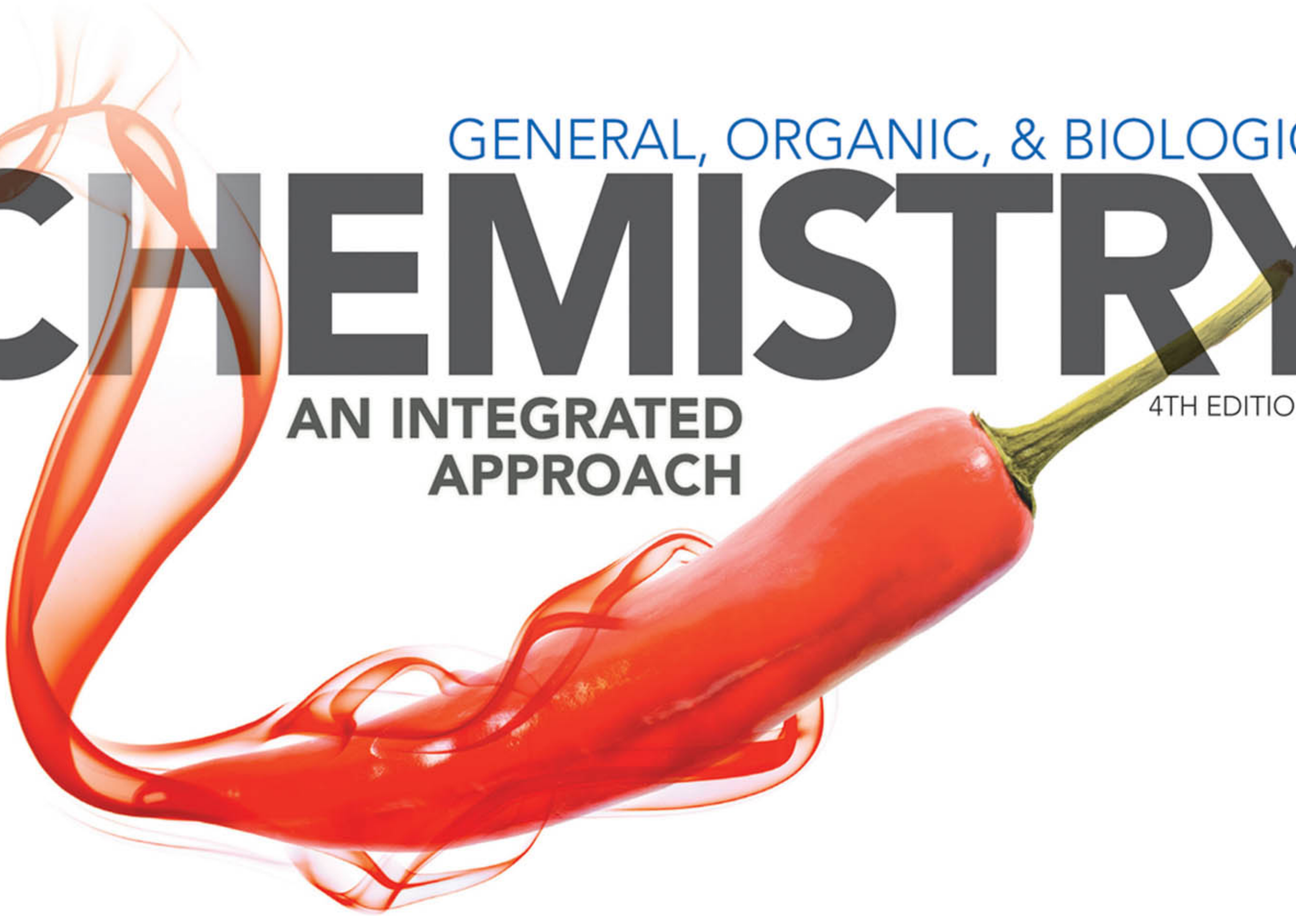
GENERAL, ORGANIC, & BIOLOGICAL

CHEMISTRY

AN INTEGRATED APPROACH

4TH EDITION



KENNETH W. RAYMOND

QUICK REFERENCE GUIDE

ACIDS AND BASES

AMINO ACIDS, PROTEINS, AND ENZYMES

ATOMS

BONDING

CARBOHYDRATES

ENERGY

GASES, LIQUIDS, AND SOLIDS

HEALTH

IONS AND IONIC COMPOUNDS

LIPIDS

MATH

NUCLEIC ACIDS

ORGANIC COMPOUNDS

RADIOACTIVITY

CONVERSION FACTORS

Mass

1 kilogram	= 1000 grams
	= 2.205 pounds
1 pound	= 453.59 grams
	= 16 ounces
1 milligram	= 1000 micrograms
1 grain	= 65 milligrams
1 ounce	= 28.3 grams

Length

1 meter	= 1000 millimeters
	= 3.281 feet
	= 39.37 inches
1 kilometer	= 0.621 mile
1 mile	= 1.609 kilometers
	= 5280 feet
1 inch	= 2.54 centimeters

Volume

1 liter	= 1000 milliliters
	= 1.057 quarts
1 quart	= 0.946 liter
1 gallon	= 3.785 liters
1 milliliter	= 1 centimeter^3
	= 1 cubic centimeter
	= 15 drops
1 teaspoon	= 5 milliliters
1 tablespoon	= 15 milliliters
	= 0.5 fluid ounces

Energy

1 calorie	= 4.184 joule
1 joule	= 0.2390 calorie

Temperature

K	= °C + 273.15
0 K	= −273.15 °C
	= −459.67°F
°C	$= \frac{°F-32}{1.8}$
0°C	= 273.15K
	= 32°F
°F	= (1.8 × °C) + 32

Pressure

1 atmosphere	= 14.7 pounds per square inch
	= 760 torr
	= 760 millimeters Hg

SI AND METRIC PREFIXES

Prefix	Symbol	Multiplier	
giga	G	1,000,000,000	$= 10^9$
mega	M	1,000,000	$= 10^6$
kilo	k	1,000	$= 10^3$
hecto	h	100	$= 10^2$
deka	da	10	$= 10^1$
		1	$= 10^0$
deci	d	0.1	$= 10^{-1}$
centi	c	0.01	$= 10^{-2}$
milli	m	0.001	$= 10^{-3}$
micro	μ	0.000001	$= 10^{-6}$
nano	n	0.000000001	$= 10^{-9}$
pico	p	0.000000000001	$= 10^{-12}$

GENERAL, ORGANIC, AND BIOLOGICAL CHEMISTRY

An Integrated Approach

FOURTH EDITION

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WILEY

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PREFACE

This fourth edition of *General, Organic, and Biological Chemistry: An Integrated Approach* has, like the earlier editions, been written for students preparing for careers in health-related fields such as nursing, dental hygiene, nutrition, occupational therapy, athletic training, and medical technology. The text is also suitable for students majoring in other fields where it is important to have an understanding of chemistry and its relationship to living things. Students who use this text do not need to have a previous background in chemistry but should possess basic math skills. For those whose math is a bit rusty, the text provides reviews of the important material. While designed for use in one-semester or two quarter General, Organic, and Biochemistry (GOB) courses, instructors have found that it also works well for one-year courses, especially when combined with the supplement *Chemistry Case Studies for Allied Health Students* by Colleen Kelley and Wendy Weeks.

In a GOB course it is essential to show how the subject matter relates to the students' future careers. For that reason, this text makes extensive use of real-life examples from the health sciences.

ORGANIZATION

TAKING AN INTEGRATED APPROACH

Most GOB texts are divided into three distinct parts: general chemistry, organic chemistry, and biochemistry. The integrated approach used in this text integrates these subject areas by juxtaposing chapters of related information. For example, a study of bonding and compounds (Chapter 3) is followed by a first look at organic compounds (Chapter 4) and then an introduction to inorganic and organic reactions (Chapter 5). Other examples of this integration at the chapter level include the study of acid–base chemistry (Chapter 7) followed by a chapter that includes organic acids and bases (Chapter 8), and the chemistry of alcohols, aldehydes, and ketones (Chapter 9) followed by that of carbohydrates (Chapter 10). Studies have shown that effective learning can take place when material is presented in a context that shows its relationship to the "big picture." The arrangement of chapters in this text helps students to see how inorganic chemistry and organic chemistry are linked to the biochemistry and health sciences that are so important to their future careers.

BENEFITS OF AN INTEGRATED APPROACH

Whether taught in one semester or two, the GOB curriculum is very full. Using an integrated approach can shorten the cycle time for returning to similar themes from the different branches of chemistry. Having a shorter time interval between when a topic is first presented and when it is reintroduced can help students assimilate the material more readily.

An added benefit of integrating GOB course material is that students get a better sense of how the chemistry being presented relates to their future careers, and as a result, their interest and motivation are enhanced.

TRANSITIONING TO AN INTEGRATED APPROACH

For instructors, making the transition from the traditional approach to an integrated one should not pose a problem. The integration of material takes place at the chapter level, and required introductory material is always presented before a new organic chemistry or biochemistry topic is begun. For example, instead of introducing carboxylic acids, phenols, and amines in their traditional position—late in the group of chapters devoted to organic chemistry—this text places these organic acids and bases (Chapter 8) directly after the introduction to acids and bases (Chapter 7). Supplements to the text can also assist with making the transition to an integrated text. These include *Chemistry Case Studies for Allied Health Students*, an instructor's manual, an instructor's solutions manual, PowerPoint lecture slides, and a test bank.

KEY FEATURES OF THE FOURTH EDITION

In terms of organization, some major changes have been made to this edition of the text. A number of these modifications were suggested by reviewers and by instructors who have used previous editions. Many reviewers recommended moving the chemistry of hydrocarbons from Chapter 4 to a chapter later in the text. In this fourth edition, hydrocarbons appear in Chapter 8. The latter part of Chapter 4 now introduces the key organic families. One new feature of the text is the "Did you Know?" paragraphs that briefly highlight topics that relate to the chemistry being presented in each chapter. Numerous end of chapter problems, sample problems, and practice problems have been added or revised in the Fourth Edition. Other changes that will be noted by those familiar with the text include:

Chapter 1

- A new chapter section titled "Measurement in General, Organic, and Biochemistry" shows how the topics presented in Chapter 1 relate to these three fields of chemistry.
- This chapter now includes a discussion of the kinetic molecular theory, phase changes, heat of fusion, and heat of vaporization. In previous editions of the text this material appeared in Chapter 6.

Chapter 2

- A new chapter section related to trace elements has been added.
- In earlier editions, Chapter 2 included a section on fission and fusion. This chapter section has been dropped in the new edition.
- Three new *Health Links* were added: Stable Isotopes and Drug Testing, Lead, and Radioisotopes for Sale.

Chapter 3

- The *Health Link* Pass the Salt, Please was added.

Chapter 4

- The chapter-opening vignette was changed.
- Hydrocarbon chemistry (Sections 4.4–4.8 in earlier editions) has been moved to Chapter 8. In its place, a new chapter section related to organic families was added.

Chapter 5

- The discussion of ΔG was expanded by introducing the concept of $\Delta G^{o\prime}$.

Chapter 6

- A discussion of inhaled anesthetics and their solubility in blood was added.

Chapter 7

- The effect of pressure and temperature on equilibrium is now described.
- The *Biochemistry Link* The Henderson-Hasselbalch Equation was added.

Chapter 8

- A new section (Section 8.8 Reactions of Hydrocarbons) gathers topics that, in previous editions, were presented in earlier chapters. Section 8.8 also introduces the alkane halogenation and aromatic substitution.
- The topics of decarboxylation (Section 8.9) and phenol oxidation (Section 8.8) have been removed.
- There is now a greater emphasis on skeletal structures than in previous editions.

Chapter 9

- The treatment of nucleophilic substitution (Section 9.2) was trimmed and is now tied to the alkane halogenation reactions introduced in Chapter 8.

Chapter 10

- Examples of simple glycosides have been added as part of the introduction to glycosidic bonds.

Chapter 11

- The structure of esters and their hydrolysis are reviewed just before the discussion of triglycerides and saponification.

Chapter 12

- Two new *Health Links* were added: Tamiflu and Relenza; and Immunotherapy.

Chapter 13

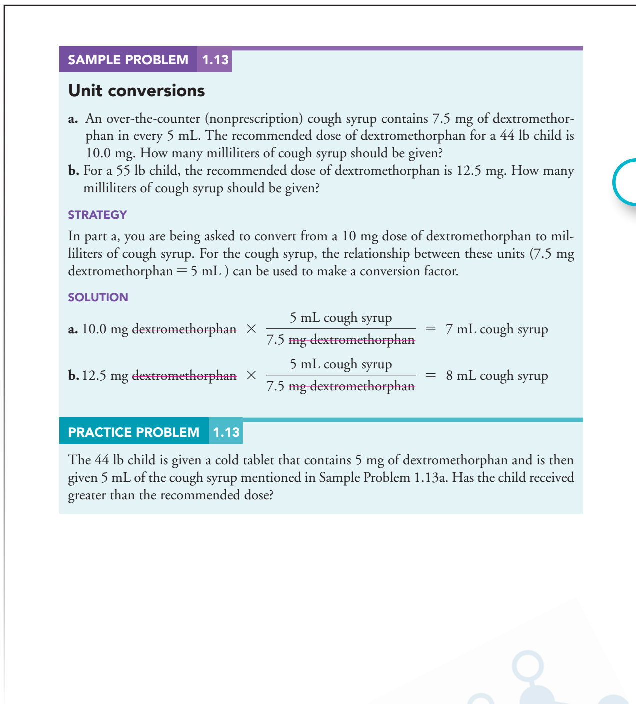
- The *Health Link* Lupus was added.
- The *Biochemistry Link* Glowing Cats was added.

Chapter 14

- Figures were modified and sample and practice problems were added.

PROBLEM SOLVING

Learning to do anything requires practice, and in chemistry this practice involves solving problems. This text offers students ample opportunities to do so.



SAMPLE PROBLEM 1.13

Unit conversions

a. An over-the-counter (nonprescription) cough syrup contains 7.5 mg of dextromethorphan in every 5 mL. The recommended dose of dextromethorphan for a 44 lb child is 10.0 mg. How many milliliters of cough syrup should be given?

b. For a 55 lb child, the recommended dose of dextromethorphan is 12.5 mg. How many milliliters of cough syrup should be given?

STRATEGY

In part a, you are being asked to convert from a 10 mg dose of dextromethorphan to milliliters of cough syrup. For the cough syrup, the relationship between these units (7.5 mg dextromethorphan = 5 mL) can be used to make a conversion factor.

SOLUTION

a. $10.0 \text{ mg } \cancel{\text{dextromethorphan}} \times \frac{5 \text{ mL cough syrup}}{7.5 \cancel{\text{ mg dextromethorphan}}} = 7 \text{ mL cough syrup}$

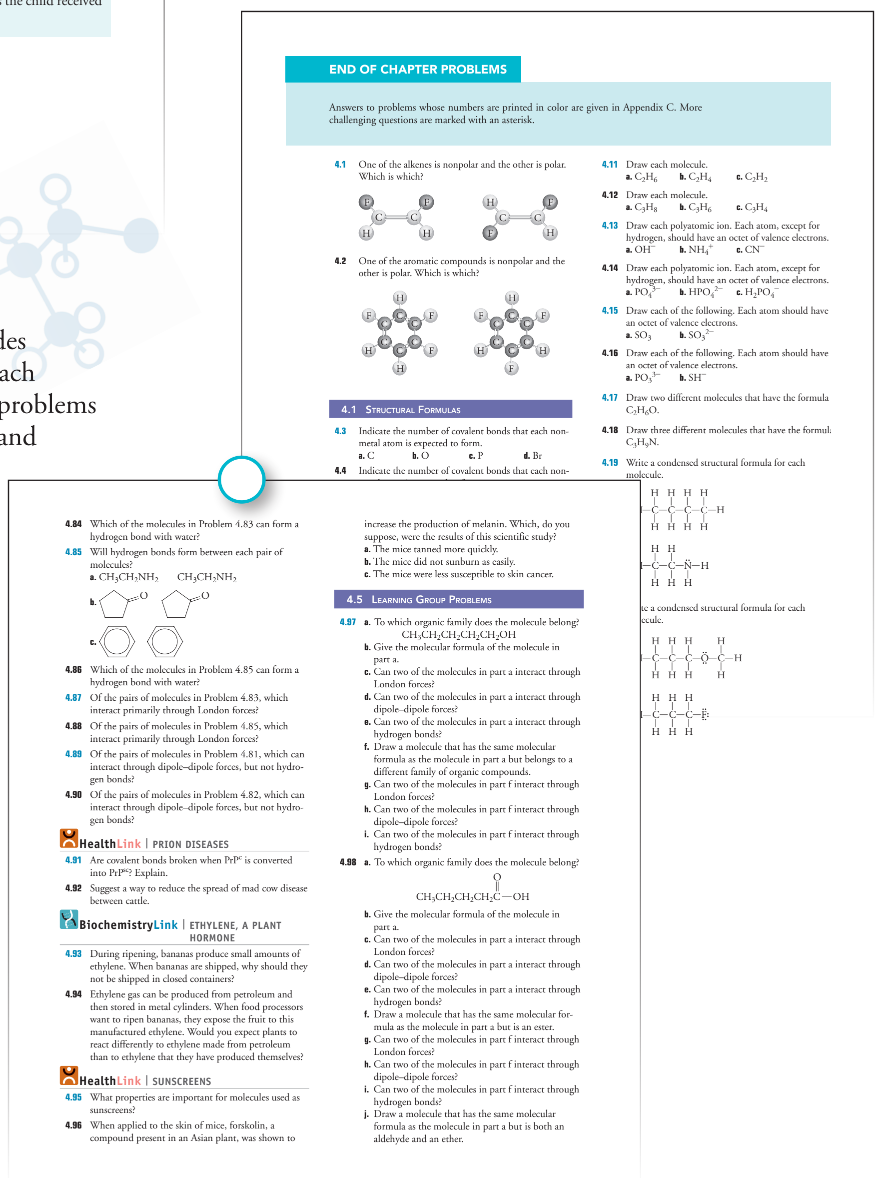
b. $12.5 \text{ mg } \cancel{\text{dextromethorphan}} \times \frac{5 \text{ mL cough syrup}}{7.5 \cancel{\text{ mg dextromethorphan}}} = 8 \text{ mL cough syrup}$

PRACTICE PROBLEM 1.13

The 44 lb child is given a cold tablet that contains 5 mg of dextromethorphan and is then given 5 mL of the cough syrup mentioned in Sample Problem 1.13a. Has the child received greater than the recommended dose?

Sample Problems and Practice Problems

Each major topic is followed by a sample problem and a related practice problem. The solution to each sample problem is accompanied by a strategy to use when solving the problem. The answers to practice problems are given at the end of the chapter.



END OF CHAPTER PROBLEMS

Answers to problems whose numbers are printed in color are given in Appendix C. More challenging questions are marked with an asterisk.

4.1 One of the alkenes is nonpolar and the other is polar. Which is which?

4.2 One of the aromatic compounds is nonpolar and the other is polar. Which is which?

4.1 Structural Formulas

4.3 Indicate the number of covalent bonds that each nonmetal atom is expected to form.
a. C **b.** O **c.** P **d.** Br

4.4 Indicate the number of covalent bonds that each non-

4.11 Draw each molecule.
a. C_2H_6 **b.** C_2H_4 **c.** C_2H_2

4.12 Draw each molecule.
a. C_3H_8 **b.** C_3H_6 **c.** C_3H_4

4.13 Draw each polyatomic ion. Each atom, except for hydrogen, should have an octet of valence electrons.
a. OH^- **b.** NH_4^+ **c.** CN^-

4.14 Draw each polyatomic ion. Each atom, except for hydrogen, should have an octet of valence electrons.
a. PO_4^{3-} **b.** HPO_4^{2-} **c.** $H_2PO_4^-$

4.15 Draw each of the following. Each atom should have an octet of valence electrons.
a. SO_3 **b.** SO_3^{2-}

4.16 Draw each of the following. Each atom should have an octet of valence electrons.
a. PO_3^{3-} **b.** SH^-

4.17 Draw two different molecules that have the formula C_2H_6O.

4.18 Draw three different molecules that have the formul C_3H_9N.

4.19 Write a condensed structural formula for each molecule.

4.84 Which of the molecules in Problem 4.83 can form a hydrogen bond with water?

4.85 Will hydrogen bonds form between each pair of molecules?
a. $CH_3CH_2NH_2$ $CH_3CH_2NH_2$
b.
c.

4.86 Which of the molecules in Problem 4.85 can form a hydrogen bond with water?

4.87 Of the pairs of molecules in Problem 4.83, which interact primarily through London forces?

4.88 Of the pairs of molecules in Problem 4.85, which interact primarily through London forces?

4.89 Of the pairs of molecules in Problem 4.81, which can interact through dipole–dipole forces, but not hydrogen bonds?

4.90 Of the pairs of molecules in Problem 4.82, which can interact through dipole–dipole forces, but not hydrogen bonds?

HealthLink | PRION DISEASES

4.91 Are covalent bonds broken when PrP^C is converted into PrP^{SC}? Explain.

4.92 Suggest a way to reduce the spread of mad cow disease between cattle.

BiochemistryLink | ETHYLENE, A PLANT HORMONE

4.93 During ripening, bananas produce small amounts of ethylene. When bananas are shipped, why should they not be shipped in closed containers?

4.94 Ethylene gas can be produced from petroleum and then stored in metal cylinders. When food processors want to ripen bananas, they expose the fruit to this manufactured ethylene. Would you expect plants to react differently to ethylene made from petroleum than to ethylene that they have produced themselves?

HealthLink | SUNSCREENS

4.95 What properties are important for molecules used as sunscreens?

4.96 When applied to the skin of mice, forskolin, a compound present in an Asian plant, was shown to increase the production of melanin. Which, do you suppose, were the results of this scientific study?
a. The mice tanned more quickly.
b. The mice did not sunburn as easily.
c. The mice were less susceptible to skin cancer.

4.5 Learning Group Problems

4.97 **a.** To which organic family does the molecule belong?
$CH_3CH_2CH_2CH_2CH_2OH$
b. Give the molecular formula of the molecule in part a.
c. Can two of the molecules in part a interact through London forces?
d. Can two of the molecules in part a interact through dipole–dipole forces?
e. Can two of the molecules in part a interact through hydrogen bonds?
f. Draw a molecule that has the same molecular formula as the molecule in part a but belongs to a different family of organic compounds.
g. Can two of the molecules in part f interact through London forces?
h. Can two of the molecules in part f interact through dipole–dipole forces?
i. Can two of the molecules in part f interact through hydrogen bonds?

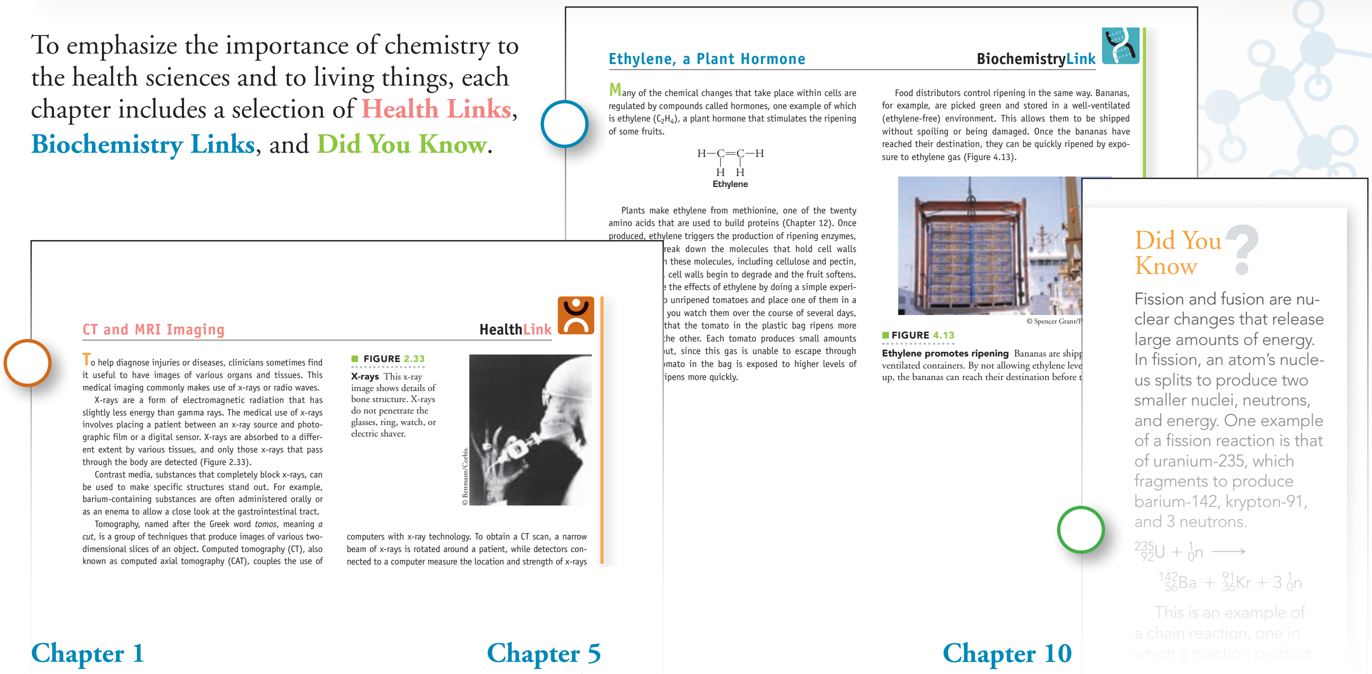
4.98 **a.** To which organic family does the molecule belong?
$CH_3CH_2CH_2CH_2C(=O)-OH$
b. Give the molecular formula of the molecule in part a.
c. Can two of the molecules in part a interact through London forces?
d. Can two of the molecules in part a interact through dipole–dipole forces?
e. Can two of the molecules in part a interact through hydrogen bonds?
f. Draw a molecule that has the same molecular formula as the molecule in part a but is an ester.
g. Can two of the molecules in part f interact through London forces?
h. Can two of the molecules in part f interact through dipole–dipole forces?
i. Can two of the molecules in part f interact through hydrogen bonds?
j. Draw a molecule that has the same molecular formula as the molecule in part a but is both an aldehyde and an ether.

End of Chapter Problems

Problems are paired and Appendix C provides answers for the odd-numbered problems. Each chapter includes multistep *Learning Group* problems designed to be worked with other students and *Thinking It Through* problems that ask students to go a bit further with one or more of the concepts presented in the chapter-opening vignette.

HEALTH LINKS, BIOCHEMISTRY LINKS, AND DID YOU KNOW?

To emphasize the importance of chemistry to the health sciences and to living things, each chapter includes a selection of **Health Links**, **Biochemistry Links**, and **Did You Know**.



Chapter 1
- Science and Medicine
- Diabetes Mellitus
- The Gulf of Mexico Oil Spill
- Body Mass Index
- Body Temperature
- The Mars Climate Orbiter
- Making Weight

Chapter 2
- Lead
- Recent Element Names
- Stable Isotopes and Drug Testing
- Lead
- Bioluminescence
- X Ray Scanners
- Half-Life
- CT and MRI Imaging
- Radioisotopes for Sale

Chapter 3
- Ionophores and Biological Ion Transport
- Salt Consumption
- The Patina on the Statue of Liberty
- Pass the Salt, Please
- Dental Fillings
- Nitric Oxide
- Sunscreens

Chapter 4
- Some Organic Chemistry History
- FoldIt
- Prion Diseases
- Ethylene, a Plant Hormone
- Origin of Organic Family Names

Chapter 5
- Lightning
- Procaine
- Antiseptics and Oxidation
- Carbonic Anhydrase

Chapter 6
- Weather Reports
- Blood Pressure
- Breathing
- Scale
- Prodrugs
- Saliva
- Diffusion and the Kidneys

Chapter 7
- Diving Mammals, Oxygen, and Myoglobin
- Plants as pH Indicators
- Fish and Amines
- The Henderson-Hasselbalch Equation
- Altitude Alkalosis

Chapter 8
- A Chili Pepper Painkiller
- Alpha Hydroxy Acids
- Juicy Fruit
- Adrenaline and Related Compounds
- Biofilms
- Aspartame
- A Cure for Fleas

Chapter 9
- Skunk Spray
- Treating Antifreeze Poisoning
- Aldehdye Dehydrogenase
- Protective Enzymes
- Drugs in the Environment

Chapter 10
- Trehalose
- Natural and Artificial Sweeteners
- The Sweetest Compounds
- Lufenuron and Chitin

Chapter 11
- Omega-3 Fatty Acids
- Phospholipase A2
- *Trans* Fats
- Olestra
- Human Growth Hormone
- Anabolic Steroids

Chapter 12
- Hemoglobin, a Globular Protein, and Collagen, a Fibrous Protein
- Immunotherapy
- Miraculin
- OMP Decarboxylase
- Tamiflu and Relenza
- Proteins in Medicine

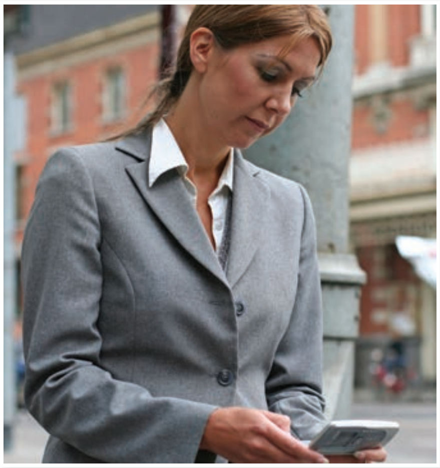
Chapter 13
- Lupus
- Viruses
- RNA Interference
- Breast Cancer Genes
- Glowing Cats

Chapter 14
- Mitochondria
- Glycolysis and Cancer
- Brown Fat

OTHER TEXT FEATURES

Chapter Opening Vignettes

Each chapter begins with a story that focuses on the connection between chemistry and high-interest, everyday topics that students can relate to. At the end of the chapter, the chemistry just presented is used to finish the story.



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AN ACCIDENTAL OVERDOSE

A woman pulled out her cell phone and saw that she had a voicemail message. It was from the gastroenterologist's office, reminding her of a follow-up appointment scheduled for the next day. The previous week she had had a close call when treating a bad cold. She was taking extra-strength pain relief tablets to treat her headache, a multi-ingredient flu and cold medicine to clear up her cold symptoms, and a nighttime cold medicine to help her sleep. After using more than the recommended dosage of each of these medications for a number of days, she began to experience nausea and vomiting. A trip to the emergency room and subsequent blood tests showed that she was suffering from liver damage due to acetaminophen poisoning.

4.4 *Families of Organic Compounds* 141

AN ACCIDENTAL OVERDOSE . . . REVISITED

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Acetaminophen is an analgesic (painkilling) and antipyretic (fever-reducing) drug that is available without prescription. It is the most widely used painkiller in the United States and is an active ingredient in hundreds of different medicines. Accidental poisonings can occur when a person is using more than one drug that contains acetaminophen and takes in more than the recommended limit of 4000 mg per day. Acetaminophen poisoning is the most common cause of acute (rapid onset) liver failure in the United States and is the second most common cause of liver damage that leads to a transplant.

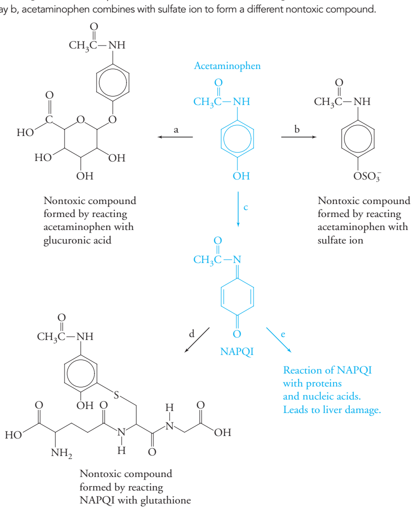
Liver damage caused by taking too much acetaminophen is related to how the liver metabolizes (makes chemical changes to) this drug. In the case of acetaminophen, there are two major ways that acetaminophen is modified for removal from the body. In pathway a (see diagram), acetaminophen combines with a molecule called glucuronic acid to form a nontoxic compound. In pathway b, acetaminophen combines with sulfate ion to form a different nontoxic compound.

If too much acetaminophen is present in the liver, pathways a and b become overloaded and the drug gets metabolized by pathway c, which produces NAPQI (*N*-acetyl-*p*-benzoquinone imine). In pathway d, NAPQI reacts with a compound called gluathione to form another nontoxic product. The harmful effects of acetaminophen arise when so much NAPQI is formed that all available glutathione gets consumed. In that case, leftover NAPQI reacts with proteins and nucleic acids (pathway e) in the liver, causing liver damage.

Note how the biochemistry described here is closely linked to organic chemistry. These biochemical molecules belong to many of the organic families described in this chapter.

THINKING IT THROUGH

Identify as many organic families as you can in the molecules shown on this page.



1 Science and Measurements

ABOUT THIS CHAPTER

In the first chapter of this health science chemistry text, we take a look at the scientific method and at the particular field of science called chemistry. Chemistry is important to health science students because having some knowledge of this field is part of understanding the human body, its diseases, and the medicines used to treat disease. In this chapter we also consider a group of topics related to making measurements.

CHAPTER 1 OBJECTIVES

After completing this chapter, you should be able to:

1. Explain the terms law, hypothesis, experiment, and theory.
2. Define the terms matter and energy. Describe the three states of matter and the two forms of energy.
3. Describe and give examples of physical properties and physical change.
4. Identify metric, English, and SI units.
5. Express values using scientific notation and metric prefixes.
6. Describe the difference between the terms accurate and precise.
7. Use the correct number of significant figures to report the results of calculations involving measured quantities.
8. Identify conversion factors and use them to convert from one unit to another.
9. Explain the terms density, specific gravity, and specific heat.
10. Recognize the difference between general chemistry, organic chemistry, and biochemistry.

CHAPTER 1 OBJECTIVES

OBJECTIVE	SUMMARY	SECTION	SAMPLE AND PRACTICE PROBLEMS	END OF CHAPTER PROBLEMS
1. Explain the terms **law**, **hypothesis**, **experiment**, and **theory**.	Scientific **laws** describe observations but do not attempt to explain them. A **theory** is a **hypothesis** (tentative explanation) that has survived repeated testing by **experiments**.	1.1	1.1	1.3–1.6
2. Define the terms **matter** and **energy**. Describe the three states of matter and the two forms of energy.	**Matter** has mass and occupies space, while **energy** is the capacity to do work and transfer heat. Matter is typically found as a **solid** (fixed shape and volume), a **liquid** (variable shape and fixed volume), or **gas** (variable shape and volume). **Potential energy** is stored energy and **kinetic energy** is the energy of motion.	1.2	1.3	1.7, 1.8, 1.13–1.26
3. Describe and give examples of **physical properties** and **physical change**.	**Physical properties**, including odor and melting point, and **physical changes**, including boiling and crushing, can be determined without affecting **chemical composition**.	1.2	1.2, 1.4	1.9–1.12
4. Identify **metric**, **English**, and **SI units**.	**Metric units** include grams, meters, and liters; **English units** include pounds, feet, and quarts; and **SI units** include kilograms, meters, and cubic meters.	1.3	1.5	1.27–1.30
5. Express values using **scientific notation** and metric prefixes.	In **scientific notation**, values are expressed as a number between 1 and 10, multiplied by a power of ten ($0.025 = 2.5 \times 10^{-2}$). Metric prefixes are used to create units of different sizes (2503 m = 2.503 km).	1.4	1.6, 1.7	1.31–1.44

Objectives

Each chapter begins with a list of goals for the student to achieve. These objectives identify key concepts within each chapter. A summary of how these objectives were met appears at the end of each chapter.

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SUPPORT PACKAGE FOR STUDENTS

Student Solutions Manual Written by Adeliza Flores, of Las Positas College, this supplement contains worked-out solutions to all of the odd-numbered text problems.

Laboratory Manual Written by Charles D. Anderson, David Macaulay, Joseph Bauer, and Molly Bloomfield, this lab manual is written for the one- or two-term chemistry lab course for students in the allied health sciences and related fields. These experiments are presented in an integrated table of contents and contain chapter references from *General, Organic, and Biological Chemistry: An Integrated Approach*, Fourth Edition.

Chemistry Case Studies for Allied Health Students Written by Colleen Kelley and Wendy Weeks of Pima Community College, this manual was designed to bring relevance and critical-thinking skills to the allied health chemistry course. Students are encouraged to become "diagnosticians" and apply their newly acquired chemistry knowledge to solving real-life health and environmental cases. The case manual also encourages a holistic approach by asking students to synthesize information across topics. *Case Studies* topics include food and forensics, antibiotics, parasites, toothaches, red blood cells, sickle cell anemia, and gallstones, in addition to several other topics that help to illustrate the role of chemistry in our lives.

SUPPORT PACKAGE FOR INSTRUCTORS

PowerPoint Lecture Slides Created by Elizabeth Clizbe of Brockport College, these slides contain lecture outlines and key topics from each chapter of the text, along with supporting artwork and figures from the text. The slides also contain assessment questions and questions for in-class discussion.

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Instructor's Solutions Manual Written by Adeliza Flores of Las Positas College, this supplement contains worked-out solutions to all of the end-of-chapter problems.

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BRIEF CONTENTS

The asterisks are color coded to indicate which chapters are integrated.

CONTENTS

Media Bakery

AT THE CLINIC

A patient arrives at the oncologist's office for his scheduled chemotherapy treatment. The waiting room is completely full, so he suspects that they are running behind schedule. After checking in with the receptionist, he settles in for a long wait. He catches up on his email, sends a few texts to friends, and reads an eight-month-old copy of *Sports Illustrated* from cover to cover before hearing his name called. The nurse leads him from the waiting room, weighs him, takes his temperature, and measures his blood pressure. After preparing his medication, she inserts a needle into a vein in the back of his hand, has another nurse double-check the prescription, and hooks him up to an IV bag. Discovering that all the IV pumps are in use, she decides to set the drip rate manually. After opening the valve and adjusting the flow to 150 milliliters per hour, she makes a note to check for an available pump in 20 minutes, once the patient has received 50 milliliters of IV solution.

1 Science and Measurements

ABOUT THIS CHAPTER

In the first chapter of this health science chemistry text, we take a look at the scientific method and at the particular field of science called chemistry. Chemistry is important to health science students because having some knowledge of this field is part of understanding the human body, its diseases, and the medicines used to treat disease. In this chapter we also consider a group of topics related to making measurements.

CHAPTER 1 OBJECTIVES

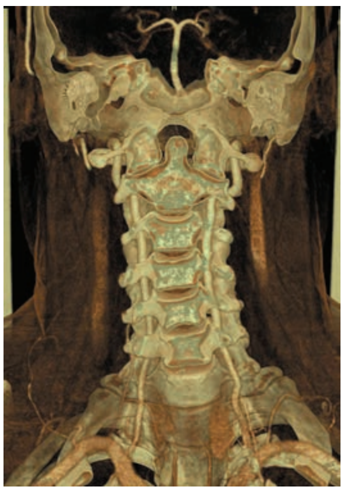
After completing this chapter, you should be able to:

1. **Explain the terms law, hypothesis, experiment, and theory.**
2. **Define the terms matter and energy. Describe the three states of matter and the two forms of energy.**
3. **Describe and give examples of physical properties and physical change.**
4. **Identify metric, English, and SI units.**
5. **Express values using scientific notation and metric prefixes.**
6. **Describe the difference between the terms accurate and precise.**
7. **Use the correct number of significant figures to report the results of calculations involving measured quantities.**
8. **Identify conversion factors and use them to convert from one unit to another.**
9. **Explain the terms density, specific gravity, and specific heat.**
10. **Recognize the difference between general chemistry, organic chemistry, and biochemistry.**

1.1 | THE SCIENTIFIC METHOD

SPL/Photo Researchers, Inc.

(*a*)



Gondelon/Photo Researchers, Inc.

(*b*)

FIGURE 1.1

Medical imaging (*a*) The first x-ray of the human body was taken in 1895 by Wilhelm Roentgen, the discoverer of x-rays. In this x-ray, you can see the bones of his wife's hand and her wedding ring. (*b*) With the improvements that have been made to x-ray equipment, clinicians can now obtain sharper and more detailed images, as in this scan of a patient's vertebrae.

Science is an approach that is used to try to make sense out of how the universe operates, ranging in scale from the very large (understanding how stars form) to the very small (understanding the behavior of the tiny particles from which everything is made). The knowledge gained from scientific studies has impacted our lives in many ways. For example, the discovery of DNA has led to the use of DNA fingerprinting in solving crimes and the development of genetically engineered crops that are better able to deal with pests and pesticides. Studies on energy production are leading to the development of cleaner ways to power our cars, including hydrogen, electricity, and electric/gasoline hybrids. Science has also played an important role in our ever-improving ability to treat diseases. CT and MRI scanners and many of the therapeutic drugs (including anticancer monoclonal antibodies) used today are available as a result of the careful work of scientists (Figure 1.1).

Because science, as a whole, covers such a wide range of subject areas, it is divided into various branches or disciplines. These include chemistry, biology, biochemistry, geology, astronomy, physics, health science, and others. **Chemistry**, the branch of science involved with *the study of matter and its changes,* lays an important groundwork for studies in other fields of science, whether they involve designing artificial antibodies to treat disease, testing drinking water for contaminants, or determining the makeup of planets that orbit nearby stars.

When doing science, regardless of the particular discipline, information is gathered and interpreted using the **scientific method**. Making observations is an important part of this process. One well-known story regarding the importance of observation involves the English scientist Isaac Newton (1642–1727). Reportedly, seeing an apple fall out of a tree led him to formulate the law of gravity, which states that *there is an attractive force between any two objects* (in this case, between the earth and an apple). This and other scientific **laws** are statements that *describe things that are consistently and reproducibly observed*. While a law does not explain why things happen, it can be used to predict what might happen in the future. For example, the law of gravity does not explain why things fall, but it does allow you to predict what will happen if you jump off a ladder.

Finding explanations for observations and laws is a key component of the scientific method. Based on observations or currently known facts, a **hypothesis**, *a tentative explanation (educated guess),* can be constructed. Clinicians, for example, make educated guesses when treating patients. If a patient complains of stomach pains, the clinician will ask a few questions and make a few observations before coming up with a hypothesis (diagnosis) as to the nature of the problem. This hypothesis is based on knowledge of symptoms and diseases.

Once a hypothesis has been constructed, it must be tested by doing careful **experiments**. To test a hypothesis related to a patient's illness, a clinician might call for a series of medical tests (experiments) to be run. If the test results support the diagnosis, treatment can begin. If they invalidate the diagnosis, the clinician must revise the hypothesis and look for another cause of the illness.

Experiments must be designed so that the observations made are directly related to the question at hand. For example, if a patient has stomach pains, taking an x-ray of his or her big toe will probably not help find the cause of the illness.

If a hypothesis survives repeated testing, it may become a **theory**—*an experimentally tested explanation of an observed behavior*. For a theory to survive, it must be consistent with existing experimental evidence, must accurately predict the results of future experiments, and must explain future observations.

Figure 1.2 shows the interconnections of the various parts of the scientific method—making an observation, forming a hypothesis, performing experiments, and creating a theory. Scientists do not necessarily follow these steps in order, nor do they always use

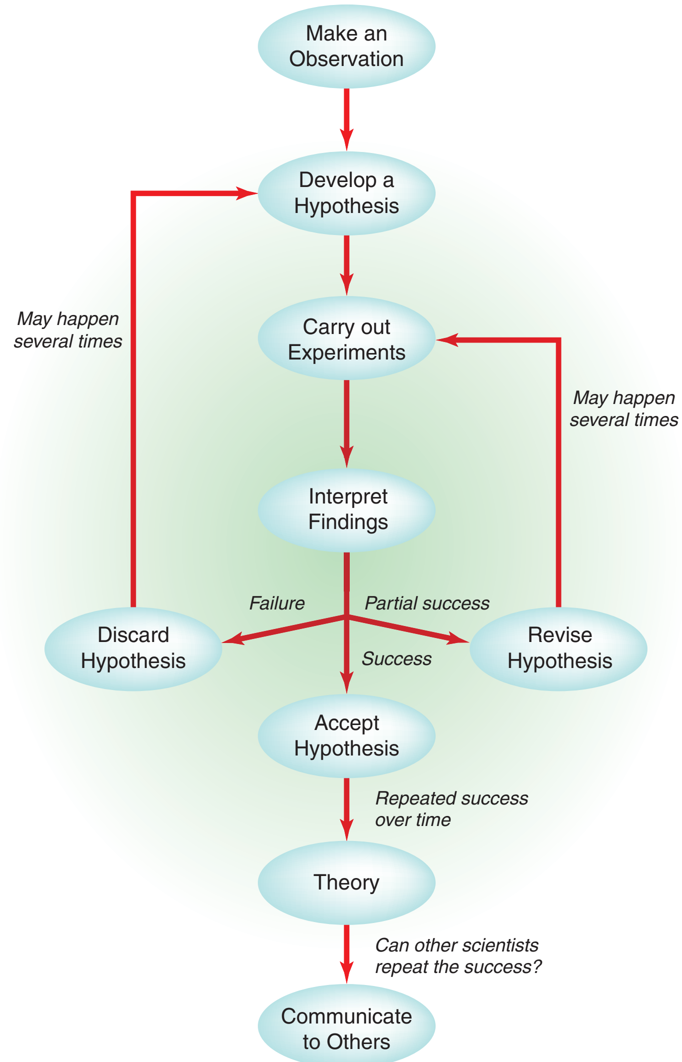


FIGURE 1.2

The scientific method In the scientific method, experiments provide the information used to discard, revise, or accept hypotheses.

all of the steps. It may be that an existing law suggests a new experiment or that a set of published experiments suggests a radically new hypothesis. Creativity is an important part of science; sometimes new theories arise when someone discovers an entirely new way of interpreting experimental results that hundreds of others had looked at before but could not explain. In addition to creativity, a scientist must have sufficient knowledge of the field to be able to interpret experimental results and to evaluate hypotheses and experiments.

SAMPLE PROBLEM 1.1

The scientific method

Suppose that while rearranging your room a few months ago, you moved your favorite plant. Now you notice that the plant is dying. Which of the following explanations are testable hypotheses?

1. The plant is dying because it was moved to a darker location.
2. The plant is dying because it is sad.
3. The plant is dying because it was moved to a warmer location.

STRATEGY

If a statement is a testable hypothesis, you should be able to suggest an experiment to test it.

SOLUTION

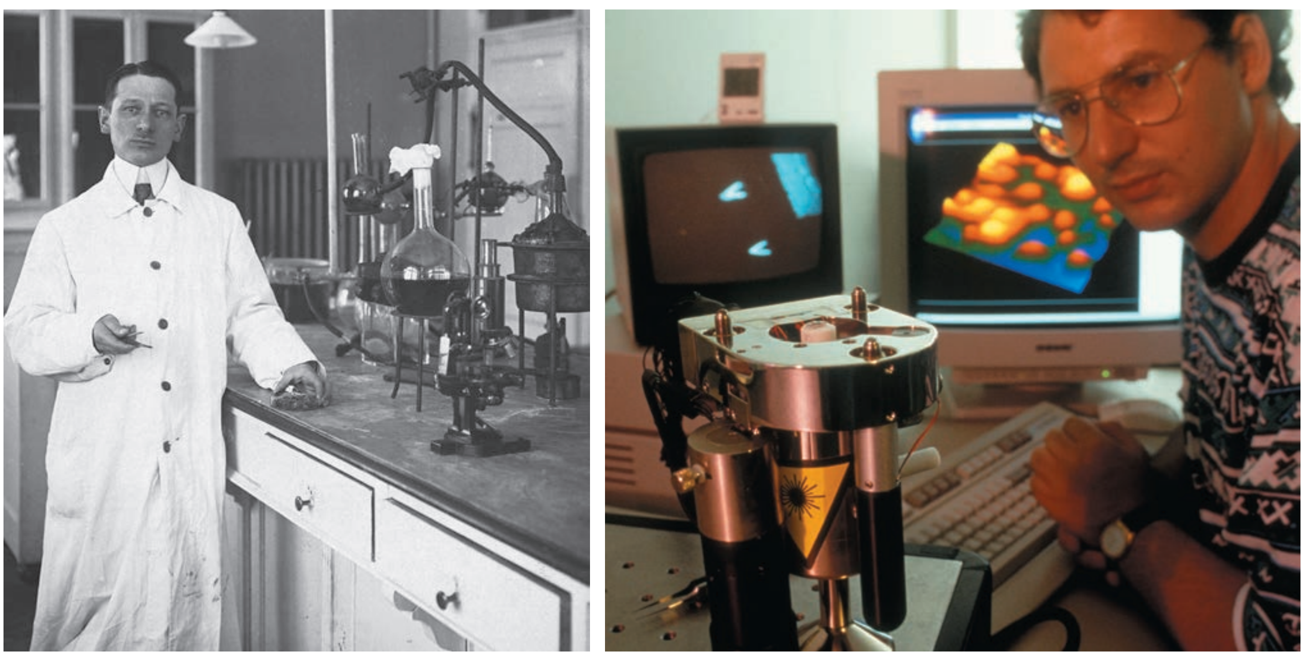
Statements 1 and 3 are testable hypotheses. You could test hypothesis 1 by adjusting the amount of light in the room, and hypothesis 3 by varying the temperature.

PRACTICE PROBLEM 1.1

You get in your car one morning and discover that it won't start. Describe two hypotheses that could explain this and a corresponding experiment that could test each.

Improvements in technology also play an important role in science. The fact that theories are based on experimental observations means that as the scientific instruments used to perform experiments improve, theories may have to be changed. In Section 2.1 two theories of the atom, the fundamental particle from which matter is created, are discussed. One of these theories dates back to the early 1800s, when technology was not very advanced and experiments provided much less information than is obtainable today (Figure 1.3). While the earliest theory of the atom accounted for the observations made up until the early 1800s, once better experimental results were obtained, errors were revealed.

Whether scientists study atoms or inherited diseases, theories must be continually reevaluated and, if necessary, revised as new experiments provide additional information. This change is an expected part of science.



Hulton-Deutsch Collection/© Corbis.

Stegerphoto/PeterArnold/Getty Images, Inc.

(*a*) (*b*)

FIGURE 1.3

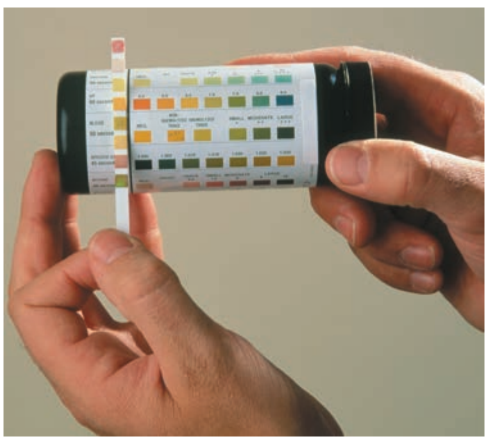
Modifying theories Theories are sometimes revised when improved scientific equipment allows better experimental results to be obtained.

Science and Medicine

HealthLink

The level of glucose (blood sugar) in the body is controlled by a hormone called insulin. Diabetes is the disease that occurs when insulin is not produced in sufficient amounts or when the body is not sensitive to its effects. As science has progressed over the years, so has our understanding of this disease and our ability to treat it. In the mid-1800s, before it was known that high levels of glucose cause the symptoms of diabetes, some physicians recommended that their diabetic patients eat lots of sugar. Others recommended starvation. Scientific studies in the late 1800s and early 1900s led to an understanding of the role that the pancreas plays in glucose metabolism and to the discovery of insulin, which is produced by the pancreas. Insulin was first used in 1922 to treat diabetes in humans. Because the insulin used then was not very pure, patients were given injections—often painful—of up to 2 teaspoons (10 milliliters) at a time. As the science of isolating and purifying insulin improved, dosages dropped to less than one-tenth of that size. Other advances in the treatment of diabetes included the use of oral drugs to control insulin levels (introduced in 1955), the use of genetically engineered human insulin (introduced in 1982) in place of that isolated from cattle and pigs, and the development of new methods for testing blood glucose levels (Figure 1.4).

(*a*)



(*b*)

(*c*)

FIGURE 1.4

Glucose testing (*a*) The urine of diabetics can contain higher than normal amounts of glucose. Many centuries ago, glucose levels were tested by seeing if ants were attracted to a patient's urine. Sometimes physicians tasted urine to check for sweetness. (*b*) When these test strips are dipped in a urine sample, the array of colors produced indicates the amount of glucose present. (*c*) Measuring blood glucose levels is the most accurate way to keep track of diabetes. Blood glucose monitors require just a small drop of blood.

Did You Know?

Diabetes mellitus, or diabetes, gets its name from two Greek words related to symptoms of the disease. The word *diabetes* refers to excessive urination and *mellitus* to "honey-sweet urine," which dates to the time when tasting a patient's urine was part of the diagnosis.

1.2 | MATTER AND ENERGY

In the earlier discussion of the various branches of science, chemistry was described as the study of matter and the changes that it undergoes. This leads to the question "what is matter?" In scientific terms, **matter** is *anything that has mass and occupies space*. In everyday terms, this definition includes your body, the air that you breathe, this book, and all of the other material around you.

- Matter can exist in the solid, liquid, and gas states.

We can describe matter in terms of **physical properties**, those characteristics that can be determined without changing the **chemical composition** of matter (what it is made of). For example, a piece of silver is shiny, conducts electricity, and can be pounded without breaking, while a cube of sugar is white, tastes sweet, can be crushed, and is odorless. The act of measuring these and other physical properties, including melting point (melting temperature), does not change the composition of matter. Silver is still silver and sugar is still sugar.

Matter is typically found in one of three different physical states or phases—as a **solid**, a **liquid**, or a **gas**. From our direct experience we know that

- *Solids have fixed shapes and volumes.*
- *Liquids have variable shapes and fixed volumes.*
- *Gases have variable shapes and volumes.*

FIGURE 1.5

Gas, liquid, and solid A paint can (a solid), paint (a liquid), and paint fumes (a gas) illustrate the three physical states of matter.

Think about what happens if an opened can of paint gets spilled (Figure 1.5). Whether it is standing upright or lying on its side, the can (a solid) has the same shape and occupies the same volume of space. The paint (a liquid) keeps its original 1 gallon volume but changes its shape as it spreads out across the floor. The paint fumes (a gas) quickly change their shape and volume as they spread through the air in the room.

The particular state in which a substance appears depends, in part, on the strength of the interactions between its particles. The term "particles" refers to atoms, molecules, and ions—all three of which we will learn about in future chapters. For now, let's just think of a water molecule (H_2O) as a particle built from three smaller particles (2 H atoms and 1 O atom).

The particles in a solid are strongly attracted to one another and are held fairly rigidly in one spot. This is true for each of the water molecules that make up ice—they are locked into place through attractions to other water molecules in the solid (Figure 1.6*a*). The particles in a liquid, including liquid water, are less strongly attracted and are able to slip and slide past one another (Figure 1.6*b*). The particles that make up a gas are attracted to one another only very weakly, if at all, and are free to move (Figure 1.6*c*). In later chapters we will take a close look at the types of forces that can attract one particle to another.

Moving between physical states, including from ice to liquid water to steam, is a type of **physical change**, change in which *the chemical composition of matter is not altered* (Figure 1.7). Melting iron, crushing a cube of sugar, and bending a copper wire are also examples of physical change.

- The term "substance" is used to refer to the matter of which something consists. Later, we will learn details about the nature of this matter.

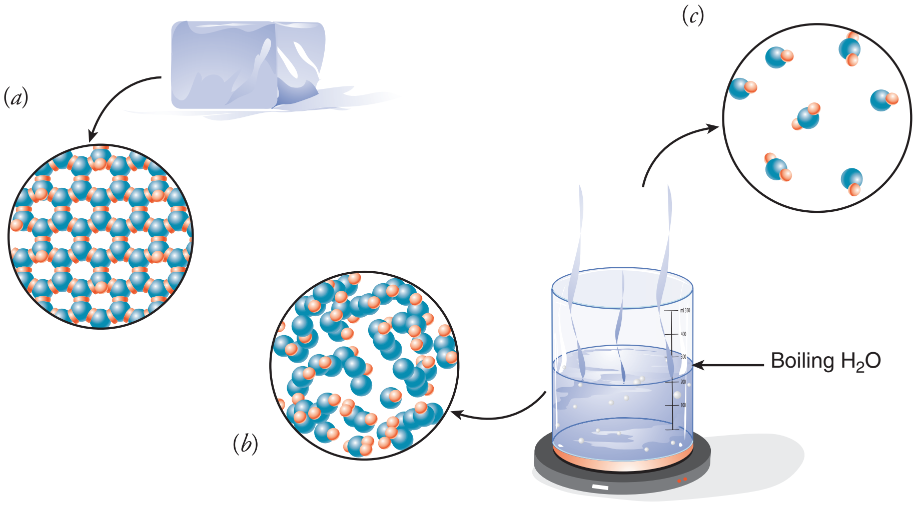


FIGURE 1.6

Physical states of water
(*a*) The water molecules in ice are held to one another strongly and their motion is limited. (*b*) Those in liquid water are less strongly attracted to one another and they can move past one another. (*c*) The molecules in steam (gaseous water) are attracted to one another only very weakly, if at all, and move freely. Molecules will be described in Chapter 4.

Peter Van Rijn/SUPERSTOCK.

FIGURE 1.7

Physical change When snow melts in the spring, rivers fill with water. The conversion of snow into water is a physical change.

SAMPLE PROBLEM 1.2

Physical change

Which of the following involve physical change?

a. Ripping a piece of paper
b. Burning a piece of paper
c. Melting a cube of butter

STRATEGY

Read the preceding paragraph to find the definition of physical change.

SOLUTION

In a physical change, the chemical composition of matter is not altered. When paper is ripped or butter is melted, nothing new is created. Burning a piece of paper converts it into something new: ash, gases, and heat.

PRACTICE PROBLEM 1.2

When baking soda (a solid) is mixed with vinegar (a liquid), carbon dioxide bubbles are formed. Is this an example of a physical change or a chemical change (change in chemical composition)? Explain.

Any time that matter is changed in any way, **work** has been done. This includes the physical changes just mentioned, as well as walking, running, or turning the pages of this book. All of these activities involve **energy**, which is defined as *the ability to do work and to transfer heat*.

Energy can be found in two forms, as **potential energy** (*stored energy*) or as **kinetic energy** (*the energy of motion*). The water sitting behind a dam has potential energy. When the floodgates are opened and the water begins to pour through, potential energy is converted into kinetic energy.

■ Potential energy is stored energy. Kinetic energy is the energy of motion.

All matter contains energy, so changes in matter (work) and changes in energy (potential or kinetic) are connected to one another. For example, if you drive a car, some of the potential energy of gasoline is converted into the kinetic energy used to move the pistons in the engine (doing work) and some is converted into heat, a form of kinetic energy related to the motion of the particles from which things are made.

SAMPLE PROBLEM 1.3

Potential versus kinetic energy

a. You pick up a rubber band and stretch it. What change takes place in the potential energy of the rubber band?
b. You let go of the rubber band and it snaps back to its original shape. What change takes place in the potential energy of the rubber band? What changes take place in its kinetic energy?
c. Is stretching then releasing the rubber band a physical change?

STRATEGY

Recall that potential energy is stored energy and that kinetic energy is the energy of motion.

SOLUTION

a. The rubber band contains more stored energy, so its potential energy increases.
b. Its potential energy decreases as it releases back to its original shape. As it snaps, the rubber band's kinetic energy (motion) initially increases but then decreases.
c. Yes, nothing new is created.

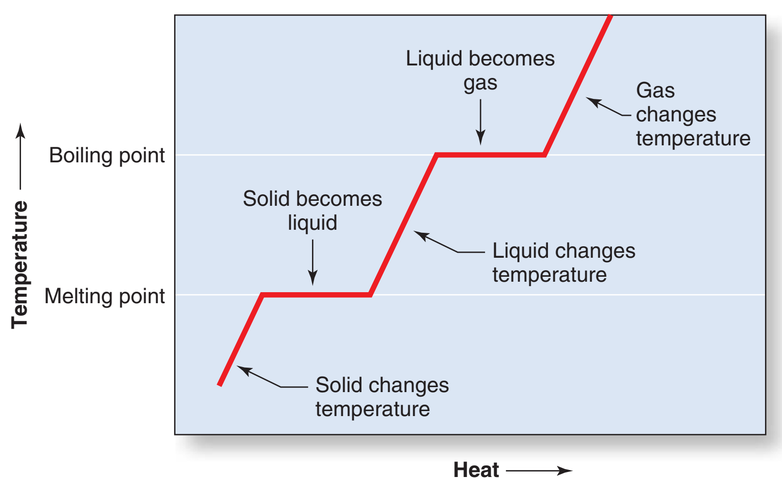
PRACTICE PROBLEM 1.3

a. Which has greater potential energy, a cup of coffee held at waist level or one held at shoulder level?
b. Which has greater kinetic energy, a cup of hot coffee or a cup of cold coffee?

Above, we saw that the strength of the attractions between particles determines, in part, whether a substance is found as a solid, a liquid, or a gas. Heat also plays a role. For example, boiling water to form steam (gaseous water) requires the addition of heat. Let us take a look at the effect that heat has on the three phases of water: ice, liquid water, and steam. The water molecules in ice are held in place and have a relatively low kinetic energy. If heat is added to water until it melts, liquid water is formed in which the molecules have a greater kinetic energy than in ice. (The higher the temperature of something, the greater the kinetic energy of the particles from which it is made.) Although the water molecules still interact with one another, their increased motion allows them to move around. If heat is added to water until it boils, steam is formed. The even greater kinetic energy allows the water molecules to separate completely from one another and move freely through the container that holds them.

Figure 1.8 shows the temperature changes that accompany ice to liquid water to steam phase changes. Beginning with ice at a temperature of −20°C (−4°F), for example, and

■ The units used to measure temperature, including degrees Celsius (°C) and degrees Fahrenheit (°F) are discussed in Section 1.3.



■ **FIGURE 1.8**

Phase change of water The energy required to convert ice into water is called the heat of fusion. The energy required to convert water into steam is the heat of vaporization.

gradually adding heat energy to warm it, we will see an increase in temperature. When the temperature reaches 0°C (32°F), the melting point of ice or the freezing point of water, the temperature remains constant—even as more heat is added—until all of the ice has melted. The energy put in during this melting process is called the **heat of fusion**. With the continued addition of heat energy, water temperature rises until it reaches 100°C (212°F), the boiling point of water. As the water begins boiling, the temperature remains constant as heat is added, until all of the water has been converted to steam. The energy that goes into converting water from the liquid to the gas phase is called the **heat of vaporization**. Once the water has all boiled, the addition of more heat causes the temperature of the steam to rise.

- Heat of fusion is the heat required to melt a solid.
- Heat of vaporization is the heat required to evaporate a liquid.

This process can be reversed. As heat energy is removed from steam, its temperature drops. At a temperature of 100°C, where steam condenses to form liquid water, the temperature remains constant until only water is present. Further loss of heat energy lowers the temperature of water until, at 0°C, water begins to freeze. Again, the temperature remains at 0°C until all of the water has been converted into ice. Removal of more heat energy lowers the temperature of the ice.

Under certain conditions, some substances will skip the liquid phase and jump directly between the liquid and gas phases. The conversion of a solid directly into a gas is called **sublimation** and the reverse of this process is called **deposition**. Dry ice, solid carbon dioxide, is a common example of a substance that undergoes sublimation (Figure 1.9).

Charles D. Winters/Photo Researchers, Inc.

FIGURE 1.9

Sublimation The sublimation of dry ice involves the direct conversion of solid carbon dioxide into gaseous carbon dioxide.

SAMPLE PROBLEM 1.4

Energy and changes in physical state

It was once common to reduce a fever by applying isopropyl alcohol to the skin. As the alcohol evaporates (liquid becomes gas), the skin cools. Explain the changes in heat energy as this process takes place. Note: Reducing a fever this way is no longer recommended.

STRATEGY

To answer this question you must decide whether heat energy must be put into or removed from rubbing alcohol to convert it into a gas.

SOLUTION

The heat energy required to convert rubbing alcohol from a liquid to a gas is provided by the heat in the skin. As heat moves from the skin into the rubbing alcohol, the skin cools.

PRACTICE PROBLEM 1.4

The boiling point of water is 100°C and that of ethyl alcohol is 78°C. In which liquid are the particles (molecules) held to one another more strongly?

1.3 UNITS OF MEASUREMENT

Making measurements is part of everyday life. Every time that you look at your watch to see how many minutes of class remain, tell a friend about your 5-mile run this morning, or save money by buying products with the lowest unit price, you are using measurements. Measurements are also a key part of the job of health professionals. A nurse might measure your pulse, blood pressure, and temperature; a dental hygienist might measure the depth of your gum pockets; or an occupational therapist might measure your hand strength to gauge the degree of recovery from an injury (Figure 1.10).