General, Organic, and Biochemistry

Third Edition

Katherine J. Denniston
Towson University

Joseph J. Topping
Towson University

Robert L. Caret
San José State University

Boston Burr Ridge, IL Dubuque, IA Madison, WI New York San Francisco St. Louis
Bangkok Bogotá Caracas Lisbon London Madrid
Mexico City Milan New Delhi Seoul Singapore Sydney Taipei Toronto

McGraw-Hill Higher Education

A Division of The ***McGraw-Hill*** *Companies*

GENERAL, ORGANIC, AND BIOCHEMISTRY
THIRD EDITION

Published by McGraw-Hill, an imprint of The McGraw-Hill Companies, Inc., 1221 Avenue of the Americas, New York, NY 10020.

Some ancillaries, including electronic and print components, may not be available to customers outside the United States.

This book is printed on acid-free paper.

1 2 3 4 5 6 7 8 9 0 VNH/VNH 0 9 8 7 6 5 4 3 2 1 0

ISBN 0–07–231784–1
ISBN 0–07–118073–7 (ISE)

Vice president and editor-in-chief: *Kevin T. Kane*
Publisher: *James M. Smith*
Sponsoring editor: *Kent A. Peterson*
Developmental editor: *Shirley R. Oberbroeckling*
Editorial assistant: *Jennifer L. Bensink*
Senior marketing manager: *Martin J. Lange*
Senior marketing assistant: *Tami Petsche*
Senior project manager: *Marilyn M. Sulzer*
Production supervisor: *Sandy Ludovissy*
Design manager: *Stuart D. Paterson*
Cover/interior designer: *Elise Lansdon*
Cover image: *FPG International*
Senior photo research coordinator: *Lori Hancock*
Photo research: *Feldman and Associates*
Senior supplement coordinator: *Brenda A. Ernzen*
Compositor: *GAC—Indianapolis*
Typeface: *10/12 Palatino*
Printer: *Von Hoffman Press, Inc.*

The credits section for this book begins on page 823 and is considered an extension of the copyright page.

Library of Congress Cataloging-in-Publication Data

Denniston, K. J. (Katherine J.)
General, organic, and biochemistry / Katherine J. Denniston, Joseph J. Topping, Robert L. Caret. — 3rd ed.
p. ; cm.
Rev. ed. of : Principles & applications of organic & biological chemistry / Robert L. Caret, Katherine J. Denniston, Joseph J. Topping. 2nd ed. © 1997.
Includes index.
ISBN 0–07–231784–1
1. Chemistry, Organic. 2. Biochemistry. I. Topping, Joseph J. II. Caret, Robert L., 1947– . III. Caret, Robert L., 1947– Principles & applications of organic & biological chemistry. IV. Title.
[DNLM: 1. Chemistry. 2. Biochemistry. 3. Chemistry, Organic. QD 33 D411g 2001]
QD253 . C27 2001
547—dc21 99–088202
CIP

INTERNATIONAL EDITION ISBN 0–07–118073–7

www.mhhe.com

Brief Contents

General Chemistry

Organic Chemistry

Biochemistry

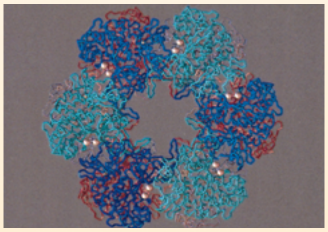
Contents

5 Calculations and the Chemical Equation 117

6 States of Matter: Gases, Liquids, and Solids 149

7 Reactions and Solutions 175

20 Enzymes 565



21 Carbohydrate Metabolism 599

Chemistry Connections and Perspectives

Chemistry Connection

A Human Perspective

A Clinical Perspective

A Medical Perspective

An Environmental Perspective

Preface

Ours is an age when an understanding of chemistry has become an increasingly important aspect of medicine. The third edition of *General, Organic, and Biochemistry* has been designed to help undergraduate health-related majors and students of all majors understand key concepts and appreciate the significant connections between chemistry, health, disease, and the treatment of disease. This text strikes a balance between theoretical and practical chemistry, while emphasizing material that is unique to health-related studies. It is written at a level intended for students whose professional goals do not include a mastery of chemistry, but for whom an understanding of the principles of chemistry and their practical ramifications is a necessity.

Key Changes to the Third Edition

In the preparation of the third edition, we have been guided by the collective wisdom of reviewers who represent the diversity of higher education experiences, including two-year and four-year colleges and universities. Over fifty different reviewers participated in the review process. We also received very valuable comments from a focus group of faculty who regularly teach this material.

New Organization

Recognizing that courses based on this textbook are organized in a variety of formats within both quarter and semester systems, we have reorganized the chapter sequence into three sections: inorganic chemistry (Chapters 1–10), organic chemistry (Chapters 11–16), and biochemistry (Chapters 17–24). The new organization will allow tremendous latitude in usage. The course may be taught in a traditional sense, following the new chapter order, within either the semester or quarter system. If you prefer the organization in the second edition, you may continue to teach using the different teaching order without affecting your students' understanding of the material. Many users of the second edition choose to integrate traditional organic and biochemistry and we have constructed the chapters to allow for alternate order of coverage. Frequent use of cross-referencing and reviewing of material discussed earlier in the book support this needed flexibility.

Clear Presentation

Today's students have numerous demands on their time. Many students are nontraditional students, working full time, who have families. Students need to be able to identify important concepts quickly and easily. Each section of the book was reviewed with the goal of becoming more concise while retaining the intellectual rigor of a college textbook. Some of the ways we have accomplished this goal include:

- **New design** facilitates access to information and engages student interest.
- **Key terms** are bolded and are immediately defined.
- **In-chapter examples** provide stepwise guidance to problem-solving strategies.
- **New tables** were created allowing easier access to information.
- **More headings** allow students to find important material faster.

Key Features of the Third Edition

Engaging Applications

We believe that there are a variety of factors in a text that can promote student learning and facilitate teaching. It is important to engage the interest of the student, especially when the subject may appear difficult and does not seem directly related to the student's career goals. We have included a diverse array of applications to accomplish our goals.

- **Perspectives:** We have added eleven new Clinical, Medical, and Human Perspectives throughout the book. A list of Chemistry Connections and Perspectives is provided on page xviii. These provide new and updated applications of chemistry to engage the students' interest and help them understand chemistry in the context of their daily lives.

- **Learning goal icons** 1 : These icons help to alert the student to the important concepts covered in the text. An icon is placed next to the textual material that supports the learning goal.

Supplementary Materials

Supplements

This text has a complete support package for instructors and students. Several print and media supplements have been prepared to accompany the text and make learning as meaningful and up-to-date as possible.

For the Instructor:

1. **Instructor's Manual:** The Instructor's Manual contains the printed test item file and solutions to the even-numbered problems. Written by the authors, this ancillary also contains suggestions for organizing lectures, additional "Perspectives," and a list of each chapter's key problems and concepts.
2. **Transparencies:** A set of 100 transparencies is available to help the instructor coordinate the lecture with key illustrations from the text.
3. **Computerized Test Bank:** This computerized classroom management system/service includes a database of test questions, reproducible student self-quizzes, and a grade-recording program. Disks are available for IBM and Macintosh computers, and require no programming experience.
4. **Laboratory Resource Guide:** This helpful prep guide contains the hints that the authors have learned over the years to ensure students' success.
5. **Book-Specific Website:** A book-specific website is available to students and instructors using this text. The website will offer quizzes, key definitions, and interesting links for the students. The instructor will find a downloadable version of the Test Bank, the transparencies in a PowerPoint Presentation, the Instructor's Manual, and Solutions Manual. Also available for the instructor is PageOut, which allows the instructor to create his or her own personal course website. The address for the book-specific website is http://www.mhhe.com/physsci/chemistry/denniston.

For the Students:

1. **Student Study Guide/Solutions Manual:** A separate Student Study Guide/Solutions Manual is available. It contains the answers and complete solutions for the odd-numbered problems. It also offers students a variety of exercises and keys for testing their comprehension of basic, as well as difficult, concepts.
2. **Laboratory Manual:** Written by Charles H. Henrickson, Larry C. Byrd, and Norman W. Hunter, all of Western Kentucky University, *Experiments in General, Organic, and Biochemistry,* carefully and safely guides students through the process of scientific inquiry. The manual features self-contained experiments that can easily be reorganized to suit individual course needs.
3. **Is Your Math Ready for Chemistry?** Developed by Walter Gleason of Bridgewater State College, this unique booklet provides a diagnostic test that measures the student's math ability. Part II of the booklet provides helpful hints in the math skills needed to successfully complete a chemistry course.
4. **Problem Solving Guide to General Chemistry:** Written by Ronald DeLorenzo of Middle Georgia College, this exceptional supplement provides the student with over 2500 problems and questions. The guide holds the student's interest by integrating the solution of chemistry problems with real-life applications, analogies, and anecdotes.
5. **Schaum's Outline of General, Organic, and Biological Chemistry:** Written by George Odian and Ira Blei, this supplement provides students with over 1400 solved problems with complete solutions. It also teaches effective problem-solving techniques.
6. **How to Study Science:** Written by Fred Drewes of Suffolk County Community College, this excellent workbook offers students helpful suggestions for meeting the considerable challenges of a science course. It offers tips on how to take notes and how to overcome science anxiety. The book's unique design helps to stir critical thinking skills, while facilitating careful note taking on the part of the student.
7. **Book-Specific Website:** A book-specific website is available to students and instructors using this text. The website will offer quizzes, key definitions, and interesting links for the students. The address for the book-specific website is http://www.mhhe.com/physsci/chemistry/denniston.

Acknowledgements

We are grateful to our families, whose patience and support made it possible for us to undertake this project. We are grateful to our colleagues at McGraw-Hill, especially Jim Smith, publisher, and Kent Peterson, sponsoring editor, for their support of our book. We would like to thank Shirley Oberbroeckling, developmental editor, for her guidance during the reviewing and writing process. We also would like to express our appreciation to Marilyn Sulzer, project manager, for her skilled assistance throughout production.

A revision cannot move forward without the feedback of professors teaching the course. The reviewers have our gratitude and assurance that their comments received serious consideration.

The following professors provided reviews, participated in a focus group, or gave valuable advice for the preparation of the third edition:

Hugh Akers, *Lamar University*
Catherine A. Anderson, *San Antonio College*
A. G. Andrewes, *Saginaw Valley State University*
Mark A. Benvenuto, *University of Detroit-Mercy*
Warren L. Bosch, *Elgin Community College*
James R. Braun, *Clayton College and State University*
Philip A. Brown, *Barton College*
Teresa L. Brown, *Rochester Community College*
Scott Carr, *Trinity Christian College*
Bernadette Corbett, *Metropolitan Community College*
Wayne B. Counts, *Georgia Southwestern State University*
Robert P. Dixon, *Southern Illinois University*
Wes Fritz, *College of DuPage*
Edwin J. Geels, *Dordt College*
Deepa Godambe, *William Rainey Harper College*
Judith M. Iriarte-Gross, *Middle Tennessee State University*
T. G. Jackson, *University of South Alabama*
Paul G. Johnson, *Duquesne University*
Warren Johnson, *University of Wisconsin-Green Bay*
James F. Kirby, *Quinnipiac College*
Roscoe E. Lancaster, *Golden West College*
Richard H. Langley, *Stephen F. Austin State University*
Julie E. Larson, *Bemidji State University*
K. W. Loach, *Plattsburgh State University*
Ralph Martinez, *Humboldt State University*
John Mazzella, *William Paterson University*
Lawrence McGahey, *College of St. Scholastica*
Cleon McKnight, *Hinds Community College*
Melvin Merken, *Worcester State College*
Robert Midden, *Bowling Green State University*
David Millsap, *South Plains College*
Ellen M. Mitchell, *Bridgewater College*
Jay Mueller, *Green River Community College*
Lynda P. Nelson, *Westark College*
Richard E. Parent, *Housatonic Community Technical College*
Chetna Patel, *Aurora University*
Jeffrey A. Rahn, *Eastern Washington University*
B. R. Ramachandran, *Indiana State University*
John W. Reasoner, *Western Kentucky University*
Rill Ann Reuter, *Winona State University*
Terry Salerno, *Minnesota State University-Mankato*
Karen Sanchez, *Florida Community College at Jacksonville*
Sarah Selfe, *University of Washington*
Kevin R. Siebenlist, *Marquette University*
Steven M. Socal, *Southern Utah University*
Gordon Sproul, *University of South Carolina-Beaufort*
Pratibha Varma-Nelson, *Saint Xavier University*
Robert T. Wang, *Salem State University*
Steven Weitstock, *Indiana University*
Catherine Woytowicz, *Loyola University*
Jesse Yeh, *South Plains College*
Edward P. Zovinka, *St. Francis College*

The following professors provided reviews and other valuable advice for the previous editions:

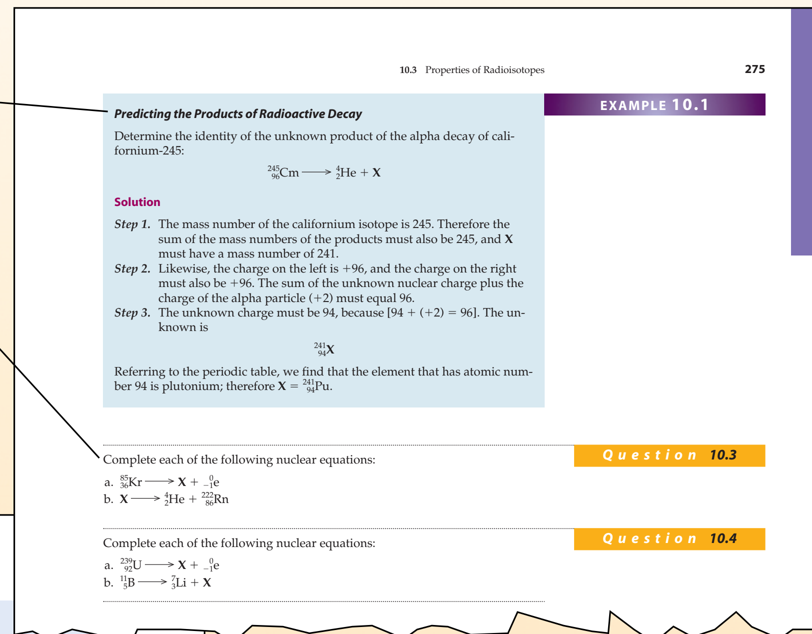
Raymond D. Baechler, *Russell Sage College*
Satinder Bains, *Arkansas State University-Beebe*
Sister Marjorie Baird, O.P., *West Virginia Northern Community College*
Ronald Bost, *North Central Texas College*
Fred Brohn, *Oakland Community College*
Sister Helen Burke, *Chestnut Hill College*
Sharmaine S. Cady, *East Stroudsburg University*
Robert C. Costello, *University of South Carolina-Sumter*
Marianne Crocker, *Ozarks Technical Community College*
Peter DiMaria, *Delaware State University*
Ronald Dunsdon, *Iowa Central Community College*
Donald R. Evers, *Iowa Central Community College*
Patrick Flash, *Kent State University-Ashtabula*

The *General, Organic, and Biochemistry* Learning System

The *General, Organic, and Biochemistry* Learning System is easy to follow, and will allow the student to excel in this course. The materials are presented in such a way that the student will effectively learn and retain the important information.

Clear Approach to Solving Problems

Because problem solving is most efficiently learned by a combination of studying examples and practicing, problems with step-by-step solutions are provided wherever appropriate. Examples are followed by a question requiring the student to integrate the newly learned material.



10.3 Properties of Radioisotopes 275

EXAMPLE 10.1

Predicting the Products of Radioactive Decay

Determine the identity of the unknown product of the alpha decay of californium-245:

$$^{245}_{96}\text{Cm} \longrightarrow {}^{4}_{2}\text{He} + \mathbf{X}$$

Solution

Step 1. The mass number of the californium isotope is 245. Therefore the sum of the mass numbers of the products must also be 245, and **X** must have a mass number of 241.

Step 2. Likewise, the charge on the left is +96, and the charge on the right must also be +96. The sum of the unknown nuclear charge plus the charge of the alpha particle (+2) must equal 96.

Step 3. The unknown charge must be 94, because [94 + (+2) = 96]. The unknown is

$$^{241}_{94}\mathbf{X}$$

Referring to the periodic table, we find that the element that has atomic number 94 is plutonium; therefore $\mathbf{X} = {}^{241}_{94}\text{Pu}$.

Question 10.3

Complete each of the following nuclear equations:

a. $^{85}_{36}\text{Kr} \longrightarrow \mathbf{X} + {}^{0}_{-1}\text{e}$

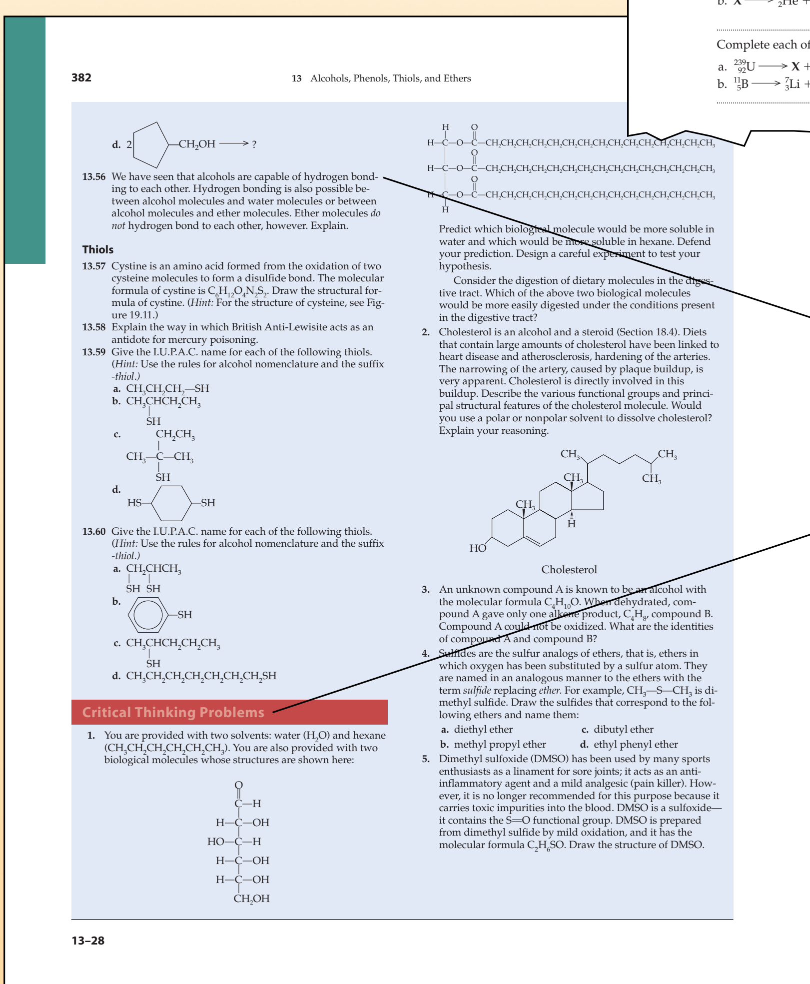
b. $\mathbf{X} \longrightarrow {}^{4}_{2}\text{He} + {}^{222}_{86}\text{Rn}$

Question 10.4

Complete each of the following nuclear equations:

a. $^{239}_{92}\text{U} \longrightarrow \mathbf{X} + {}^{0}_{-1}\text{e}$

b. $^{11}_{5}\text{B} \longrightarrow {}^{7}_{3}\text{Li} + \mathbf{X}$



382 13 Alcohols, Phenols, Thiols, and Ethers

d. 2 (cyclopentyl)$-CH_2OH \longrightarrow$?

13.56 We have seen that alcohols are capable of hydrogen bonding to each other. Hydrogen bonding is also possible between alcohol molecules and water molecules or between alcohol molecules and ether molecules. Ether molecules *do not* hydrogen bond to each other, however. Explain.

Thiols

13.57 Cystine is an amino acid formed from the oxidation of two cysteine molecules to form a disulfide bond. The molecular formula of cystine is $C_6H_{12}O_4N_2S_2$. Draw the structural formula of cystine. (*Hint:* For the structure of cysteine, see Figure 19.11.)

13.58 Explain the way in which British Anti-Lewisite acts as an antidote for mercury poisoning.

13.59 Give the I.U.P.A.C. name for each of the following thiols. (*Hint:* Use the rules for alcohol nomenclature and the suffix *-thiol.*)

a. $CH_3CH_2CH_2-SH$

b. $CH_3CH(SH)CH_2CH_3$

c. $CH_3-C(CH_2CH_3)(SH)-CH_3$

d. HS–(cyclohexane)–SH

13.60 Give the I.U.P.A.C. name for each of the following thiols. (*Hint:* Use the rules for alcohol nomenclature and the suffix *-thiol.*)

a. $CH_2(SH)CH(SH)CH_3$

b. (benzene)–SH

c. $CH_3CH(SH)CH_2CH_2CH_3$

d. $CH_3CH_2CH_2CH_2CH_2CH_2CH_2SH$

Critical Thinking Problems

1. You are provided with two solvents: water (H_2O) and hexane ($CH_3CH_2CH_2CH_2CH_2CH_3$). You are also provided with two biological molecules whose structures are shown here:

Predict which biological molecule would be more soluble in water and which would be more soluble in hexane. Defend your prediction. Design a careful experiment to test your hypothesis.

Consider the digestion of dietary molecules in the digestive tract. Which of the above two biological molecules would be more easily digested under the conditions present in the digestive tract?

2. Cholesterol is an alcohol and a steroid (Section 18.4). Diets that contain large amounts of cholesterol have been linked to heart disease and atherosclerosis, hardening of the arteries. The narrowing of the artery, caused by plaque buildup, is very apparent. Cholesterol is directly involved in this buildup. Describe the various functional groups and principal structural features of the cholesterol molecule. Would you use a polar or nonpolar solvent to dissolve cholesterol? Explain your reasoning.

Cholesterol

3. An unknown compound A is known to be an alcohol with the molecular formula $C_4H_{10}O$. When dehydrated, compound A gave only one alkene product, C_4H_8, compound B. Compound A could not be oxidized. What are the identities of compound A and compound B?

4. Sulfides are the sulfur analogs of ethers, that is, ethers in which oxygen has been substituted by a sulfur atom. They are named in an analogous manner to the ethers with the term *sulfide* replacing *ether.* For example, CH_3-S-CH_3 is dimethyl sulfide. Draw the sulfides that correspond to the following ethers and name them:

a. diethyl ether
b. methyl propyl ether
c. dibutyl ether
d. ethyl phenyl ether

5. Dimethyl sulfoxide (DMSO) has been used by many sports enthusiasts as a linament for sore joints; it acts as an anti-inflammatory agent and a mild analgesic (pain killer). However, it is no longer recommended for this purpose because it carries toxic impurities into the blood. DMSO is a sulfoxide—it contains the S=O functional group. DMSO is prepared from dimethyl sulfide by mild oxidation, and it has the molecular formula C_2H_6SO. Draw the structure of DMSO.

13–28

A variety of questions and problems that range in level of difficulty help students measure their mastery of the chapter material. The odd-numbered questions are answered in the back of the text.

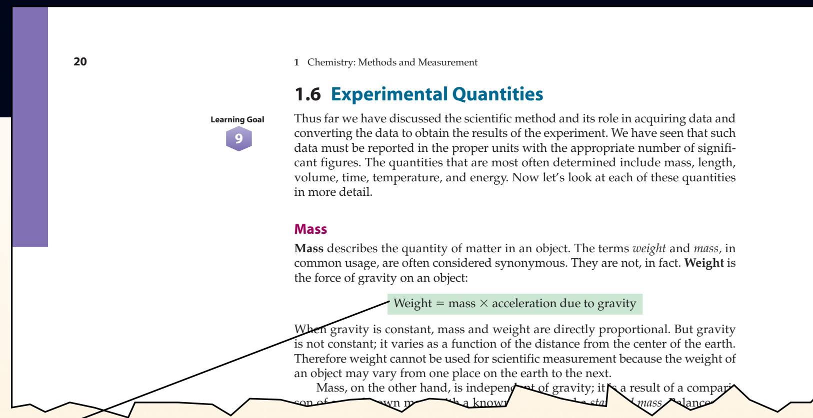
At the end of the chapter, the student will find several problems that require thought-provoking answers dealing with daily life and the health care sciences.

◀ | ▶ | e-Text Main Menu | Textbook Table of Contents | Study Guide Table of Contents

Dynamic Visuals

Many of the equations and reactions are color coded to help the student understand the chemical changes that occur in complex reactions. The student can easily recognize the chemical groups being added or removed in a reaction by the color coding. Green background illustrates an important equation or key reaction; yellow background illustrates energy in the general and biochemistry sections and reveals the parent chain of a compound in the organic section; red and blue lettering distinguish two or more compounds that appear similar.

The art program has been significantly updated with the use of molecular art and drawings. The students will gain a better perspective and understanding of a molecule with a Spartan computer-generated model.


20 1 Chemistry: Methods and Measurement

1.6 Experimental Quantities

Learning Goal 9

Thus far we have discussed the scientific method and its role in acquiring data and converting the data to obtain the results of the experiment. We have seen that such data must be reported in the proper units with the appropriate number of significant figures. The quantities that are most often determined include mass, length, volume, time, temperature, and energy. Now let's look at each of these quantities in more detail.

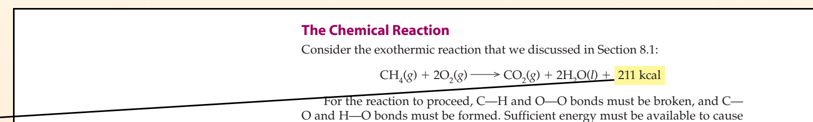
Mass

Mass describes the quantity of matter in an object. The terms *weight* and *mass*, in common usage, are often considered synonymous. They are not, in fact. **Weight** is the force of gravity on an object:

Weight = mass × acceleration due to gravity

When gravity is constant, mass and weight are directly proportional. But gravity is not constant; it varies as a function of the distance from the center of the earth. Therefore weight cannot be used for scientific measurement because the weight of an object may vary from one place on the earth to the next.

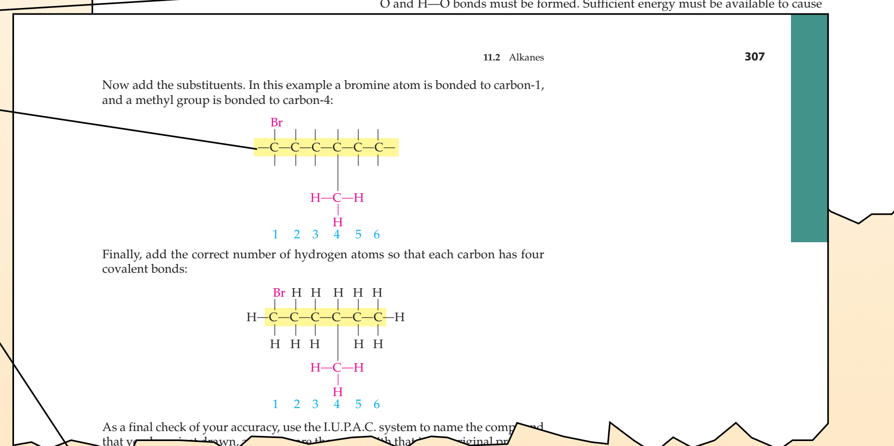
Mass, on the other hand, is independent of gravity; it is a result of a compari...


The Chemical Reaction

Consider the exothermic reaction that we discussed in Section 8.1:

$$CH_4(g) + 2O_2(g) \longrightarrow CO_2(g) + 2H_2O(l) + 211\ kcal$$

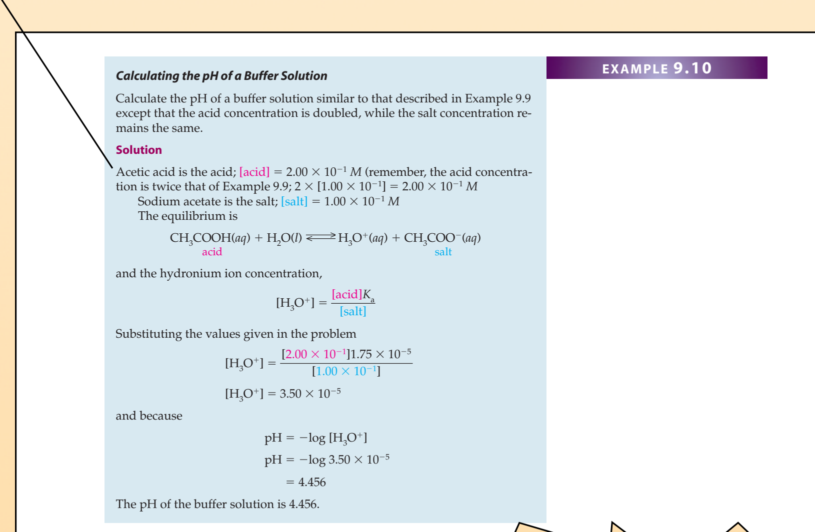
For the reaction to proceed, C—H and O—O bonds must be broken, and C—O and H—O bonds must be formed. Sufficient energy must be available to cause


11.2 Alkanes 307

Now add the substituents. In this example a bromine atom is bonded to carbon-1, and a methyl group is bonded to carbon-4:

Finally, add the correct number of hydrogen atoms so that each carbon has four covalent bonds:

As a final check of your accuracy, use the I.U.P.A.C. system to name the compound that you have drawn...


EXAMPLE 9.10

Calculating the pH of a Buffer Solution

Calculate the pH of a buffer solution similar to that described in Example 9.9 except that the acid concentration is doubled, while the salt concentration remains the same.

Solution

Acetic acid is the acid; [acid] = 2.00×10^{-1} *M* (remember, the acid concentration is twice that of Example 9.9; 2 × [1.00×10^{-1}] = 2.00×10^{-1} *M*)

Sodium acetate is the salt; [salt] = 1.00×10^{-1} *M*

The equilibrium is

$$\underset{acid}{CH_3COOH(aq)} + H_2O(l) \rightleftharpoons H_3O^+(aq) + \underset{salt}{CH_3COO^-(aq)}$$

and the hydronium ion concentration,

$$[H_3O^+] = \frac{[acid]K_a}{[salt]}$$

Substituting the values given in the problem

$$[H_3O^+] = \frac{[2.00 \times 10^{-1}]1.75 \times 10^{-5}}{[1.00 \times 10^{-1}]}$$

$$[H_3O^+] = 3.50 \times 10^{-5}$$

and because

$$pH = -\log [H_3O^+]$$
$$pH = -\log 3.50 \times 10^{-5}$$
$$= 4.456$$

The pH of the buffer solution is 4.456.

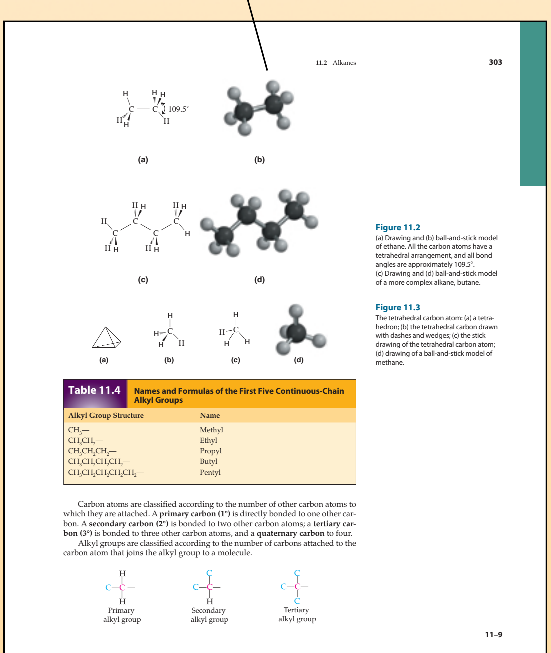

11.2 Alkanes 303

Figure 11.2 (a) Drawing and (b) ball-and-stick model of ethane. All the carbon atoms have a tetrahedral arrangement, and all bond angles are approximately 109.5°. (c) Drawing and (d) ball-and-stick model of a more complex alkane, butane.

Figure 11.3 The tetrahedral carbon atom: (a) a tetrahedron; (b) the tetrahedral carbon drawn with dashes and wedges; (c) the stick drawing of the tetrahedral carbon atom; (d) drawing of a ball-and-stick model of methane.

Table 11.4 Names and Formulas of the First Five Continuous-Chain Alkyl Groups

Alkyl Group Structure	Name
CH_3—	Methyl
CH_3CH_2—	Ethyl
$CH_3CH_2CH_2$—	Propyl
$CH_3CH_2CH_2CH_2$—	Butyl
$CH_3CH_2CH_2CH_2CH_2$—	Pentyl

Carbon atoms are classified according to the number of other carbon atoms to which they are attached. A **primary carbon (1°)** is directly bonded to one other carbon. A **secondary carbon (2°)** is bonded to two other carbon atoms; a **tertiary carbon (3°)** is bonded to three other carbon atoms, and a **quaternary carbon** to four.

Alkyl groups are classified according to the number of carbons attached to the carbon atom that joins the alkyl group to a molecule.

Primary alkyl group Secondary alkyl group Tertiary alkyl group

11-9

◀ | ▶ | e-Text Main Menu | Textbook Table of Contents | Study Guide Table of Contents

Health/Life Related Applications

There are four different Perspective boxes in the text. Chemistry Connections provides an introductory scenario for the chapter, Medical Perspective and Clinical Perspective demonstrate use of the chapter material in an allied health field, Environmental Perspective demonstrates chapter concepts in ecological problems, and Human Perspective demonstrates how important chemistry is in our day to day lives.


144 5 Calculations and the Chemical Equation

A MEDICAL PERSPECTIVE

Pharmaceutical Chemistry: The Practical Significance of Percent Yield

In recent years the major pharmaceutical industries have introduced a wide variety of new drugs targeted to cure or alleviate the symptoms of a host of diseases that afflict humanity.

The vast majority of these drugs are synthetic; they are made in a laboratory or by an industrial process. These substances are complex molecules that are patiently designed and constructed from relatively simple molecules in a series of chemical reactions. A series of ten to twenty "steps," or sequential reactions, is not unusual to put together a final product that has the proper structure, geometry, and reactivity for efficacy against a particular disease.

Although a great deal of research occurs to ensure that each of these steps in the overall process is efficient (having a large percent yield), the overall process is still very inefficient (low percent yield). This inefficiency, and the research needed to minimize it, at least in part determines the cost and availability of both prescription and over-the-counter preparations.

Consider a hypothetical five-step sequential synthesis. If each step has a percent yield of 80% our initial impression might be that this synthesis is quite efficient. However, on closer inspection we find quite the contrary to be true.

The overall yield of the five-step reaction is the product of the decimal fraction of the percent yield of each of the sequential reactions. So, if the decimal fraction corresponding to 80% is 0.80:

$$0.80 \times 0.80 \times 0.80 \times 0.80 \times 0.80 = 0.33$$

Converting the decimal fraction to percentage:

$$0.33 \times 100\% = 33\% \text{ yield}$$

Many reactions are considerably less than 80% efficient, especially those that are used to prepare large molecules with complex arrangements of atoms. Imagine a more realistic scenario in which one step is only 20% efficient (a 20% yield) and the other four steps are 50%, 60%, 70%, and 80% efficient. Repeating the calculation with these numbers (after conversion to a decimal fraction):

$$0.20 \times 0.50 \times 0.60 \times 0.70 \times 0.80 = 0.0336$$

Converting the decimal fraction to a percentage:

$$0.0336 \times 100\% = 3.36\% \text{ yield}$$

a very inefficient process.

If we apply this logic to a fifteen- or twenty-step synthesis we gain some appreciation of the difficulty of producing modern pharmaceutical products. Add to this the challenge of predicting the most appropriate molecular structure that will have the desired biological effect and be relatively free of side effects. All these considerations give new meaning to the term *wonder drug* that has been attached to some of the more successful synthetic products.

We will study some of the elementary steps essential to the synthesis of a wide range of pharmaceutical compounds in later chapters, beginning with Chapter 11.

Summary

5.1 The Mole Concept an

5-28


156 6 States of Matter: Gases, Liquids, and Solids

A CLINICAL PERSPECTIVE

Autoclaves and the Gas Laws

Jacques Charles and Joseph Gay-Lussac were eighteenth-century chemists and physicists. They were also balloon enthusiasts. It is clear that their hobby and their scientific pursuits were intertwined. Charles's law is actually attributed to the work of both men. The observation that the pressure and temperature of a gas are directly proportional

$$P \propto T$$

follows directly from Charles's law and Boyle's law. The equality

$$P = kT$$

is often termed *Gay-Lussac's law*. You can readily verify this proportionality by observing the fate of a balloon when it is heated or cooled (try putting an inflated balloon in the refrigerator, remove it, and allow it to return to room temperature).

A very practical application of Gay-Lussac's law is the autoclave, a piece of equipment commonly found in hospital, clinical, and biological laboratories. It is designed and used to sterilize laboratory materials such as glassware, surgical instruments, and so forth. It uses steam at high temperatures and pressures and takes advantage of the exceptionally high heat capacity (energy storage capability) of steam.

The autoclave kills microorganisms by using the heat energy in steam. However, steam has a temperature of 100°C at normal atmospheric pressure; this temperature is too low (insufficient energy) to kill all harmful bacteria. Gay-Lussac's law predicts that, at a constant volume (the volume of the autoclave), if the steam is heated further, both the pressure and temperature of the steam will increase. At the maximum safe operating pressure of the autoclave, temperatures may reach as much as 150°C; when maintained for a sufficient interval, this temperature is sufficiently high to kill most microorganisms.

Question 6.6

A sample of nitrogen gas has a volume of 3.00 L at 25°C. What volume will it occupy at each of the following temperatures if the pressure and number of moles are constant?

a. 546 K b. 0.00°C c. 373 K

Figure 6.4
Charles's law predicts that the volume of air in the balloon will increase when heated. We assume that the volume of the balloon is fixed; consequently, some air will be pushed out. The air remaining in the balloon is less dense (same volume, less mass) and the balloon will rise. When the heater is turned off the air cools, the density increases, and the balloon returns to earth.

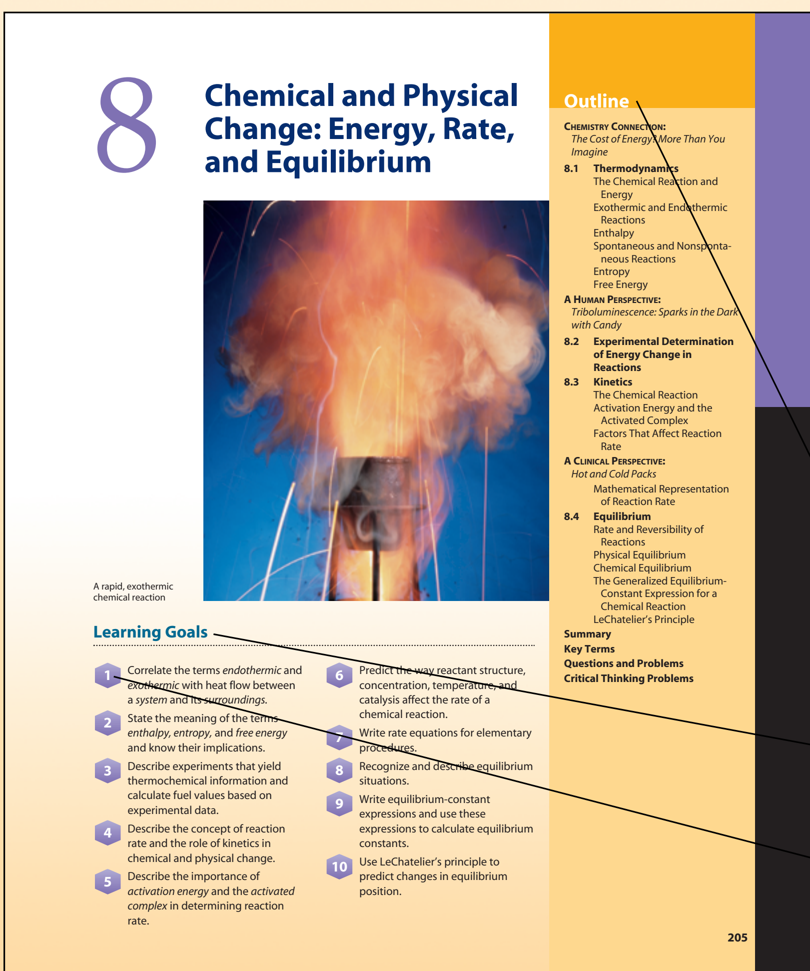
The behavior of a hot-air balloon is a commonplace consequence of Charles's law. The balloon rises because air expands when heated (Figure 6.4). The volume of the balloon is fixed because the balloon is made of an inelastic material; as a result, when the air expands some of the air must be forced out. Hence the density of the remaining air is less (less mass contained in the same volume), and the balloon rises. Turning down the heat reverses the process, and the balloon descends.

Boyle's law describes the inverse proportional relationship between volume and pressure; Charles's law shows the direct proportional relationship between volume and temperature.

Combined Gas Law

Often, a sample of gas (a fixed number of moles of gas) undergoes change involving volume, pressure, and temperature simultaneously. It would be useful to have one equation that describes such processes.

6–8


8 **Chemical and Physical Change: Energy, Rate, and Equilibrium**

A rapid, exothermic chemical reaction

Outline

CHEMISTRY CONNECTION: *The Cost of Energy? More Than You Imagine*

8.1 **Thermodynamics**
The Chemical Reaction and Energy
Exothermic and Endothermic Reactions
Enthalpy
Spontaneous and Nonspontaneous Reactions
Entropy
Free Energy

A HUMAN PERSPECTIVE: *Triboluminescence: Sparks in the Dark with Candy*

8.2 **Experimental Determination of Energy Change in Reactions**

8.3 **Kinetics**
The Chemical Reaction
Activation Energy and the Activated Complex
Factors That Affect Reaction Rate

A CLINICAL PERSPECTIVE: *Hot and Cold Packs*
Mathematical Representation of Reaction Rate

8.4 **Equilibrium**
Rate and Reversibility of Reactions
Physical Equilibrium
Chemical Equilibrium
The Generalized Equilibrium-Constant Expression for a Chemical Reaction
LeChatelier's Principle

Summary
Key Terms
Questions and Problems
Critical Thinking Problems

Learning Goals

1. Correlate the terms *endothermic* and *exothermic* with heat flow between a *system* and its *surroundings*.
2. State the meaning of the terms *enthalpy*, *entropy*, and *free energy* and know their implications.
3. Describe experiments that yield thermochemical information and calculate fuel values based on experimental data.
4. Describe the concept of reaction rate and the role of kinetics in chemical and physical change.
5. Describe the importance of *activation energy* and the *activated complex* in determining reaction rate.
6. Predict the way reactant structure, concentration, temperature, and catalysis affect the rate of a chemical reaction.
7. Write rate equations for elementary processes.
8. Recognize and describe equilibrium situations.
9. Write equilibrium-constant expressions and use these expressions to calculate equilibrium constants.
10. Use LeChatelier's principle to predict changes in equilibrium position.

205

Clear Presentation

Each chapter begins with an outline that introduces students to the topics to be presented. This outline also provides the instructor with a quick topic summary to organize lecture material.

A list of learning goals, based on the major concepts covered in the chapter, enables students to preview the material and become aware of the topics they are expected to master.

This icon is found within the chapters wherever the associated learning goal is first presented, allowing the student to focus attention on the major concepts.

Because k_2 is a constant, we may equate them, resulting in

$$\frac{V_i}{T_i} = \frac{V_f}{T_f}$$

and use this expression to solve some practical problems.

Consider a gas occupying a volume of 10.0 L at 273 K. The ratio V/T is a constant, k_2. Doubling the temperature, to 546 K, increases the volume to 20.0 L as shown here:

Appendix A contains a review of the mathematics used here.

$$\frac{10.0\ \text{L}}{273\ \text{K}} = \frac{V_f}{546\ \text{K}}$$

$$V_f = 20.0\ \text{L}$$

Tripling the temperature, to 819 K, increases the volume by a factor of 3:

$$\frac{10.0\ \text{L}}{273\ \text{K}} = \frac{V_f}{819\ \text{K}}$$

Summary

13.1 Alcohols: Structure and Physical Properties

Alcohols are characterized by the *hydroxyl group (—OH)* and have the general formula R—OH. They are very polar, owing to the polar hydroxyl group, and are able to form intermolecular hydrogen bonds. Because of hydrogen bonding between alcohol molecules, they have higher boiling points than hydrocarbons of comparable molecular weight. The smaller alcohols are very water soluble.

13.2 Alcohols: Nomenclature

In the I.U.P.A.C. system, alcohols are named by determining the parent compound and replacing the *-e* ending with *-ol*. The chain is numbered to give the hydroxyl group the lowest possible number. Common names are derived from the alkyl group corresponding to the parent compound.

13.3 Medically Important Alcohols

Methanol is a toxic alcohol that is used as a solvent. Ethanol is the alcohol consumed in beer, wine, and distilled liquors. Isopropanol is used as a disinfectant. Ethylene glycol (1,2-ethanediol) is used as antifreeze, and glycerol (1,2,3-propanetriol) is used in cosmetics and pharmaceuticals.

13.4 Classification of Alcohols

Alcohols may be classified as *primary, secondary,* or *tertiary,* depending on the number of alkyl groups attached to the *carbinol* carbon, the carbon bearing the hydroxyl group. A primary alcohol has a single alkyl group bonded to the *carbinol carbon*. Secondary and tertiary alcohols have two and three alkyl groups, respectively.

13.5 Reactions Involving Alcohols

Alcohols can be prepared by the *hydration* of alkenes. Alcohols can undergo *dehydration* to yield alkenes. Primary and secondary alcohols undergo oxidation reactions to yield aldehydes and ketones, respectively. Tertiary alcohols do not undergo oxidation.

13.6 Oxidation and Reduction in Living Systems

In organic and biological systems *oxidation* involves the gain of oxygen or loss of hydrogen. *Reduction* involves the loss of oxygen or gain of hydrogen. Nicotinamide adenine dinucleotide, NAD^+, is a coenzyme involved in many biological oxidation and reduction reactions.

13.7 Phenols

Phenols are compounds in which the hydroxyl group is attached to a benzene ring; they have the general formula Ar—OH. Many phenols are important as antiseptics and disinfectants.

13.8 Ethers

Ethers are characterized by the R—O—R functional group. Ethers are generally nonreactive but are extremely flammable. Diethyl ether was the first general anesthetic used in medical practice. It has since been replaced by penthrane and enthrane, which are less flammable.

13.9 Thiols

Thiols are characterized by the sulfhydryl group (—SH). The amino acid cysteine is a thiol that is extremely important for maintaining the correct shapes of proteins. Coenzyme A is a thiol that serves as a "carrier" of acetyl groups in biochemical reactions.

Key Terms

alcohol (13.1)
carbinol carbon (13.4)
dehydration (13.5)
disulfide (13.9)
elimination reaction (13.5)
ether (13.8)
fermentation (13.3)
hydration (13.5)
hydroxyl group (13.1)
oxidation (13.6)
phenol (13.7)
primary (1°) alcohol (13.4)
reduction (13.6)
secondary (2°) alcohol (13.4)
tertiary (3°) alcohol (13.4)
thiol (13.9)
Zaitsev's rule (13.5)

Questions and Problems

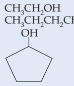
Alcohols: Structure and Physical Properties

13.11 Arrange the following compounds in order of increasing boiling point, beginning with the lowest:

a. $CH_3CH_2CH_2CH_2CH_3$
b. $CH_3CH(OH)CH_2CH(OH)CH_3$
c. $CH_3CH(OH)CH_2CH_2CH_3$
d. $CH_3CH_2CH_2—O—CH_2CH_3$

13.12 Why do alcohols have higher boiling points than alkanes? Why are small alcohols readily soluble in water whereas large alcohols are much less soluble?

13.13 Which member of each of the following pairs is more soluble in water?

a. CH_3CH_2OH or $CH_3CH_2CH_2CH_2OH$
b. $CH_3CH_2CH_2CH_2CH_3$ or $CH_3CH_2CH_2CH_2—OH$
c.  or $CH_3CH(OH)CH_3$

Media