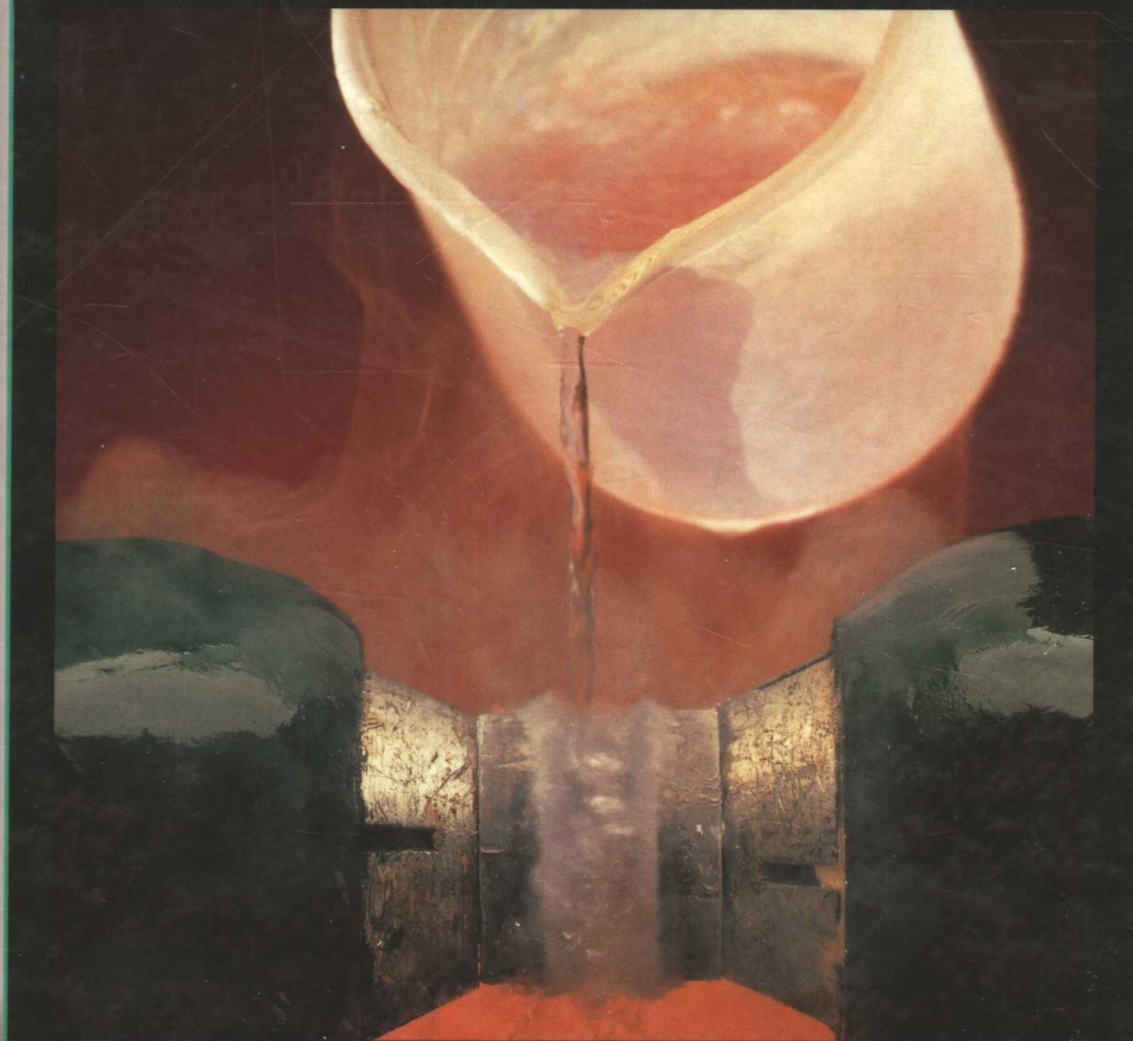


GENERAL CHEMISTRY

Principles & Modern Applications



SIXTH EDITION

PETRUCCI • HARWOOD

GENERAL CHEMISTRY

Principles and Modern Applications

SIXTH EDITION

RALPH H. PETRUCCI

California State University, San Bernardino

WILLIAM S. HARWOOD

University of Maryland, College Park

MACMILLAN PUBLISHING COMPANY New York

MAXWELL MACMILLAN CANADA Toronto

Editor: Paul F. Corey
Development Editor: Madalyn Stone
Production Supervisor: Elisabeth H. Belfer
Production Manager: Nicholas Sklitsis
Text Designer: Hudson River Studio
Cover Designer: Patricia Smythe
Cover Photograph: © Richard Megna/Fundamental Photographs
Photo Researchers: Yvonne Gerin and Ray Segal
Illustrations: Hudson River Studio

This book was set in Times Roman and Helvetica by York Graphic Services, Inc., printed and bound by R. R. Donnelley & Sons Company. The cover was printed by Lehigh Press.

Copyright © 1993 by Macmillan Publishing Company, a division of Macmillan, Inc. Printed in the United States of America

All rights reserved. No part of this book may be reproduced or transmitted in any form or by any means, electronic or mechanical, including photocopying, recording, or any information storage and retrieval system, without permission in writing from the publisher.

Earlier editions by Ralph H. Petrucci copyright © 1989 by Macmillan Publishing Company and copyright © 1972, 1977, 1982, and 1985 by Ralph H. Petrucci.

Macmillan Publishing Company
866 Third Avenue, New York, New York 10022

Macmillan Publishing Company is part of the Maxwell Communication Group of Companies.

Maxwell Macmillan Canada, Inc.
1200 Eglinton Avenue East
Suite 200
Don Mills, Ontario M3C 3N1

Library of Congress Cataloging-in-Publication Data

Petrucci, Ralph H.

General chemistry : principles and modern applications / Ralph H. Petrucci, William S. Harwood. — 6th ed.

p. cm.

Includes index.

ISBN 0-02-394931-7

I. Chemistry. I. Harwood, William S. II. Title.

QD31.2.P48 1993

540—dc20

92-13854

CIP

Printing: 2 3 4 5 6 7 8

Year: 3 4 5 6 7 8 9 0 1 2

GENERAL CHEMISTRY

Principles and Modern Applications

PREFACE

We are aware that most general chemistry students have career interests, not in chemistry, but in biology, medicine, engineering, and environmental and agricultural sciences, to name but a few. We also know that general chemistry will be the only college chemistry course for many students and their only opportunity to learn some practical applications of chemistry. We have designed this text for these “typical” students.

Students of this text probably have studied some chemistry previously, but those with no prior background will find that the early chapters develop fundamental concepts from the most elementary of ideas. Students who do plan to become professional chemists will also find opportunities in the text to pursue their special interests.

We think that the typical student needs help in identifying and applying principles and in visualizing their physical significance. The pedagogical features of this text are designed to provide this help, but at the same time we hope the text serves to sharpen student skills in problem solving and critical thinking. Throughout, we have attempted to strike the proper balances between principles and applications, qualitative and quantitative discussions, and rigor and simplification.

Organizational Changes

A major organizational change in this edition is in the treatment of descriptive chemistry. In the fifth edition, one long chapter placed in the middle of the book presented an introduction to the descriptive chemistry of the first 20 elements. The remaining descriptive chapters came at the end of the book. In this edition a much shorter chapter dealing with the atmospheric gases and hydrogen is placed earlier in the text (Chapter 8), and again the remaining descriptive chapters come toward the end of the text.

The early descriptive chapter follows the opening series of chapters that deal with the fundamentals of chemistry and precedes the several chapters that concern atomic and molecular structure, liquids, solids, etc. This early descriptive chapter serves,

in part, to show how previously learned principles can be applied to descriptive topics and, in part, to establish the need for additional principles yet to come.

In addition to the new Chapter 8, other changes in the treatment of descriptive chemistry include moving the discussions of extractive metallurgy and the Group 2B metals from the chapter on main-group metals (Chapter 22) to the one on transition elements (Chapter 24). In Chapter 24 various metallurgical topics are taken up together early in the chapter. As in the fifth edition, many descriptive topics are interwoven into chapters throughout the text.

Other organizational changes involve the addition of a few topics and the deletion, reorganization, or relocation of others. For example, an introduction to the periodic table has been moved to an earlier position in Chapter 3. The concept of net ionic equations has been moved from Chapter 4 (Chemical Reactions) to Chapter 5 (Introduction to Reactions in Aqueous Solution). Heats of reaction and calorimetry have been moved to an earlier location in the thermochemistry chapter (Chapter 7). A section has been added at the end of Chapter 10 to apply the periodic table and atomic properties to a discussion of several periodic trends among elements and compounds. Bond energies and the energetics of ionic bonding have been moved to the end of the first chapter on chemical bonding (Chapter 11) to allow for a more rapid development of ideas concerning covalent Lewis structures. The discussion of molecular orbital theory in the second chapter on bonding (Chapter 12) has been shortened and simplified. The separate discussions of qualitative analysis in Chapters 5 and 19 of the fifth edition have been combined into a single section in Chapter 19. The discussions of equivalent weights in relation to acid–base reactions (Chapter 18) and oxidation–reduction reactions (Chapter 21) have been deleted in this edition.

Special Features

The text contains a number of pedagogical features whose purposes are as follows.

Important Expressions. So that students may find them more readily, the most significant equations and expressions are highlighted with a yellow panel. Instructors are, of course, free to add to this list.

Summary/Key Terms/Glossary. Each chapter concludes with a comprehensive verbal Summary of important concepts and factual information, followed by a list of Key Terms. These terms appear in boldface type in the text and are also defined again in the Glossary (Appendix E). Students can use Key Terms lists and the Glossary to help them master the terminology of general chemistry.

Are You Wondering . . . In an attempt to clarify matters that often puzzle students, occasional questions are posed and answered under this heading. These questions are cast in the form in which students often ask them. Some are designed to help students avoid common pitfalls; others to provide analogies or alternate explanations of a concept.

In-Text Illustrative Examples. In each chapter most concepts—especially those that students will be expected to apply in homework assignments and examinations—are illustrated with worked-out examples. Often a line drawing or photograph accompanies an example to help students visualize what is “going on” in the problem.

Practice Examples. In previous editions, in-text illustrative examples made reference to similar examples among the end-of-chapter exercises. In this edition, illustrative examples are accompanied by practice examples that give students im-

mediate practice in applying the principle(s) illustrated in the example. More important, though, is that in some instances students are required to carry the calculation a step further than in the illustrative example or to use an additional concept previously learned. In these instances students are usually given hints. The idea is to help bridge the gap between the simpler one-step Review Questions and the more comprehensive Exercises and Advanced Exercises at the ends of the chapters. Answers to all Practice Examples are given in Appendix F. Complete solutions are given in the Student Study Guide.

Summarizing Examples. Each chapter concludes with a multipart example, usually of a practical nature. These examples link various important problem types introduced in the chapter with each other and often with problem types of earlier chapters. In the fifth edition these summarizing examples were solved, but in the present edition a solution is only outlined and intermediate results and a final answer given. Students are expected to work out the details of the solution. Complete solutions are given in the Student Study Guide.

End-of-Chapter Exercises. Each chapter has three categories of exercises. Review Questions require straightforward application of principles introduced in the chapter, each usually involving a single concept. Exercises are grouped by subject matter and are of a broader nature than the Review Questions. The Advanced Exercises are not grouped by type. As expected, some of these are more difficult than those in the other sections, but some are “advanced” only in the sense that they pursue certain ideas further than is done in the text or introduce new ideas. Answers to most Review Questions and to those Exercises and Advanced Exercises designated by green numbers or letters are given in Appendix F.

Focus On. It is our belief that relevant applications should be an integral part of the text, that asides should be limited to marginal notes and occasional Are You Wondering features, and that interesting but less vital issues should follow the main text of a chapter. With this view in mind, we have concluded the text of each chapter with a short essay on a practical topic appropriate to the subject matter of the chapter. These essays, which may be considered optional reading, focus on an idea introduced in the chapter. For example, the feature in Chapter 4 (Chemical Reactions) concerns industrial chemistry, the one in the first bonding chapter (Chapter 11) describes the recently discovered fullerenes, and the one in Chapter 17 (Acids and Bases) deals with acid rain.

Supplements

The Student Study Guide is organized around a set of learning objectives for each chapter and features brief discussions of these objectives, drill problems, self quizzes, and sample tests.

The laboratory manual *Experiments in General Chemistry* contains 37 experiments that parallel the text, including a final group of six experiments on qualitative cation analysis. There is an accompanying instructor's manual.

The Solutions Manual contains worked-out solutions to all the Review Questions and Exercises.

The Instructor's Manual offers alternative organizational schemes for the general chemistry course, notes and comments on each chapter, and worked-out solutions of the Advanced Exercises.

A Test Bank, in printed form or computerized, and a set of 125 full-color transparencies, selected from the text, are available to adopters.

Acknowledgments

The following colleagues helped by reviewing manuscript and/or being available for consultation on various matters that arose during the preparation of this text-book: from Cal State/San Bernardino—Arlo Harris, Dennis Pederson, Kenneth Mantei, James Crum, John Tate, and Lee Kalbus; from U Maryland/College Park—Alfred C. Boyd, Jr., Howard DeVoe, (late) Glen Gordon, James Huheey, Alice Mignerey, and William Walters. WSH would also like to thank Thomas Flores for his assistance with library research. Both authors want to acknowledge a special debt of gratitude to Robert K. Wismer (Millersville University) who, in addition to his own efforts in producing many of the supplements to this text, commented extensively on the manuscript, read proof, and acted as a sounding board for many of the new features.

We are grateful to many people at Macmillan Publishing Company for their help and encouragement, starting with our editor Paul Corey. Madalyn Stone, our development editor, read the entire manuscript in the spirit of an eager student and offered many helpful suggestions. Her unflagging enthusiasm was greatly appreciated. Special thanks to Elisabeth Belfer, our production supervisor, who has managed to convert manuscript, cut pages, scribbled notes, rough sketches, and telephone conversations into a very attractive final product. All this under very stringent deadlines.

We are also grateful for the patience and encouragement of our wives, Ruth Petrucci and Diana Harwood. Without their love and support, this book would not have been possible.

We appreciate the significant contributions of those who commented on the fifth edition or reviewed manuscript chapters of this edition.

Robert Allendorfer
State University of New York @ Buffalo

Conrad H. Bergo
East Stroudsburg University

Muriel B. Bishop
Clemson University

Bruce E. Cleare
Tallahassee Community College

H. Lawrence Clever
Emory University

Frank Dalton
Grove City College

Geoffrey Davies
Northeastern University

John DeKorte
Northern Arizona University

Paul Engelking
University of Oregon

Clark Fields
University of Northern Colorado

L. Peter Gold
Pennsylvania State University

Frank J. Gomba
The United States Naval Academy

Thomas J. Greenbowe
Iowa State University

Albert Haim
State University of New York @ Stony
Brook

David Harris
University of California @ Santa
Barbara

Leland Harris
University of Arizona

Alton Hassell
Baylor University

Sherman Henzel
Monroe Community College

J. R. Hoover
Rose State College

Colin D. Hubbard
University of New Hampshire

Harold R. Hunt, Jr.
Georgia Institute of Technology

Paul W. W. Hunter
Michigan State University

D. C. Kleinfelter
University of Tennessee

Robert M. Kren
The University of Michigan @ Flint

Bette A. Kreuz
The University of Michigan @ Dearborn

Frank M. Lanzafame
Monroe Community College

Gardiner H. Myers
University of Florida

Robert Nakon
West Virginia University

Lee Pederson
University of North Carolina @ Chapel
Hill

John V. Rund
University of Arizona

Peter S. Sheridan
Colgate University

Wayne L. Smith
Colby College

R. H. P.
W. S. H.

TO THE STUDENT

To some students chemistry is an almost magical art. Chemists seem to produce new compounds much as a magician pulls a rabbit out of a hat. In this course of study you will learn how these feats can be accomplished. As with magic, there are both mystery and excitement to chemistry. No one knows all the answers and many aspects of our science are not well understood. New materials, new methods, and, most important, new ideas are needed in all areas of chemistry.

In studying chemistry you will discover some of the ideas and concepts chemists use to understand and direct chemical changes. Some students find it possible to pursue a course in chemistry just by memorizing facts and mathematical equations, but we urge you not to settle for this approach. Demand of yourself, this text, and your instructors explanations of the why and how of chemistry. Seek the concepts behind the facts and equations.

Of course, skill in algebra and the assimilation of facts are important, but imagination is the key to mastering chemistry. At the heart of most chemistry problems is perceiving a connection between an observation in the macroscopic world—the “real” world—and an imagined change in the microscopic world—the world of atoms, ions, and molecules. Once you perceive this connection, finding the solution to a problem should become much simpler.

This book contains a number of special features designed to help you gain an understanding of the concepts and methods used by chemists. Read about these features in the Preface and take full advantage of them as you proceed through the text.

One study idea that you may find useful is to make a study sheet containing information on important concepts and methods. Include on the sheet information from your lecture notes as well as from the text. With the study sheet at hand, practice solving problems similar to those assigned as homework. You should attempt problems for which answers are not given as well as those that are answered in the text. This will allow you to simulate an exam situation where you do not have access to answers. Encourage a study partner also to solve some unanswered problems. If you both get the same answer, independently, then the answer is probably correct. If your answers differ, discuss the situation and determine which of you, if either, is correct. This type of discussion is an excellent stimulus to learning new material.

WARNING: Many of the compounds described or pictured in this text are hazardous, as are many of the chemical reactions. The reader should not attempt any experiment pictured or implied in the text. Experiments should be performed only in authorized laboratory settings and under adequate supervision.

BRIEF CONTENTS

- 1 Matter—Its Properties and Measurement *1*
 - 2 Atoms and the Atomic Theory *32*
 - 3 Chemical Compounds *62*
 - 4 Chemical Reactions *98*
 - 5 Introduction to Reactions in Aqueous Solutions *132*
 - 6 Gases *168*
 - 7 Thermochemistry *208*
 - 8 The Atmospheric Gases and Hydrogen *248*
 - 9 Electrons in Atoms *278*
 - 10 The Periodic Table and Some Atomic Properties *316*
 - 11 Chemical Bonding I: Basic Concepts *352*
 - 12 Chemical Bonding II: Additional Aspects *400*
 - 13 Liquids, Solids, and Intermolecular Forces *432*
 - 14 Solutions and Their Physical Properties *476*
 - 15 Chemical Kinetics *512*
 - 16 Principles of Chemical Equilibrium *552*
 - 17 Acids and Bases *588*
 - 18 Additional Aspects of Acid–Base Equilibria *630*
 - 19 Solubility and Complex-Ion Equilibria *664*
 - 20 Spontaneous Change: Entropy and Free Energy *698*
 - 21 Electrochemistry *730*
 - 22 Representative (Main-Group) Elements I: Metals *770*
 - 23 Representative (Main-Group) Elements II: Nonmetals *802*
 - 24 The Transition Elements *840*
 - 25 Complex Ions and Coordination Compounds *872*
 - 26 Nuclear Chemistry *904*
 - 27 Organic Chemistry *936*
 - 28 Chemistry of the Living State *970*
- APPENDIXES**
- A Mathematical Operations *A1*
 - B Some Basic Physical Concepts *A9*
 - C SI Units *A14*
 - D Data Tables *A16*
 - E Glossary *A30*
 - F Answers to Practice Examples and Selected Exercises *A50*
- INDEX** *II*

CONTENTS

1 MATTER—ITS PROPERTIES AND MEASUREMENT 1

1-1	The Scope of Chemistry	2	
1-2	The Scientific Method	2	
1-3	Properties of Matter	4	
1-4	Classification of Matter	5	
1-5	Measurement of Matter: SI (Metric) Units	8	
1-6	Using Measured Quantities: Problem Solving	12	
1-7	Density and Percent Composition: Their Use in Problem Solving		16
1-8	Uncertainties in Scientific Measurements	20	
1-9	Significant Figures	21	
	<i>Focus On The Scientific Method at Work: Polywater</i>	24	
	<i>Summary, 26 Summarizing Example, 26 Key Terms, 27</i>		
	<i>Review Questions, 27 Exercises, 28 Advanced Exercises, 31</i>		

2 ATOMS AND THE ATOMIC THEORY 32

2-1	Early Chemical Discoveries and the Atomic Theory	34	
2-2	Electrons and Other Discoveries in Atomic Physics	36	
2-3	The Nuclear Atom	40	
2-4	Chemical Elements	42	
2-5	Atomic Masses	46	
2-6	The Avogadro Constant and the Concept of the Mole	48	
2-7	Using the Mole Concept in Calculations	51	
	<i>Focus On Occurrence and Abundances of the Elements</i>	54	
	<i>Summary, 55 Summarizing Example, 56 Key Terms, 56</i>		
	<i>Review Questions, 56 Exercises, 57 Advanced Exercises, 60</i>		

3	CHEMICAL COMPOUNDS	62
3-1	An Introduction to the Periodic Table	64
3-2	Types of Chemical Compounds and Their Formulas	65
3-3	The Mole Concept and Chemical Compounds	68
3-4	Composition of Chemical Compounds	71
3-5	Oxidation States: A Useful Tool in Describing Chemical Compounds	79
3-6	Naming Inorganic Compounds	81
	<i>Focus On Polymers—Macromolecular Substances</i>	90
	<i>Summary, 90 Summarizing Example, 92 Key Terms, 92</i>	
	<i>Review Questions, 92 Exercises, 93 Advanced Exercises, 96</i>	
4	CHEMICAL REACTIONS	98
4-1	Chemical Reactions and the Chemical Equation	100
4-2	The Chemical Equation and Stoichiometry	104
4-3	Chemical Reactions in Solution	109
4-4	Determining the Limiting Reagent	115
4-5	Other Practical Matters in Reaction Stoichiometry	118
	<i>Focus On Industrial Chemistry</i>	122
	<i>Summary, 124 Summarizing Example, 124 Key Terms, 124</i>	
	<i>Review Questions, 125 Exercises, 126 Advanced Exercises, 129</i>	
5	INTRODUCTION TO REACTIONS IN AQUEOUS SOLUTIONS	132
5-1	The Nature of Aqueous Solutions	134
5-2	Precipitation Reactions	137
5-3	Acid–Base Reactions	141
5-4	Oxidation–Reduction: Some General Principles	146
5-5	Balancing Oxidation–Reduction Equations	149
5-6	Oxidizing and Reducing Agents	154
5-7	Stoichiometry of Reactions in Aqueous Solutions: Titrations	155
	<i>Focus On Water Treatment</i>	160
	<i>Summary, 159 Summarizing Example, 159 Key Terms, 159</i>	
	<i>Review Questions, 160 Exercises, 163 Advanced Exercises, 166</i>	
6	GASES	168
6-1	Properties of Gases: Gas Pressure	170
6-2	The Simple Gas Laws	174
6-3	The Ideal Gas Equation	180
6-4	Applications of the Ideal Gas Equation	184
6-5	Gases in Chemical Reactions	186
6-6	Mixtures of Gases	189
6-7	Kinetic-Molecular Theory of Gases	192
6-8	Gas Properties Relating to the Kinetic-Molecular Theory	196
6-9	Nonideal (Real) Gases	198

<i>Focus On The Chemistry of Air-Bag Systems</i>	200
<i>Summary, 201 Summarizing Example, 202 Key Terms, 202</i>	
<i>Review Questions, 202 Exercises, 203 Advanced Exercises, 206</i>	

7 THERMOCHEMISTRY 208

7-1 Getting Started: Some Terminology	210
7-2 Work	211
7-3 Heat	212
7-4 Heats of Reaction and Calorimetry	216
7-5 The First Law of Thermodynamics	220
7-6 Heats of Reaction and Enthalpy Change, ΔH	222
7-7 Indirect Determination of ΔH : Hess's Law	225
7-8 Standard Enthalpies of Formation	228
7-9 Fuels as Sources of Energy	234
<i>Focus On Fats, Carbohydrates, and Energy Storage</i>	238
<i>Summary, 238 Summarizing Example, 240 Key Terms, 240</i>	
<i>Review Questions, 240 Exercises, 242 Advanced Exercises, 246</i>	

8 THE ATMOSPHERIC GASES AND HYDROGEN 248

8-1 The Atmosphere	250
8-2 Nitrogen	253
8-3 Oxygen	259
8-4 The Noble Gases	264
8-5 Oxides of Carbon	266
8-6 Hydrogen	269
<i>Focus On The Carbon Cycle</i>	272
<i>Summary, 273 Summarizing Example, 274 Key Terms, 274</i>	
<i>Review Questions, 274 Exercises, 275 Advanced Exercises, 277</i>	

9 ELECTRONS IN ATOMS 278

9-1 Electromagnetic Radiation	280
9-2 Atomic Spectra	284
9-3 Quantum Theory	286
9-4 The Bohr Atom	288
9-5 Two Ideas Leading to a New Quantum Mechanics	292
9-6 Wave Mechanics	294
9-7 Quantum Numbers and Electron Orbitals	297
9-8 Electron Spin—A Fourth Quantum Number	301
9-9 Multielectron Atoms	301
9-10 Electron Configurations	303
<i>Focus On Helium-Neon Lasers</i>	310
<i>Summary, 309 Summarizing Example, 309 Key Terms, 309</i>	
<i>Review Questions, 312 Exercises, 313 Advanced Exercises, 315</i>	

10	THE PERIODIC TABLE AND SOME ATOMIC PROPERTIES	316
10-1	Classifying the Elements: The Periodic Law and the Periodic Table	318
10-2	Description of a Modern Periodic Table—The Long Form	321
10-3	Electron Configurations and the Periodic Table	322
10-4	Metals and Nonmetals and Their Ions	326
10-5	The Sizes of Atoms and Ions	328
10-6	Ionization Energy	333
10-7	Electron Affinity	337
10-8	Magnetic Properties	338
10-9	Periodic Properties of the Elements	340
	<i>Focus On The Periodic Law and Mercury</i>	346
	<i>Summary, 346 Summarizing Example, 347 Key Terms, 348</i>	
	<i>Review Questions, 348 Exercises, 349 Advanced Exercises, 351</i>	
11	CHEMICAL BONDING I: BASIC CONCEPTS	352
11-1	Lewis Theory—An Overview	354
11-2	Covalent Bonding—An Introduction	356
11-3	Polar Covalent Bonds	360
11-4	Writing Lewis Structures	364
11-5	Resonance	370
11-6	Exceptions to the Octet Rule	372
11-7	The Shapes of Molecules	375
11-8	Bond Energies	386
11-9	Energy Changes in the Formation of Ionic Crystals	389
	<i>Focus On Fullerenes: "Buckyballs"</i>	392
	<i>Summary, 392 Summarizing Example, 394 Key Terms, 394</i>	
	<i>Review Questions, 395 Exercises, 396 Advanced Exercises, 399</i>	
12	CHEMICAL BONDING II: ADDITIONAL ASPECTS	400
12-1	What a Bonding Theory Should Do	402
12-2	Introduction to the Valence Bond Model	403
12-3	Hybridization of Atomic Orbitals	405
12-4	Multiple Covalent Bonds	412
12-5	Molecular-Orbital Theory	415
12-6	Delocalized Electrons: Bonding in the Benzene Molecule	420
12-7	Bonding in Metals	423
	<i>Focus On Semiconductors</i>	426
	<i>Summary, 425 Summarizing Example, 426 Key Terms, 427</i>	
	<i>Review Questions, 428 Exercises, 428 Advanced Exercises, 430</i>	

13 LIQUIDS, SOLIDS, AND INTERMOLECULAR FORCES 432

- 13-1 Intermolecular Forces and Some Properties of Liquids 434
 13-2 Vaporization of Liquids: Vapor Pressure 436
 13-3 Some Properties of Solids 444
 13-4 Phase Diagrams 445
 13-5 Van der Waals Forces 449
 13-6 Hydrogen Bonding 453
 13-7 Chemical Bonds as Intermolecular Forces 455
 13-8 Crystal Structures 458
Focus On Liquid Crystals 466
Summary, 468 Summarizing Example, 469 Key Terms, 469
Review Questions, 469 Exercises, 471 Advanced Exercises, 474

14 SOLUTIONS AND THEIR PHYSICAL PROPERTIES 476

- 14-1 Types of Solutions: Some Terminology 478
 14-2 Solution Concentration 478
 14-3 Intermolecular Forces and the Solution Process 482
 14-4 Solution Formation and Equilibrium 486
 14-5 Solubilities of Gases 489
 14-6 Vapor Pressures of Solutions 491
 14-7 Freezing Point Depression and Boiling Point Elevation of Nonelectrolyte Solutions 494
 14-8 Additional Consequences of Vapor Pressure Lowering: Osmotic Pressure 497
 14-9 Solutions of Electrolytes 500
Focus On Colloidal Mixtures 502
Summary, 505 Summarizing Example, 505 Key Terms, 505
Review Questions, 505 Exercises, 506 Advanced Exercises, 510

15 CHEMICAL KINETICS 512

- 15-1 The Rate of a Chemical Reaction 514
 15-2 Measuring Reaction Rates 516
 15-3 The Effect of Concentrations on Rates of Reaction: The Rate Law 519
 15-4 Zero-Order Reactions 523
 15-5 First-Order Reactions 523
 15-6 Second-Order Reactions 529
 15-7 Reaction Kinetics: A Summary 531
 15-8 Theoretical Models for Chemical Kinetics 532
 15-9 The Effect of Temperature on Reaction Rates 535
 15-10 Reaction Mechanisms 537
 15-11 Catalysis 540
Focus On Combustion and Explosions 542
Summary, 544 Summarizing Example, 545 Key Terms, 545
Review Questions, 545 Exercises, 547 Advanced Exercises, 550

16	PRINCIPLES OF CHEMICAL EQUILIBRIUM	552
16-1	The Condition of Dynamic Equilibrium	554
16-2	The Equilibrium Constant Expression	554
16-3	Relationships Involving Equilibrium Constants	558
16-4	Significance of the Magnitude of an Equilibrium Constant	563
16-5	The Reaction Quotient, Q : Predicting the Direction of a Reaction	564
16-6	Altering Equilibrium Conditions: Le Châtelier's Principle	567
16-7	Equilibrium Calculations: Some Illustrative Examples	572
	<i>Focus On Chemical Equilibria and the Nitrogen Cycle</i>	578
	<i>Summary, 579 Summarizing Example, 580 Key Terms, 580</i>	
	<i>Review Questions, 580 Exercises, 582 Advanced Exercises, 585</i>	
17	ACIDS AND BASES	588
17-1	The Arrhenius Theory: A Brief Review	590
17-2	Brønsted-Lowry Theory of Acids and Bases	591
17-3	The Self-ionization of Water and the pH Scale	594
17-4	Strong Acids and Strong Bases	597
17-5	Weak Acids and Weak Bases	598
17-6	Polyprotic Acids	606
17-7	Ions as Acids and Bases	610
17-8	Molecular Structure and Acid-Base Behavior	614
17-9	Lewis Acids and Bases	619
	<i>Focus On Acid Rain</i>	622
	<i>Summary, 622 Summarizing Example, 623 Key Terms, 624</i>	
	<i>Review Questions, 624 Exercises, 625 Advanced Exercises, 628</i>	
18	ADDITIONAL ASPECTS OF ACID-BASE EQUILIBRIA	630
18-1	The Common-Ion Effect in Acid-Base Equilibria	632
18-2	Buffer Solutions	634
18-3	Acid-Base Indicators	644
18-4	Neutralization Reactions and Titration Curves	646
18-5	Solutions of Salts of Polyprotic Acids	653
18-6	Acid-Base Equilibrium Calculations: A Summary	655
	<i>Focus On Buffers in Blood</i>	656
	<i>Summary, 656 Summarizing Example, 657 Key Terms, 658</i>	
	<i>Review Questions, 658 Exercises, 659 Advanced Exercises, 662</i>	
19	SOLUBILITY AND COMPLEX-ION EQUILIBRIA	664
19-1	The Solubility Product Constant, K_{sp}	666
19-2	Relationship Between Solubility and K_{sp}	667
19-3	The Common-Ion Effect in Solubility Equilibria	669
19-4	Limitations of the K_{sp} Concept	671
19-5	Criteria for Precipitation and Its Completeness	673