CHEMISTRY

The Study of Matter and Its Changes

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PREFACE

The successes of this text in its previous incarnations can be attributed to their relaxed writing style, student-friendly attitude, the clarity of definitions, and the thoroughness of the explanations of difficult concepts. We have retained these features in this text, but we have adopted a new title to reflect a broadening of the scope of the text and to emphasize that *this is a text for the mainstream general chemistry course for science and engineering students.*

OVERALL PHILOSOPHY AND GOALS

A general chemistry course must serve several goals in the education of a student. The primary goal is to provide a solid foundation in the basic concepts and facts of chemistry, particularly those needed by future scientists and engineers. The general chemistry course must also give the student an appreciation of the importance of chemistry to society in general and to daily life in particular. Because of the logical nature of chemistry, the course will also develop skills in analytical thinking and problem solving. When both the experimental and logical nature of chemistry are seen together in lecture and laboratory settings, the student will better appreciate how scientists work, how observations are used to formulate theories, and how theories are used to suggest additional experiments.

Scientists at their best know that the marvelous tools of logic and reason lead directly, not to fact but to theory, and that any good theory must still face such questions as, "Is the theory right or wrong?" The appreciation of these distinctions together with reasoning skills have significance far beyond the chemistry classroom or laboratory.

FEATURES THAT SERVE THE PHILOSOPHY AND GOALS

To fulfill the goals described above, we have focused on a number of major areas.

Organization: Our goal was to provide a logical progression of topics arranged to give maximum flexibility for the teacher in organizing his or her course.

Level: We have carefully developed discussions to provide students with clear, easily understood presentations of difficult topics while maintaining a light and student-friendly writing style.

Pedagogy: Aware of student difficulties in problem solving, we have adopted a unique approach to developing thinking skills. We distinguish three types of learning aids: those that further comprehension and learning; those that enhance problem-solving skills; and those that extend the breadth and knowledge of the student.

Illustrations: Modern, accurate illustrations that are eye appealing have been chosen to aid students in acquiring an understanding of complex concepts.

Photographs: A large collection of carefully chosen photographs play a pedagogically useful role in supplementing discussions throughout the text.

Supplements: A carefully integrated package of supplements is designed to aid both student and teacher in their respective roles.

Organization

The first 12 chapters emphasize the structure of matter, the states of matter, and the most fundamental kinds of chemical reactions, including their stoichiometric and thermochemical aspects. These chapters often form the first of a two-term sequence.

One of the goals of the first three chapters is to enable the instructor to plan an interesting and educationally meaningful laboratory program for the students. Many concepts, kinds of substances, and terms must be introduced early. Thus we intentionally do not say everything that must be said, for example about atomic and molecular structure, in one place. Basic concepts of structure come early (Chapter 2), largely to develop a vocabulary, as well as an important pattern such as the periodic law, and then important details are taken up later. By the end of Chapter 3, the student will have been introduced to the basic terms and concepts needed to benefit from the chemistry laboratory experience.

Chemists have believed for over a century that *structure determines properties.* This is the logic behind the placement of chapters 4–7, which take the student deep into the structures of atoms and molecules and the ways that electrical forces can become organized into chemical bonds. This study will foster an understanding of the states of matter, of chemical properties, and of the driving forces of reactions. By the end of Chapter 7, the student should have a sufficient understanding of molecular structure and the chemical bond to embark on an in-depth study of both the physical and chemical properties of matter and the parameters that govern chemical changes.

Chapters 8–10 take the student to a deeper study of the states of matter and to one particular kind of matter, the homogeneous mixture or solution. With a detailed background in molecular structure, chemical bonds, physical states, and the nature of a solution, the student is now ready to survey two of the major *kinds* of chemical reactions.

At the end of chapters 11 and 12, the student should have a rather broad background in structure and in both chemical and physical properties. The periodic table and LeChâtelier's principle have provided important correlations. The instructor who occasionally teases the class with the question, "What *drives* chemical and physical changes?" as these properties and correlations are studied will have aroused a strong curiosity. Chapters 13–15 take the student into the study of the fundamental factors that determine the spontaneity of both change and equilibrium. Chapter 13 (Thermodynamics) seeks to answer the question "Is a change possible?" Chapter 14 (Kinetics) examines the question "If a change *is* possible, how fast does it occur?" And Chapter 15 (Equilibrium) addresses the question "What is a system like when it ceases to change?"

Chapters 16–18 apply equilibrium concepts to major chemical systems. Except for nuclear chemistry, a study of the most basic concepts and theories of chemistry is now completed. *How nature works at the atomic and molecular level, as seen by chemists, has now been examined.* Many applications remain, including several impinging on chemistry, industry, the environment, and the biological sciences. Chapters 19–25 round out the study of the important properties of the most common elements.

Level

Students are not assumed to have had a previous course in chemistry and mastery of only basic algebra is expected. The level of the discussions in this book is probably best judged by the topic coverage in Chapters 13–16, those that deal with the driving forces for reactions, with chemical equilibria, and with exercises calling for a combination of thinking and computational skills. We believe that the level is right for the mainstream general college chemistry course.

Pedagogical Features

Features That Further Comprehension and Learning

Margin comments make it easy to enrich a discussion, without carrying the aura of being essential. Some margin comments jog the student's memory concerning a definition of a term.

Boldface terms alert the student to "must-learn" items.

Chapter summaries use the boldface terms to show how the terms fit into statements that summarize concepts.

Features that Enhance Problem-Solving Abilities

Many students entering college today lack experience in analytical thinking. A course in chemistry should provide an ideal opportunity to help students sharpen their skills because problem solving in chemistry operates on two levels. In addition to mathematics, because of the nature of the subject, many problems also involve the application of theoretical concepts. Students have difficulty at *both* levels, and one of the goals of this text has been to develop a *unified approach* that addresses each level.

Chemical Tools Approach to Problem Analysis. In studying chemistry, students learn many simple skills, such as finding the number of grams in a mole of a substance or writing the Lewis structure of a molecule. Problem solving involves bringing together a sequence of such simple tasks. Therefore, if we are to teach problem solving, we must teach students how to seek out the necessary relationships required to obtain solutions to problems.

In this text we take a new and innovative approach to problem solving that makes use of an analogy between the abstract tools of chemistry and the concrete tools of a mechanic. Students are taught to think of simple skills as tools that can be used to solve more complex problems. When faced with a new problem, the student is encouraged to examine the tools that have been taught and to select those that bear on the problem at hand.

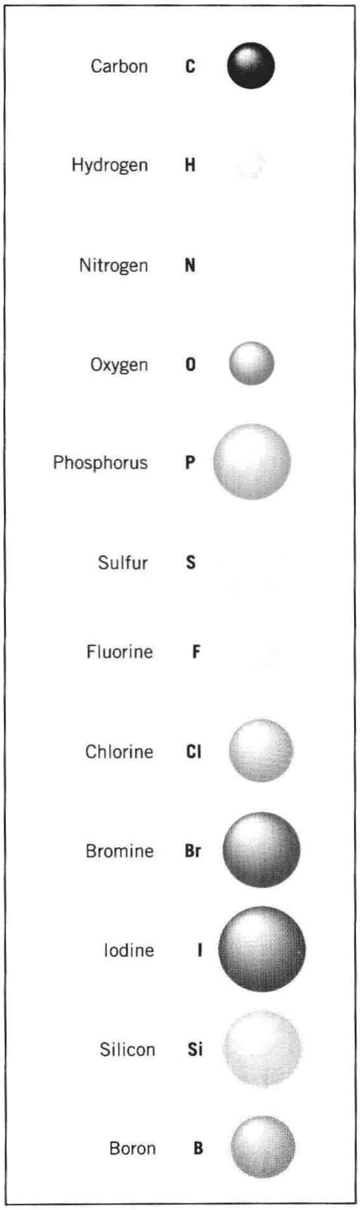
To foster this approach to thinking through problems, we present a comprehensive program of reinforcement and review:

This **icon** in the margin calls attention to each chemical tool when it is first introduced. Following the Summary at the end of the chapter, the tools are reviewed under the heading **Tools You Have Learned,** preparing students for the exercises that follow.

Worked Examples that involve an assemblage of concepts include a section entitled *Analysis* that describes the thought processes involved in the identification of the tools needed to solve the problem.

Practice Exercises follow the worked examples to enable the student to apply what has just been studied to a similar problem.

Thinking it Through is an innovative selection of end-of-chapter problems that takes the emphasis of problem solving away from the answer itself and focuses it instead *on the information needed to solve the problem.* The intent of the Thinking It Through problems is to further accustom the student to analyzing a problem before trying to carry out any computations.



Review Exercises provide routine practice in the use of basic tools as well as opportunities to incorporate these tools in the solution of more complex problems. Most Review Exercises are classified according to topic type, but several **Additional Exercises** at the ends of most problem sets are unclassified. Many problems are cumulative, requiring two or more concepts, and several in later chapters require skills learned in earlier chapters.

Tests of Facts and Concepts provide students with an opportunity to review concepts from the preceding chapters, and they include many problems that require the student to use concepts from more than one chapter.

Features that Extend the Breadth of Knowledge of the Student

Chemicals in Use. These are two-page, illustrated essays placed between most chapters. The essays offer students the opportunity to learn about some practical, real-world applications of chemistry in industry, medicine, and the environment. Essay topics include "Lasers in Chemistry," "Molecular Structure and the Computer," "Synthetic Diamonds and Diamond Coatings," "The Carbonate Buffer in Blood and Respiration," and "Ozone in the Stratosphere."

Special Topics. The Special Topics sometimes resemble *Chemicals in Use* essays but have lengths unsuited to the two-page format. Some Special Topics provide historical background; others concern chemistry and the environment.

Illustrations. Illustrations, which are distributed liberally throughout the text, have been carefully crafted using modern computer techniques to provide accurate, eye-appealing complements to discussions. Color is used constructively rather than for its own sake. For example, a consistent set of colors is used to identify atoms of the elements in drawings that illustrate molecular structure. These are shown in the margin at the left.

Photographs. The large number of striking photographs in the book serve two purposes. One is to provide a sense of reality and color to the chemical and physical phenomena described in the text. Toward this end, many photographs of chemicals and chemical reactions are included. The other purpose of the photographs is to illustrate how chemistry relates to the world outside the laboratory. The chapter-opening photos, for example, call the students' attention to the relationship between the chapter's content and common (and often not-so-common) things. Similar photos within the chapters illustrate common, practical examples and applications of chemical reactions and physical phenomena.

Supplements

A comprehensive package of supplements has been created to assist both the teacher and the student and includes the following:

Study Guide by James E. Brady and John R. Holum. This Guide has been written to further enhance understanding of concepts. It is an invaluable tool for students and contains chapter overviews, additional worked-out problems, and alternate problem-solving approaches as well as extensive review exercises.

Solutions Manual by Paul L. Gaus of Wooster College. The Manual contains worked-out solutions for text problems whose answers appear in Appendix D.

Chemistry in the Laboratory: A Study of Chemical and Physical Changes by Jo A. Beran of Texas A & I University. This volume contains 40 experiments, including significant microscale experiments designed to reduce the generation of waste. Each experiment begins with an introduction providing the "big picture" relevance of the experiment.

Instructor's Manual. In addition to lecture outlines, alternate syllabi, and chapter overviews, this Manual contains suggestions for small group active-learning projects, class discussions, and short writing projects. Conversion notes are included allowing the instructor to use class notes from other texts.

Test Bank. Microtest III, available for both IBM and Macintosh by the Chariot Software Group, is designed to streamline the test design process and offer greater flexibility in test generation. Instructors can create, refine, update, store, and print a variety of tests easily and conveniently. Charts, graphs, and other images may be inserted, and tests can be saved in ASCII format for transfer to word processing or desktop publishing programs.

Computer Test Bank. IBM and Macintosh versions of the entire Test Bank are available with full editing features to help you customize tests.

Four-Color Overhead Transparencies. Over 125 four-color illustrations from the text are provided in a form suitable for projections in the classroom.

Instructor's Manual for Chemistry in the Laboratory by Jo A. Beran of Texas A & I University. This manual carefully presents the details of each experiment and includes an overview, instructor's lecture outline, teaching hints, chemicals required with instructions for their preparation, and answers to all Lab Preview and Data Sheet questions.

JAMES E. BRADY
JOHN R. HOLUM

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TO THE STUDENT

You are about to begin what could be one of the most exciting courses that you will undertake in college. It offers you the opportunity to learn what makes our world "tick" and to gain insight into the roles that natural and synthetic chemicals play in nature and in our society. This knowledge will not come without some effort, however, and this book has been carefully designed and written with an awareness of the kinds of difficulties you may face. Therefore, before you begin, let us outline some of the key features of the book that will aid you in your studies.

CHEMICAL VOCABULARY

Every specialty has its own unique vocabulary, and chemistry is no exception. In this text you will find new terms set in bold type when you first encounter them. *We have not assumed that you've had a previous course in chemistry,* so these terms will not be used until they have been clearly defined. New terms are also set in bold type in the Summary that accompanies each chapter, and they are included in a Glossary at the end of the book so you can look up their meanings at a later time, if necessary.

PROBLEM SOLVING

Students often equate problem solving with doing mathematical calculations. It is really much more than that. Solving a problem involves *thinking* and *analyzing information.* This is true whether the problem relates to chemistry, physics, psychology, or some aspect of your private life. Learning to solve problems is learning *how* to think and *how* to incorporate information into the solution.

When first faced with a genuine problem, many people have no idea where to begin. One of the goals of this text is to provide you with a way to think about problem solving so you can be successful. You may find it difficult and slow going at first, but you *can* succeed if you're willing to put in the effort. And it is an effort that will pay off, not only in your chemistry course, but in other endeavors as well.

The *Chemical Toolkit* Approach to Problem Solving

Imagine for a moment what it would be like to be an auto mechanic. Among other things, you would need to be familiar with an assortment of tools. When faced with a repair job, you would study the problem and select the proper tools for the work.

Solving chemistry problems is not much different than repairing a car; we simply use different tools. When faced with a problem, we study it to see which of the tools we have learned fit the job. After we've selected the necessary tools, we use them to obtain the solution.

This is such a useful approach to solving problems that we have organized much of the book around it. In most chapters, you will be introduced to certain important concepts that will form the basis of problem-solving tools. Sometimes they will be mathematical in nature and other times they will involve theoretical concepts. The icon that appears in the margin will be used to highlight the tools as we go along, and at the end of the chapter there is a summary titled *Tools You Have Learned.*

Within the text you will encounter worked-out Examples that illustrate how the "chemical tools" are applied. Often, the examples will include an Analysis section that describes the thought processes involved in solving the problem. Following worked-out examples are Practice Exercises that give you an immediate opportunity to apply what you have just learned.

At the end of a chapter you will find two sets of exercises. The first set, titled *Thinking it Through,* asks you to describe *how* you would solve various problems. The goal is not the answer itself, but rather a description of the tools and method needed to obtain the answer. Some of these problems are simple, while others require a lot of thinking. Be sure to work on them all, however, because once you've learned *how* to solve a problem, obtaining the answer is simple.

Following the Thinking it Through exercises is a comprehensive set of *Review Exercises* that test your knowledge of all the topics discussed in the chapter. This is also another opportunity for you to practice your problem-solving skills.

After groups of related chapters you will encounter sets of problems titled *Test of Facts and Concepts.* You can use these to help review subjects covered in previous chapters.

FEATURES OF THE BOOK

• Processes that occur in the intensely hot interiors of stars, such as the ones that belong to the Cone Nebula shown here, are responsible for the creation of all the elements that make up our known universe. Elements are the basic chemical building blocks of all substances, and you begin your study of their properties and chemical reactions in this chapter.

CHAPTER INTRODUCTION

The chapter-opening photographs and their captions vividly illustrate how chemistry relates to the world outside the laboratory, calling the student's attention to the relationship between chapter content and common (and often not-so-common) things.

CHAPTER 2

THE STRUCTURE OF MATTER: ATOMS, MOLECULES, AND IONS

2.1 ELEMENTS, COMPOUNDS, AND MIXTURES

The study of chemistry requires organization, and organization is the theme of this chapter. A casual glance around you should reveal that matter occurs in many different forms. For example, plastics, paper, wood, steel, and paint are just a few things that are probably within your view. To study these materials, we need ways to categorize them so we can look for similarities and differences.

We begin with a discussion of three principal classes of matter—elements, compounds, and mixtures. We will also study in this chapter the basic structures of atoms as well as the periodic table, the chemist's chief tool for organization.

Elements

If a chemical reaction changes one substance into two or more others, a **decomposition** has occurred. For example, if we pass electricity through molten sodium chloride (salt), the silvery metal sodium and the pale green gas chlorine are formed. In this example, we have decomposed sodium chloride into two new, simpler substances. No matter how we try, however, sodium and chlorine cannot be decomposed further by chemical reactions into still simpler substances that can be stored and studied.

We observed sodium and chlorine reacting with each other to form sodium chloride in Chapter 1.

In chemistry, *substances that cannot be decomposed into simpler materials by chemical reactions are called* **elements.** Sodium and chlorine are two examples. Others you may be familiar with include iron, chromium, lead, copper, aluminum, and carbon (as in charcoal). Some elements are gases at room temperature, including chlorine, oxygen, hydrogen, nitrogen, and helium.

The 109 elements, by themselves and in chemical combination, account for all matter in all its enormous variety everywhere in the known universe. The fact that out of the seemingly infinite variety of things there are only just over a hundred elementary substances has greatly simplified the chemist's goal to understand the workings of nature.

So far, scientists have discovered 90 existing elements in nature and have made 19 more, for a total of 109. The names of the elements are given on the inside front cover of the book. The list may seem long, but many elements are rare; we will be most interested in only a relatively small number of them.

MARGINAL COMMENTS

Some margin comments jog the student's memory concerning a definition of a term or an important point, while others enrich the text's discussion.

ILLUSTRATIONS

Modern, accurate illustrations that are visually appealing have been chosen to help students acquire an understanding of complex concepts. Color is used constructively. For example, a consistent set of colors is used to identify atoms of the elements in drawings that illustrate molecular structure.

FIGURE 2.19

(a) In water there are discrete molecules that each consist of one atom of oxygen and two atoms of hydrogen. Each particle has the formula H_2O. (b) In sodium chloride, ions are packed in the most efficient way. Each Na^+ is surrounded by six Cl^-, and each Cl^- is surrounded by six Na^+. Because individual molecules do not exist, we simply specify the ratio of ions as NaCl.

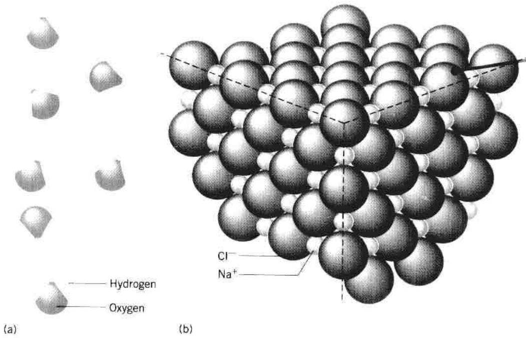

Figure 2.19 illustrates the structures of water and sodium chloride and demonstrates an important difference between molecular and ionic compounds. In water it is safe to say that two hydrogen atoms "belong" to each oxygen atom in a particle having the formula H_2O. However, in NaCl it is impossible to say that a particular Na^+ ion belongs to a particular Cl^- ion. The ions in a crystal of NaCl are simply stacked in the most efficient way, so that

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SPECIAL TOPICS

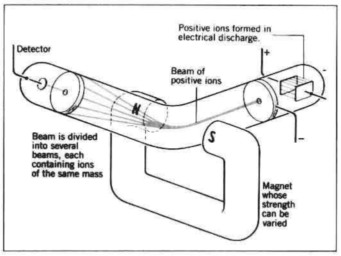
Carefully selected Special Topics provide additional real-world applications of chemistry and, occasionally, historical background.

SPECIAL TOPIC 2.3 / THE MASS SPECTROMETER AND THE MEASUREMENT OF ATOMIC MASSES

If a spark is passed through a gas, electrons are knocked off gas molecules. Because electrons are negatively charged, the particles left behind carry positive charges; they are called positive ions. These positive ions have different masses, depending on the masses of the molecules from which they are formed. Thus, some molecules have large masses and give heavy ions, while some have small masses and give light ions.

The device that is used to study the positive ions produced from gas molecules is called a *mass spectrometer* (illustrated in the figure). In a mass spectrometer, positive ions are created by passing an electrical spark (called an electric discharge) through a sample of the particular gas being studied. As the positive ions are formed, they are attracted to a negatively charged metal plate that has a small hole in its center. Some of the positive ions pass through this hole and travel onward through a tube that passes between the poles of a powerful magnet.

One of the properties of charged particles, both positive and negative, is that their paths become curved as they pass through a magnetic field. This is exactly what happens to the positive ions in the mass spectrometer as they pass between the poles of the magnet. However, the extent to which their paths are bent depends on the masses of the ions. This is because the path of a heavy ion, like that of a speeding cement truck, is difficult to change, but the path of a light ion, like the path of a lightweight auto, is influenced more easiy. As a result, heavy ions emerge from between the magnet's poles along different lines than the lighter ions. In effect, an entering beam containing ions of different mass is sorted by the magnet into a number of beams, each containing ions of the same mass. This spreading out of the ion



beam thus produces an array of different beams called a *mass spectrum.*

TABLE 2.3 Comparison of Predicted Propertie and Observed Properties of Germa

Property	Observed for silicon (Si)	Predicted for eka-silicon (Es)	Obs for (Sn)
Atomic mass	28	72	118
Melting point (°C)	1410	High	232
Density (g/cm³)	2.33	5.5	7.28
Formula of oxide	SiO_2	EsO_2	SnO
Density of oxide (g/cm³)	2.66	4.7	6.95
Formula of chloride	$SiCl_4$	$EsCl_4$	SnC
Boiling point of chloride (°C)	57.6	100	114

PHOTOS

The text's numerous and striking photographs add a sense of reality and color to the chemical and physical phenomena described in the text. Note also the story provided in the accompanying captions.

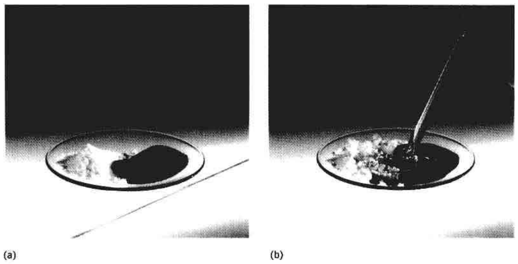


FIGURE 2.2

(*a*) Samples of powdered sulfur and powdered iron. (*b*) A mixture of sulfur and iron is made by stirring the two powders together.

FIGURE 2.3

Formation of the mixture is a physical change; it hasn't changed the iron and sulfur into a compound of these two elements. The mixture can be separated by pulling the iron out with a magnet.

One important way that mixtures differ from compounds is in the changes that occur when they form. Consider, for example, the elements iron and sulfur, which are pictured in powdered form in Figure 2.2a. We can make a mixture simply by stirring them together. In the mixture (Figure 2.2b), both elements retain their original properties. The process we use to create this mixture involves a physical change, rather than a chemical change, because no new chemical substances form. To separate the mixture, we could similarly use just physical changes. For example, we could remove the iron by stirring the mixture with a magnet — a physical operation. The iron powder sticks to the magnet as we pull it out, leaving the sulfur behind (Figure 2.3). The mixture could also be separated by treating it with a liquid called carbon disulfide, which is able to dissolve the sulfur but not the iron. Filtering the sulfur solution from the solid iron, followed by evaporating the liquid carbon disulfide from the sulfur solution, gives the original components, iron and sulfur, separated from each other.

As we noted earlier, formation of a compound from its elements involves a chemical reaction. Iron and sulfur, for example, combine to form a compound often called "fool's gold" because of its appearance. In this compound the elements no longer have the same properties they had before they were combined, and they cannot be separated by physical means. Just as the formation of

A sample of iron pyrite, commonly called "fool's gold."

PRACTICE EXERCISES

Practice Exercises enable students to apply what has just been studied in a concrete manner. Answers at the end of the text provide immediate feedback.

SOLUTIONS

Solutions carefully guide students through the problem-solving process and sometimes offer alternative paths to the answer.

ANALYSIS

Included in most examples, these sections describe the thought processes involved in identifying the tools needed to solve the problem.

22 / *Introduction*

EXAMPLE 1.4
Applying the Factor-Label Method

PROBLEM In 1975, the world record for the long jump was 29.21 ft. What is this distance in meters?

ANALYSIS The problem can be stated as

$$29.21 \text{ ft} = ? \text{ m}$$

One of several sets of relationships we can use is

$$1 \text{ ft} = 12 \text{ in.}$$

$$1 \text{ in.} = 2.54 \text{ cm} \qquad \text{(from Table 1.3)}$$

$$1 \text{ cm} = 10^{-2} \text{ m} \qquad \text{(from Table 1.2)}$$

Notice how they take us from feet to inches to centimeters to meters.

SOLUTION Now we apply the factor-label method by eliminating unwanted units to bring us to the units of the answer.

$$29.21 \cancel{\text{ft}} \times \frac{12 \cancel{\text{in.}}}{1 \cancel{\text{ft}}} \times \frac{2.54 \cancel{\text{cm}}}{1 \cancel{\text{in.}}} \times \frac{10^{-2} \text{ m}}{1 \cancel{\text{cm}}} = 8.903 \text{ m}$$

ft to in.
ft to cm
ft to m

If we were to stop after the first conversion factor, the units of the answer would be inches; if we stop after the second, the units would be centimeters, and after the third we get meters—the units we want. The answer has been rounded to four significant figures because that's how many there were in the measured distance. Notice that the numbers 12 and 2.54 do not affect the number of significant figures in the answer because they are exact numbers derived from definitions.

The relationship between the inch and the centimeter is exact, so the numbers in 1 in. = 2.54 cm have an infinite number of significant figures.

This is not the only way we could have solved this problem. Other sets of conversion factors could have been chosen. For example, we could have used

$$3 \text{ ft} = 1 \text{ yd}$$

$$1 \text{ yd} = 0.9144 \text{ m}$$

Then the problem would have been set up as

$$29.21 \cancel{\text{ft}} \times \frac{1 \cancel{\text{yd}}}{3 \cancel{\text{ft}}} \times \frac{0.9144 \text{ m}}{1 \cancel{\text{yd}}} = 8.903 \text{ m}$$

Many problems that you meet, just like this one, have more than one path to the answer. There isn't any *one* correct way to set up the solution. *The important thing is for you to be able to reason your way through a problem and find some set of relationships that can take you from the given information to the answer.* The factor-label method can help you find these relationships if you keep in mind the units that must be eliminated by cancellation.

■ **PRACTICE EXERCISE 2** Use the factor-label method to perform the following conversions: (a) 3.00 yd to inches; (b) 1.25 km to centimeters; (c) 3.27 mm to feet; (d) 20.2 miles/gallon to liters/kilometer.

WRITING

The authors' student-friendly writing style makes difficult topics clear and easy to understand.

IMPORTANT TERMS

Boldface terms alert the student to "must-learn" items.

CHEMICAL TOOLS

These icons, placed in the margin, selectively identify simple chemist's "tools" within the body of the text that students can use to solve problems.

1.7 DENSITY AND SPECIFIC GRAVITY

In Section 1.4 you learned that extensive properties (those that depend on the size of a sample) are not particularly valuable for purposes of identification. Mass and volume are two examples. If you had a sample of a silvery metal, you could not use either its mass or volume alone to determine what the metal is. This is because each of these quantities depends on how big the sample is.

An interesting thing about extensive properties is that if you take the ratio of two of them, the resulting quantity is usually independent of sample size. In effect, the sample size cancels out, and the calculated quantity becomes an intensive property. One useful property obtained this way is **density,** *which is defined as the ratio of an object's mass to its volume.* Using the symbols d for density, m for mass, and V for volume, we can express this mathematically as

$$d = \frac{m}{V} \tag{1.8}$$

Notice that to determine an object's density we make two measurements, mass and volume.

EXAMPLE 1.5
Calculating Density

PROBLEM A student measured the volume of an iron nail to be 0.880 cm³. She found that its mass was 6.92 g. What is the density of iron?

ANALYSIS This is a straightforward calculation that requires the definition of density given by Equation 1.8. Don't neglect to learn such definitions, because they are the tools you will need in situations like this.

SOLUTION To determine the density we simply take the ratio of mass to volume.

$$\text{density} = \frac{6.92\ \text{g}}{0.880\ \text{cm}^3} = 7.86\ \text{g/cm}^3$$

This could also be written as

$$\text{density} = 7.86\ \text{g/mL}$$

because 1 cm³ = 1 mL.

Each pure substance has its own characteristic density. Gold, for instance, is much more dense than iron. Each cubic centimeter of gold has a mass of 19.3 g, so its density is 19.3 g/cm³. By comparison, the density of water is 1.00 g/cm³, and the density of air at room temperature is about 0.0012 g/cm³.

Most substances, such as the mercury in the bulb of a thermometer, expand slightly when they are heated. The same amount of matter occupies a larger volume at a higher temperature, so the amount of matter packed into each cubic centimeter is less. Therefore, density decreases slightly with increasing temperature.[8] For solids and liquids the size of this change is small (see the data

Densities of Some Common Substances in g/cm³ at Room Temperature

Water	1.00
Aluminum	2.70
Iron	7.86
Silver	10.5
Gold	19.3
Glass	2.2
Air	0.0012

[8] Liquid water behaves oddly. Its maximum density is at 4 °C, so when water at 0 °C is warmed, its density increases until the temperature reaches 4 °C. As the temperature is increased further, the density of water gradually decreases.

SUMMARIES

The chapter's boldfaced terms are restated as concept statements.

SUMMARY

Elements, Compounds, and Mixtures An **element** is a substance that cannot be decomposed into something simpler by a chemical reaction. In more modern terms, an element is a substance whose atoms all have the same number of protons in their nuclei. Elements combine in fixed proportions to form **compounds.** Elements and compounds are **pure substances** that may be combined in varying proportions to give **mixtures.** A one-phase mixture is called a **solution** and is **homogeneous.** If a mixture consists of two or more phases it is **heterogeneous.** Formation or separation of a mixture into its components can be accomplished by a **physical change** in which the chemical properties of the components do not change. Formation or decomposition of a compound takes place by a **chemical change.**

Symbols, Formulas, and Equations Each element has been assigned an internationally agreed upon **chemical symbol.** These symbols are used to write **formulas** for chemical compounds in which the symbol stands for an atom of the element. Subscripts are used to specify how many atoms of each kind are present. Some compounds form crystals, called **hydrates,** that contain water molecules in definite proportions. Heating a hydrate usually can drive off the water. **Chemical equations** present before-and-after descriptions of chemical reactions. When **balanced,** a[...] equation contains **coefficients** that make the number o[...] atoms of each kind the same among the **reactants** and th[...] **products.**

Laws of Chemical Combination When accurate masses o[...] all the reactants and products in a reaction are measure[...] and compared, no observable changes in mass accompan[...] chemical reactions **(law of conservation of mass).** The mas[...] ratios of the elements in any compound are constant regard[...] less of the source of the compound or how it is prepare[...] **(law of definite proportions).** Whenever two element[...] form more than one compound, then the different masse[...] of one element that combine with a fixed mass of the othe[...] are in a ratio of small whole numbers **(law of multiple pro[...] portions,** discovered after Dalton had proposed his atomi[...] theory).

Dalton's Atomic Theory The three laws of chemical com[...] bination make most sense if we assume that matter consist[...] of atoms that can't break up during chemical reactions an[...] that have masses which don't alter throughout thes[...] changes. Most elements consist of a small number of **iso[...] topes** whose masses differ slightly. However, all of the iso[...] topes of an element have very nearly identical chemica[...] properties, and the percentages of the various isotopes tha[...] make up an element are generally so constant througho[...] the world that we can say that the average mass of the[...] atoms is a constant.

Atoms, Isotopes, and Atomic Masses Atoms can be split into **subatomic particles** such as **electrons, protons,** and **neutrons.** Protons (with a charge of 1+) and neutrons (no charge) make up the atomic **nucleus,** and the number of protons is called the **atomic number** (Z) of the element. Each element has a different atomic number. Electrons (with a charge of 1−) are found outside the nucleus, but their number equals the atomic number in a neutral atom. Isotopes of an element have identical atomic numbers but different numbers of neutrons. An element's **atomic mass (atomic weight)** is the relative mass of its atoms on a scale in which atoms of carbon-12 have a mass of exactly 12 u **(atomic mass units).**

The Periodic Table The search for similarities and differences among the properties of the elements led Mendeleev to discover that when the elements are placed in (approximate) order of increasing atomic weight, similar properties recur at regular, repeating intervals. In the modern **periodic table** the elements are arranged in rows, called **periods,** in order of increasing atomic number. The rows are stacked so that elements in the columns, called **groups** or **families,** have similar chemical and physical properties. The

Molecular and Ionic Compounds When atoms chemically combine to form compounds, the reactions produce either ions of opposite charge or neutral molecules, depending on the elements involved. An **ionic compound** always contains ions of both positive and negative charge. The ions always occur in a ratio that ensures that the net electrical charge on the **formula unit** is zero. When molecules form, the atoms are linked by the sharing of electrons. Molecules in **molecular compounds** carry no electrical charge.

When ionic **binary compounds** are formed, electrons are transferred from a metal to a nonmetal. The metal atom becomes a positive ion (a **cation**); the nonmetal atom becomes a negative ion (an **anion**). The formulas of ionic compounds are controlled by the requirement that the compound must be electrically neutral. Many ionic compounds also contain **polyatomic ions**—ions that are composed of two or more atoms. Ionic compounds tend to be brittle, high-melting, nonconducting solids. When melted or dissolved in water, however, they do conduct electricity. Most molecular compounds tend to be soft and to melt at low temperatures.

Naming Compounds International agreement between chemists provides a system that allows us to write a single formula from a compound's name. For **salts** (ionic compounds not containing OH^- or O^{2-}), the **Stock system** is preferred, but the older system must also be learned. Compounds between nonmetals use Greek prefixes to specify number. **Acids** are substances that react with water to give H_3O^+ (hydronium ions). They react with **bases** such as NaOH in **neutralization** reactions that yield water and salts. **Binary acids** are *hydro ... ic acids* and give *-ide* anions. **Oxoacids** and their anions are related: *-ic acids* produce *-ate* ions; *-ous acids* produce *-ite* ions. **Acid salts,** formed by the partial neutralization of **polyprotic acids,** contain acidic hydrogens and when named use the prefix *bi-* or contain the name *hydrogen.*

TOOLS YOU HAVE LEARNED

...Atoms in ...Equations	Counting atoms is a skill you will need to use frequently in the next chapter and at other points in the course.
Writing Formulas ...Ionic Compounds	Be sure you have mastered the rules for writing the formulas of ionic compounds. You will need to learn to use the periodic table to remember the charges on the cations and anions of the representative metals and nonmetals. You also should learn the ions formed by the transition and post-transition metals in Table 2.7, and it is essential that you learn the names and formulas of the polyatomic ions in Table 2.8.
Naming Compounds	Naming compounds is an important skill that you will need in order to communicate chemical information to others.

THINKING IT THROUGH

For each of the following problems, list all the necessary information needed to obtain the answer and briefly describe what is to be done with it. The goal here is not *to find the answer itself; instead, you are asked to assemble the available information needed to obtain the answer, state what additional experimental data (if any) are needed, and describe how you would use the data to answer the question.*

1. How many atoms are in 75 molecules of ethylene glycol, $C_2H_4(OH)_2$, the compound used in automotive antifreeze solutions?

2. How many atoms of each element (carbon, hydrogen, and oxygen) are in 40 molecules of glycerin, $C_3H_5(OH)_3$?

3. In an experiment it was found that 3.50 g of phosphorus combines with 12.0 g of chlorine to form the compound PCl_3. How many grams of chlorine would combine with 8.50 g of phosphorus to form this same compound?

4. Aluminum combines with oxygen to form aluminum

TOOLS YOU HAVE LEARNED

Tools identified in the chapter are summarized, encouraging their reexamination before beginning the end-of-chapter exercises.

THINKING IT THROUGH

This section emphasizes the importance of identifying the information needed to solve problems, fostering development of students' analytical skills.