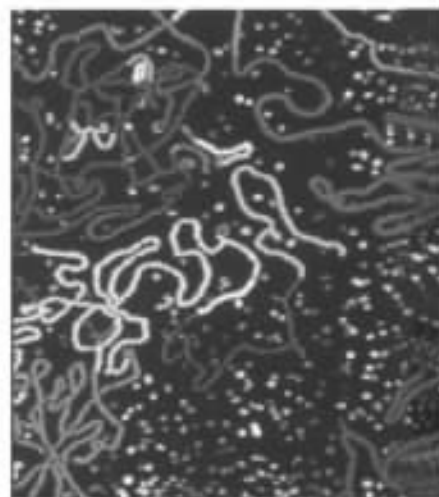
A Closer Look The Scientific Method 13

Chemistry at Work Chemistry in the News 18

Strategies in Chemistry The Importance of Practice 27

## 2 Atoms, Molecules, and Ions 35

- 2.1 The Atomic Theory of Matter 35
- 2.2 The Discovery of Atomic Structure 37  
Cathode Rays and Electrons 37 Radioactivity 39 The Nuclear Atom 39
- 2.3 The Modern View of Atomic Structure 41  
Isotopes, Atomic Numbers, and Mass Numbers 43
- 2.4 The Periodic Table 44
- 2.5 Molecules and Molecular Compounds 47  
Molecules and Chemical Formulas 47 Molecular and Empirical Formulas 48  
Picturing Molecules 48
- 2.6 Ions and Ionic Compounds 49  
Predicting Ionic Charges 50 Ionic Compounds 51
- 2.7 Naming Inorganic Compounds 54  
Names and Formulas of Ionic Compounds 54 Names and Formulas of  
Acids 58 Names and Formulas of Binary Molecular Compounds 60  
*Summary and Key Terms* 60 *Exercises* 61 *eMedia Exercises* 65



A Closer Look Basic Forces 41

Chemistry and Life Elements Required by Living Organisms 53

Strategies in Chemistry Pattern Recognition 54

### 3 Stoichiometry: Calculations with Chemical Formulas and Equations 67

3.1 Chemical Equations 68

3.2 Patterns of Chemical Reactivity 70

Using the Periodic Table 70 Combustion in Air 71 Combination and Decomposition Reactions 72

3.3 Atomic and Molecular Weights 74

The Atomic Mass Scale 74 Average Atomic Masses 75 Formula and Molecular Weights 76 Percentage Composition from Formulas 76

3.4 The Mole 77

Molar Mass 79 Interconverting Masses, Moles, and Numbers of Particles 81

3.5 Empirical Formulas from Analyses 83

Molecular Formula from Empirical Formula 84 Combustion Analysis 85

3.6 Quantitative Information from Balanced Equations 86

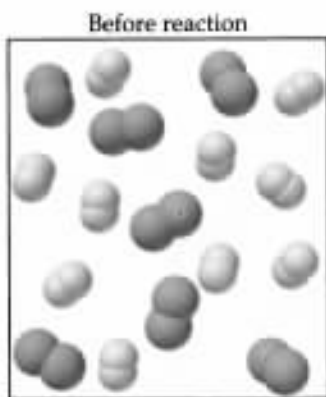
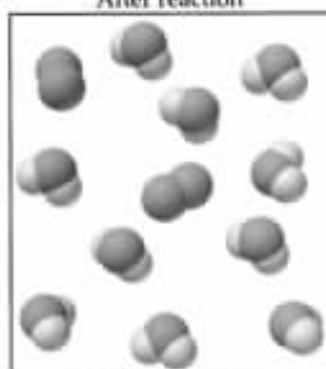
3.7 Limiting Reactants 91

Theoretical Yields 93

Summary and Key Terms 94 Exercises 95 eMedia Exercises 103

A Closer Look The Mass Spectrometer 78

Strategies in Chemistry Problem Solving 79

Chemistry at Work CO<sub>2</sub> and the Greenhouse Effect 9010 H<sub>2</sub> and 7 O<sub>2</sub>10 H<sub>2</sub>O and 2 O<sub>2</sub>

### 4 Aqueous Reactions and Solution Stoichiometry 105

4.1 General Properties of Aqueous Solutions 106

Electrolytic Properties 106 Ionic Compounds in Water 107 Molecular Compounds in Water 108 Strong and Weak Electrolytes 108

4.2 Precipitation Reactions 109

Solubility Guidelines for Ionic Compounds 110 Exchange (Metathesis) Reactions 111 Ionic Equations 112

4.3 Acid-Base Reactions 114

Acids 114 Bases 114 Strong and Weak Acids and Bases 114 Identifying Strong and Weak Electrolytes 115 Neutralization Reactions and Salts 117 Acid-Base Reactions with Gas Formation 119

4.4 Oxidation-Reduction Reactions 120

Oxidation and Reduction 120 Oxidation Numbers 121 Oxidation of Metals by Acids and Salts 122 The Activity Series 124

4.5 Concentrations of Solutions 126

Molarity 127 Expressing the Concentration of an Electrolyte 128 Interconverting Molarity, Moles, and Volume 129 Dilution 130

4.6 Solution Stoichiometry and Chemical Analysis 131

Titrations 133

Summary and Key Terms 136 Exercises 137 eMedia Exercises 143

Chemistry at Work Antacids 120

A Closer Look The Aura of Gold 126

Strategies in Chemistry Analyzing Chemical Reactions 127

## 5 Thermochemistry 145

- 5.1 The Nature of Energy 145  
Kinetic Energy and Potential Energy 146 Units of Energy 147 System and Surroundings 147 Transferring Energy: Work and Heat 147
- 5.2 The First Law of Thermodynamics 149  
Internal Energy 149 Relating  $\Delta E$  to Heat and Work 150 Endothermic and Exothermic Processes 151 State Functions 152
- 5.3 Enthalpy 153
- 5.4 Enthalpies of Reaction 155
- 5.5 Calorimetry 158  
Heat Capacity and Specific Heat 158 Constant-Pressure Calorimetry 160 Bomb Calorimetry (Constant-Volume Calorimetry) 161
- 5.6 Hess's Law 164
- 5.7 Enthalpies of Formation 166  
Using Enthalpies of Formation to Calculate Enthalpies of Reaction 168
- 5.8 Foods and Fuels 170  
Foods 170 Fuels 172 Other Energy Sources 173  
*Summary and Key Terms* 176 *Exercises* 177 *eMedia Exercises* 185

A Closer Look Energy, Enthalpy, and P-V Work 154  
Strategies in Chemistry Using Enthalpy as a Guide 158  
Chemistry and Life The Regulation of Human Body Temperature 162  
Chemistry at Work Hydrogen as a Fuel 174



## 6 Electronic Structure of Atoms 187

- 6.1 The Wave Nature of Light 187
- 6.2 Quantized Energy and Photons 190  
The Photoelectric Effect 191
- 6.3 Bohr's Model of the Hydrogen Atom 194  
Line Spectra 194 Bohr's Model 195
- 6.4 The Wave Behavior of Matter 198  
The Uncertainty Principle 199
- 6.5 Quantum Mechanics and Atomic Orbitals 200  
Orbitals and Quantum Numbers 201
- 6.6 Representations of Orbitals 203  
The *s* Orbitals 204 The *p* Orbitals 205 The *d* and *f* Orbitals 205
- 6.7 Orbitals in Many-Electron Atoms 206  
Effective Nuclear Charge 206 Energies of Orbitals 207 Electron Spin and the Pauli Exclusion Principle 208
- 6.8 Electron Configurations 209  
Periods 1, 2, and 3 211 Period 4 and Beyond 213
- 6.9 Electron Configurations and the Periodic Table 214  
*Summary and Key Terms* 218 *Exercises* 220 *eMedia Exercises* 225

Chemistry and Life The Health Effects of Low-Frequency EMFs: A Current Scientific Controversy 193  
A Closer Look Measurement and the Uncertainty Principle 200  
A Closer Look Experimental Evidence for Electron Spin 209  
Chemistry and Life Nuclear Spin and Magnetic Resonance Imaging 210



## 7 Periodic Properties of the Elements 227

- 7.1 Development of the Periodic Table 227
- 7.2 Electron Shells and the Sizes of Atoms 229  
Electron Shells in Atoms 229 Atomic Sizes 230
- 7.3 Ionization Energy 233  
Periodic Trends in Ionization Energies 234
- 7.4 Electron Affinities 236
- 7.5 Metals, Nonmetals, and Metalloids 238  
Metals 239 Nonmetals 241 Metalloids 243
- 7.6 Group Trends for the Active Metals 243  
Group 1A: The Alkali Metals 243 Group 2A: The Alkaline Earth Metals 246
- 7.7 Group Trends for Selected Nonmetals 248  
Hydrogen 248 Group 6A: The Oxygen Group 248 Group 7A: The Halogens 250 Group 8A: The Noble Gases 251  
*Summary and Key Terms* 253 *Exercises* 254 *eMedia Exercises* 259

Chemistry and Life The Improbable Development of Lithium Drugs 247  
Chemistry and Life Thermophilic Bacteria 251



## 8 Basic Concepts of Chemical Bonding 261

- 8.1 Chemical Bonds, Lewis Symbols, and the Octet Rule 261  
Lewis Symbols 262 The Octet Rule 263
- 8.2 Ionic Bonding 263  
Energetics of Ionic Bond Formation 264 Electron Configuration of Ions of the Representative Elements 266 Transition-Metal Ions 268 Polyatomic Ions 269
- 8.3 Sizes of Ions 269
- 8.4 Covalent Bonding 270  
Lewis Structures 271 Multiple Bonds 272
- 8.5 Bond Polarity and Electronegativity 273  
Electronegativity 273 Electronegativity and Bond Polarity 274 Dipole Moments 275 Bond Types and Nomenclature 277
- 8.6 Drawing Lewis Structures 278  
Formal Charge 280
- 8.7 Resonance Structures 283  
Resonance in Benzene 284
- 8.8 Exceptions to the Octet Rule 285  
Odd Number of Electrons 285 Less than an Octet 285 More than an Octet 286
- 8.9 Strengths of Covalent Bonds 288  
Bond Enthalpies and the Enthalpies of Reactions 289 Bond Enthalpy and Bond Length 291  
*Summary and Key Terms* 294 *Exercises* 295 *eMedia Exercises* 301

A Closer Look Calculation of Lattice Energies: The Born-Haber Cycle 267  
A Closer Look Oxidation Numbers, Formal Charges, and Partial Charges 282  
Chemistry at Work Explosives and Alfred Nobel 292

## 9 Molecular Geometry and Bonding Theories 303

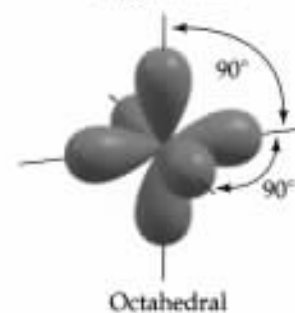
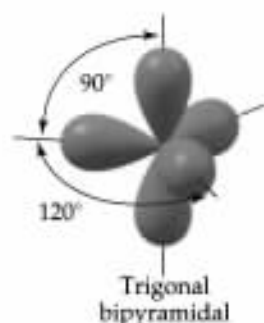
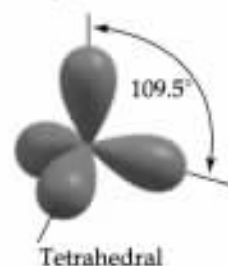
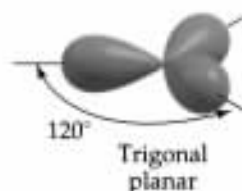
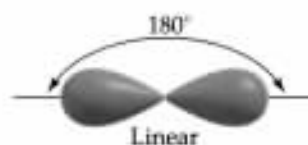
- 9.1 Molecular Shapes 304
- 9.2 The VSEPR Model 304  
The Effect of Nonbonding Electrons and Multiple Bonds on Bond Angles 310  
Molecules with Expanded Valence Shells 311 Molecules with More than One Central Atom 313
- 9.3 Polarity of Polyatomic Molecules 315
- 9.4 Covalent Bonding and Orbital Overlap 317
- 9.5 Hybrid Orbitals 318  
*sp* Hybrid Orbitals 318 *sp*<sup>2</sup> and *sp*<sup>3</sup> Hybrid Orbitals 320 Hybridization Involving *d* Orbitals 322 Summary 322
- 9.6 Multiple Bonds 324  
Delocalized  $\pi$  Bonding 327 General Conclusions 330
- 9.7 Molecular Orbitals 331  
The Hydrogen Molecule 331 Bond Order 333
- 9.8 Second-Row Diatomic Molecules 334  
Molecular Orbitals for  $\text{Li}_2$  and  $\text{Be}_2$  334 Molecular Orbitals from  $2p$  Atomic Orbitals 335 Electron Configurations for  $\text{B}_2$  Through  $\text{Ne}_2$  336 Electron Configurations and Molecular Properties 338  
*Summary and Key Terms* 343 *Exercises* 344 *eMedia Exercises* 351

Chemistry and Life The Chemistry of Vision 328  
Chemistry at Work Organic Dyes 342

## 10 Gases 353

- 10.1 Characteristics of Gases 353
- 10.2 Pressure 354  
Atmospheric Pressure and the Barometer 355 Pressures of Enclosed Gases and Manometers 356
- 10.3 The Gas Laws 358  
The Pressure-Volume Relationship: Boyle's Law 358 The Temperature-Volume Relationship: Charles's Law 360 The Quantity-Volume Relationship: Avogadro's Law 361
- 10.4 The Ideal-Gas Equation 362  
Relating the Ideal-Gas Equation and the Gas Laws 365
- 10.5 Further Applications of the Ideal-Gas Equation 367  
Gas Densities and Molar Mass 367 Volumes of Gases in Chemical Reactions 368
- 10.6 Gas Mixtures and Partial Pressures 369  
Partial Pressures and Mole Fractions 370 Collecting Gases over Water 371
- 10.7 Kinetic-Molecular Theory 373  
Application to the Gas Laws 374
- 10.8 Molecular Effusion and Diffusion 376  
Graham's Law of Effusion 377 Diffusion and Mean Free Path 378
- 10.9 Real Gases: Deviations from Ideal Behavior 379  
The van der Waals Equation 381  
*Summary and Key Terms* 383 *Exercises* 384 *eMedia Exercises* 391

Chemistry and Life Blood Pressure 358  
Strategies in Chemistry Calculations Involving Many Variables 364  
A Closer Look The Ideal-Gas Equation 375  
Chemistry at Work Gas Separations 379



## 11 Intermolecular Forces, Liquids, and Solids 393

- 11.1 A Molecular Comparison of Liquids and Solids 393
- 11.2 Intermolecular Forces 395  
 Ion-Dipole Forces 396 Dipole-Dipole Forces 396 London Dispersion Forces 397 Hydrogen Bonding 399 Comparing Intermolecular Forces 402
- 11.3 Some Properties of Liquids 404  
 Viscosity 404 Surface Tension 404
- 11.4 Phase Changes 405  
 Energy Changes Accompanying Phase Changes 406 Heating Curves 406 Critical Temperature and Pressure 408
- 11.5 Vapor Pressure 409  
 Explaining Vapor Pressure on the Molecular Level 410 Volatility, Vapor Pressure, and Temperature 410 Vapor Pressure and Boiling Point 411
- 11.6 Phase Diagrams 412  
 The Phase Diagrams of  $H_2O$  and  $CO_2$  413
- 11.7 Structures of Solids 414  
 Unit Cells 416 The Crystal Structure of Sodium Chloride 417 Close Packing of Spheres 419
- 11.8 Bonding in Solids 421  
 Molecular Solids 421 Covalent-Network Solids 422 Ionic Solids 423 Metallic Solids 425  
*Summary and Key Terms* 426 *Exercises* 427 *eMedia Exercises* 433

A Closer Look Trends in Hydrogen Bonding 400  
 Chemistry at Work Supercritical Fluid Extraction 409  
 A Closer Look The Clausius-Clapeyron Equation 412  
 A Closer Look X-ray Diffraction by Crystals 420  
 A Closer Look Buckyball 424

## 12 Modern Materials 435

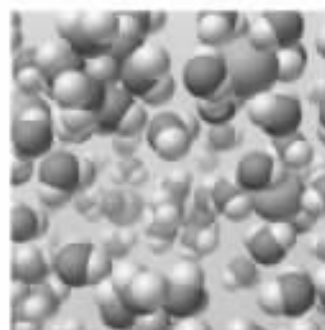
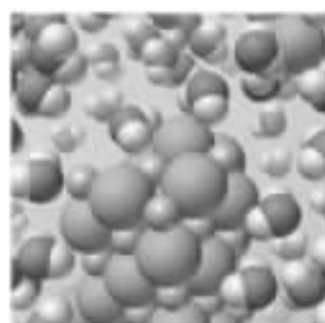
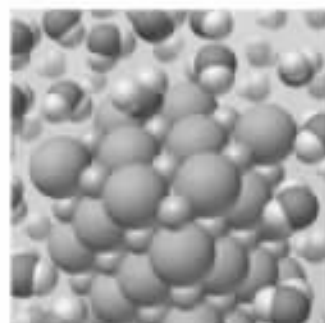
- 12.1 Liquid Crystals 436  
 Types of Liquid-Crystalline Phases 437
- 12.2 Polymers 440  
 Addition Polymerization 441 Condensation Polymerization 442  
 Types of Polymers 444 Structures and Physical Properties of Polymers 444  
 Cross-linking Polymers 446
- 12.3 Biomaterials 449  
 Characteristics of Biomaterials 449 Polymeric Biomaterials 450 Examples of Biomaterial Applications 451
- 12.4 Ceramics 454  
 Processing of Ceramics 455 Ceramic Composites 456 Applications of Ceramics 456 Superconducting Ceramics 457
- 12.5 Thin Films 459  
 Uses of Thin Films 459 Formation of Thin Films 460  
*Summary and Key Terms* 462 *Exercises* 463 *eMedia Exercises* 467

Chemistry at Work Liquid Crystal Displays 441  
 Chemistry at Work Recycling Plastics 444  
 Chemistry at Work Kevlar™, an Advanced Material 447  
 Chemistry at Work Diamond Coatings 462



## 13 Properties of Solutions 469

- 13.1 The Solution Process 469  
Energy Changes and Solution Formation 471 Solution Formation, Spontaneity, and Disorder 472 Solution Formation and Chemical Reactions 473
- 13.2 Saturated Solutions and Solubility 474
- 13.3 Factors Affecting Solubility 476  
Solute-Solvent Interactions 476 Pressure Effects 479 Temperature Effects 480
- 13.4 Ways of Expressing Concentration 482  
Mass Percentage, ppm, and ppb 482 Mole Fraction, Molarity, and Molality 483 Conversion of Concentration Units 485
- 13.5 Colligative Properties 486  
Lowering the Vapor Pressure 487 Boiling-Point Elevation 489  
Freezing-Point Depression 490 Osmosis 492 Determination of Molar Mass 493
- 13.6 Colloids 496  
Hydrophilic and Hydrophobic Colloids 496 Removal of Colloidal Particles 499  
*Summary and Key Terms* 500 *Exercises* 501 *eMedia Exercises* 507



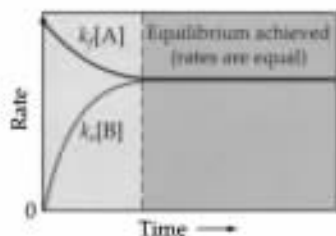
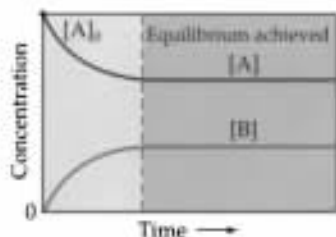
A Closer Look Hydrates 474  
Chemistry and Life Fat- and Water-Soluble Vitamins 478  
Chemistry and Life Blood Gases and Deep-Sea Diving 481  
A Closer Look Ideal Solutions with Two or More Volatile Components 488  
A Closer Look Colligative Properties of Electrolyte Solutions 494  
Chemistry and Life Sickle-Cell Anemia 498

## 14 Chemical Kinetics 509

- 14.1 Reaction Rates 510  
Rates in Terms of Concentrations 512 Reaction Rates and Stoichiometry 514
- 14.2 The Dependence of Rate on Concentration 515  
Reaction Order 517 Units of Rate Constants 517 Using Initial Rates to Determine Rate Laws 518
- 14.3 The Change of Concentration with Time 519  
First-Order Reactions 520 Half-life 521 Second-Order Reactions 523
- 14.4 Temperature and Rate 525  
The Collision Model 526 Activation Energy 527 The Orientation Factor 529 The Arrhenius Equation 529
- 14.5 Reaction Mechanisms 532  
Elementary Steps 532 Multistep Mechanisms 533 Rate Laws of Elementary Steps 534 Rate Laws of Multistep Mechanisms 535  
Mechanisms with an Initial Fast Step 537
- 14.6 Catalysis 539  
Homogeneous Catalysis 539 Heterogeneous Catalysis 540 Enzymes 543  
*Summary and Key Terms* 548 *Exercises* 549 *eMedia Exercises* 557

Chemistry at Work Methyl Bromide in the Atmosphere 524  
Chemistry at Work Catalytic Converters 542  
Chemistry and Life Nitrogen Fixation and Nitrogenase 545

## 15 Chemical Equilibrium 559



- 15.1 The Concept of Equilibrium 560
- 15.2 The Equilibrium Constant 562  
Equilibrium Constants in Terms of Pressure 566 The Magnitude of Equilibrium Constants 567 The Direction of the Chemical Equation and  $K$  567
- 15.3 Heterogeneous Equilibria 568
- 15.4 Calculating Equilibrium Constants 570
- 15.5 Applications of Equilibrium Constants 572  
Predicting the Direction of Reaction 573 Calculation of Equilibrium Concentrations 574
- 15.6 Le Châtelier's Principle 576  
Change in Reactant or Product Concentrations 576 Effects of Volume and Pressure Changes 577 Effect of Temperature Changes 579 The Effect of Catalysts 582  
*Summary and Key Terms* 584 *Exercises* 585 *eMedia Exercises* 591

Chemistry at Work The Haber Process 562

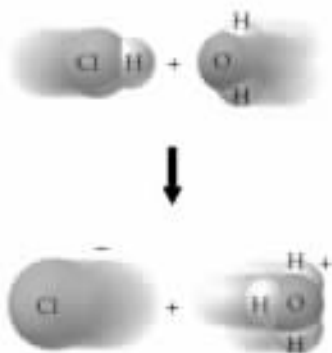
Chemistry at Work Controlling Nitric Oxide Emissions 584

## 16 Acid-Base Equilibria 593

- 16.1 Acids and Bases: A Brief Review 593
- 16.2 Brønsted–Lowry Acids and Bases 594  
The  $H^+$  Ion in Water 594 Proton-Transfer Reactions 595 Conjugate Acid–Base Pairs 596 Relative Strengths of Acids and Bases 597
- 16.3 The Autoionization of Water 599  
The Ion Product of Water 599
- 16.4 The pH Scale 601  
Other “p” Scales 603 Measuring pH 604
- 16.5 Strong Acids and Bases 605  
Strong Acids 605 Strong Bases 605
- 16.6 Weak Acids 606  
Calculating  $K_a$  from pH 607 Using  $K_a$  to Calculate pH 609 Polyprotic Acids 613
- 16.7 Weak Bases 615  
Types of Weak Bases 617
- 16.8 Relationship Between  $K_a$  and  $K_b$  618
- 16.9 Acid–Base Properties of Salt Solutions 621
- 16.10 Acid–Base Behavior and Chemical Structure 623  
Factors That Affect Acid Strength 624 Binary Acids 624 Oxyacids 624 Carboxylic Acids 627
- 16.11 Lewis Acids and Bases 627  
Hydrolysis of Metal Ions 629  
*Summary and Key Terms* 632 *Exercises* 633 *eMedia Exercises* 639

Chemistry at Work Amines and Amine Hydrochlorides 619

Chemistry and Life The Amphoteric Behavior of Amino Acids 628



## 17 Additional Aspects of Aqueous Equilibria 641

- 17.1 The Common-Ion Effect 641
- 17.2 Buffered Solutions 644  
Composition and Action of Buffered Solutions 644 Buffer Capacity and pH 646 Addition of Strong Acids or Bases to Buffers 648
- 17.3 Acid-Base Titrations 650  
Strong Acid-Strong Base Titrations 652 Weak Acid-Strong Base Titrations 655 Titrations of Polyprotic Acids 659
- 17.4 Solubility Equilibria 659  
The Solubility-Product Constant,  $K_{sp}$  660 Solubility and  $K_{sp}$  661
- 17.5 Factors That Affect Solubility 662  
Common-Ion Effect 663 Solubility and pH 665 Formation of Complex Ions 666 Amphoterism 668
- 17.6 Precipitation and Separation of Ions 669  
Selective Precipitation of Ions 670
- 17.7 Qualitative Analysis for Metallic Elements 671  
*Summary and Key Terms* 675 *Exercises* 675 *eMedia Exercises* 681
- Chemistry and Life Blood as a Buffered Solution 651  
A Closer Look Limitations of Solubility Products 663  
Chemistry and Life Tooth Decay and Fluoridation 666

## 18 Chemistry of the Environment 683

- 18.1 Earth's Atmosphere 683  
Composition of the Atmosphere 685
- 18.2 The Outer Regions of the Atmosphere 686  
Photodissociation 686 Photoionization 687
- 18.3 Ozone in the Upper Atmosphere 688  
Depletion of the Ozone Layer 690
- 18.4 Chemistry of the Troposphere 691  
Sulfur Compounds and Acid Rain 693 Carbon Monoxide 694 Nitrogen Oxides and Photochemical Smog 696 Water Vapor, Carbon Dioxide, and Climate 697
- 18.5 The World Ocean 699  
Seawater 699 Desalination 700
- 18.6 Freshwater 701  
Dissolved Oxygen and Water Quality 702 Treatment of Municipal Water Supplies 703  
*Summary and Key Terms* 705 *Exercises* 706 *eMedia Exercises* 710
- A Closer Look Stratospheric Clouds and Ozone Depletion 692  
A Closer Look Water Softening 703



## 19 Chemical Thermodynamics 713

- 19.1 Spontaneous Processes 714  
Reversible and Irreversible Processes 716
- 19.2 Entropy and the Second Law of Thermodynamics 717  
The Spontaneous Expansion of a Gas 718 Entropy 719 The Second Law of Thermodynamics 722

- 19.3 The Molecular Interpretation of Entropy 724  
 19.4 Calculation of Entropy Changes 729  
 19.5 Gibbs Free Energy 730  
     Standard Free-Energy Changes 731  
 19.6 Free Energy and Temperature 734  
 19.7 Free Energy and the Equilibrium Constant 737  
     *Summary and Key Terms* 741   *Exercises* 742   *eMedia Exercises* 749

Chemistry and Life Entropy and Life 724

A Closer Look Entropy, Disorder, and Ludwig Boltzmann 726

A Closer Look What's "Free" About Free Energy? 732

Chemistry and Life Driving Nonspontaneous Reactions 739



## 20 Electrochemistry 751

- 20.1 Oxidation-Reduction Reactions 752  
 20.2 Balancing Oxidation-Reduction Equations 753  
     Half-Reactions 754   Balancing Equations by the Method of Half-Reactions 754  
     Balancing Equations for Reactions Occurring in Basic Solution 757  
 20.3 Voltaic Cells 758  
     A Molecular View of Electrode Processes 761  
 20.4 Cell EMF 762  
     Standard Reduction Potentials 764   Oxidizing and Reducing Agents 768  
 20.5 Spontaneity of Redox Reactions 770  
     EMF and Free-Energy Change 771  
 20.6 Effect of Concentration on Cell EMF 773  
     The Nernst Equation 773   Concentration Cells 775   Cell EMF and  
     Chemical Equilibrium 777  
 20.7 Batteries 779  
     Lead-Acid Battery 780   Alkaline Battery 781   Nickel-Cadmium,  
     Nickel-Metal-Hydrate, and Lithium-Ion Batteries 781   Fuel Cells 782  
 20.8 Corrosion 782  
     Corrosion of Iron 783   Preventing the Corrosion of Iron 783  
 20.9 Electrolysis 785  
     Electrolysis of Aqueous Solutions 786   Electrolysis with Active Electrodes 788  
     Quantitative Aspects of Electrolysis 789   Electrical Work 791  
     *Summary and Key Terms* 793   *Exercises* 794   *eMedia Exercises* 803

Chemistry and Life Heartbeats and Electrocardiography 778

## 21 Nuclear Chemistry 805

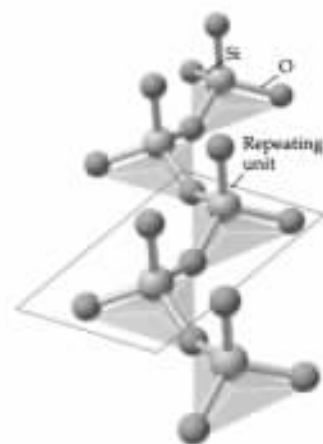
- 21.1 Radioactivity 805  
     Nuclear Equations 806   Types of Radioactive Decay 807  
 21.2 Patterns of Nuclear Stability 809  
     Neutron-to-Proton Ratio 809   Radioactive Series 811   Further  
     Observations 812  
 21.3 Nuclear Transmutations 812  
     Using Charged Particles 813   Using Neutrons 814   Transuranium  
     Elements 814  
 21.4 Rates of Radioactive Decay 815  
     Dating 816   Calculations Based on Half-life 817

- 21.5 Detection of Radioactivity 819  
Radiotracers 820
- 21.6 Energy Changes in Nuclear Reactions 820  
Nuclear Binding Energies 822
- 21.7 Nuclear Fission 824  
Nuclear Reactors 826
- 21.8 Nuclear Fusion 828
- 21.9 Biological Effects of Radiation 829  
Radiation Doses 830 Radon 831  
*Summary and Key Terms* 834 *Exercises* 835 *eMedia Exercises* 839

Chemistry and Life Medical Applications of Radiotracers 821  
A Closer Look The Dawning of the Nuclear Age 826  
Chemistry and Life Radiation Therapy 832

## 22 Chemistry of the Nonmetals 841

- 22.1 General Concepts: Periodic Trends and Chemical Reactions 841  
Chemical Reactions 843
- 22.2 Hydrogen 844  
Isotopes of Hydrogen 845 Properties of Hydrogen 845 Preparation of Hydrogen 846 Uses of Hydrogen 847 Binary Hydrogen Compounds 847
- 22.3 Group 8A: The Noble Gases 848  
Noble-Gas Compounds 849
- 22.4 Group 7A: The Halogens 850  
Properties and Preparation of the Halogens 851 Uses of the Halogens 852  
The Hydrogen Halides 853 Interhalogen Compounds 854 Oxyacids and Oxyanions 855
- 22.5 Oxygen 856  
Properties of Oxygen 856 Preparation of Oxygen 856 Uses of Oxygen 857 Ozone 857 Oxides 858 Peroxides and Superoxides 859
- 22.6 The Other Group 6A Elements: S, Se, Te, and Po 860  
General Characteristics of the Group 6A Elements 860 Occurrences and Preparation of S, Se, and Te 861 Properties and Uses of Sulfur, Selenium, and Tellurium 862 Sulfides 863 Oxides, Oxyacids, and Oxyanions of Sulfur 863
- 22.7 Nitrogen 865  
Properties of Nitrogen 865 Preparation and Uses of Nitrogen 866  
Hydrogen Compounds of Nitrogen 867 Oxides and Oxyacids of Nitrogen 868
- 22.8 The Other Group 5A Elements: P, As, Sb, and Bi 870  
General Characteristics of the Group 5A Elements 870 Occurrence, Isolation, and Properties of Phosphorus 871 Phosphorus Halides 872 Oxy Compounds of Phosphorus 872
- 22.9 Carbon 875  
Elemental Forms of Carbon 876 Oxides of Carbon 876 Carbonic Acid and Carbonates 879 Carbides 880 Other Inorganic Compounds of Carbon 880
- 22.10 The Other Group 4A Elements: Si, Ge, Sn, and Pb 881  
General Characteristics of the Group 4A Elements 881 Occurrence and Preparation of Silicon 882 Silicates 882 Glass 884 Silicones 885
- 22.11 Boron 885  
*Summary and Key Terms* 887 *Exercises* 889 *eMedia Exercises* 894



Chemistry and Life	Nitrites in Food	870
Chemistry at Work	Carbon Fibers and Composites	877

## 23 Metals and Metallurgy 897

- 23.1 Occurrence and Distribution of Metals 897  
Minerals 898 Metallurgy 899
- 23.2 Pyrometallurgy 900  
The Pyrometallurgy of Iron 901 Formation of Steel 902
- 23.3 Hydrometallurgy 903  
The Hydrometallurgy of Aluminum 904
- 23.4 Electrometallurgy 904  
Electrometallurgy of Sodium 905 Electrometallurgy of Aluminum 905  
Electrorefining of Copper 906
- 23.5 Metallic Bonding 908  
Physical Properties of Metals 908 Electron-Sea Model for Metallic  
Bonding 909 Molecular-Orbital Model for Metals 910
- 23.6 Alloys 912  
Intermetallic Compounds 914
- 23.7 Transition Metals 914  
Physical Properties 916 Electron Configurations and Oxidation States 917  
Magnetism 919
- 23.8 Chemistry of Selected Transition Metals 920  
Chromium 920 Iron 920 Copper 921  
*Summary and Key Terms* 922 *Exercises* 923 *eMedia Exercises* 927

A Closer Look	Charles M. Hall	907
A Closer Look	Insulators and Semiconductors	911
A Closer Look	Shape Memory Alloys	915

## 24 Chemistry of Coordination Compounds 929

- 24.1 The Structure of Complexes 929  
Charges, Coordination Numbers, and Geometries 931
- 24.2 Chelates 933  
Metals and Chelates in Living Systems 934 Nomenclature 936
- 24.3 Isomerism 940  
Structural Isomerism 941 Stereoisomerism 941
- 24.4 Color and Magnetism 944  
Color 944 Magnetism 946
- 24.5 Crystal-Field Theory 946  
Electron Configurations in Octahedral Complexes 951 Tetrahedral and  
Square-Planar Complexes 952  
*Summary and Key Terms* 954 *Exercises* 955 *eMedia Exercises* 959

A Closer Look	The Stability of Chelates	937
Chemistry and Life	The Battle for Iron in Living Systems	938
A Closer Look	Gemstones	948

