Introductory Chemistry

An Active Learning Approach

Cracolice | Peters

6th Edition

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SIXTH EDITION

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***Introductory Chemistry: An Active Learning Approach,* Sixth Edition**
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Dedication

This book is dedicated to the memory of Robert R. Madsen (1945–2012), who was a science instructor at Chief Dull Knife College in Lame Deer, Montana, located within the Northern Cheyenne Nation. Bob was a tireless advocate for improvement of the quality of STEM education within the State of Montana, with an emphasis on STEM education for Native Americans. Bob was a masterful collaborator who mentored many students in authentic research experiences and helped in the reform of STEM education both locally and statewide, and I cannot adequately express how selfless and dedicated he was to his profession.

Contents Overview

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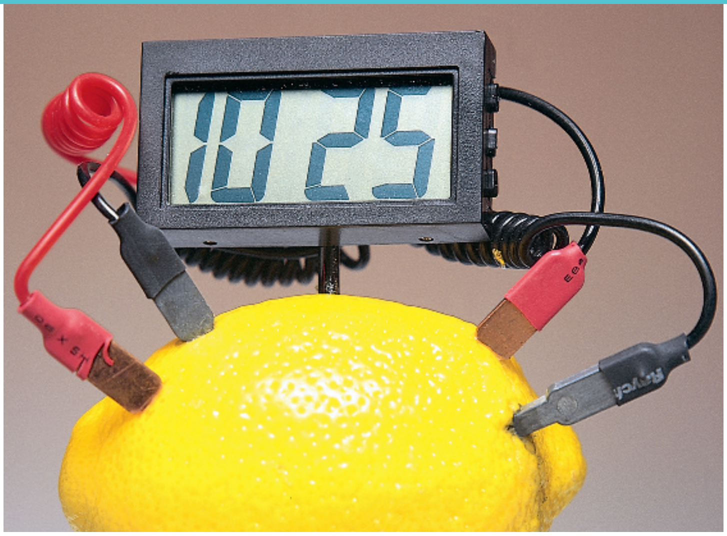

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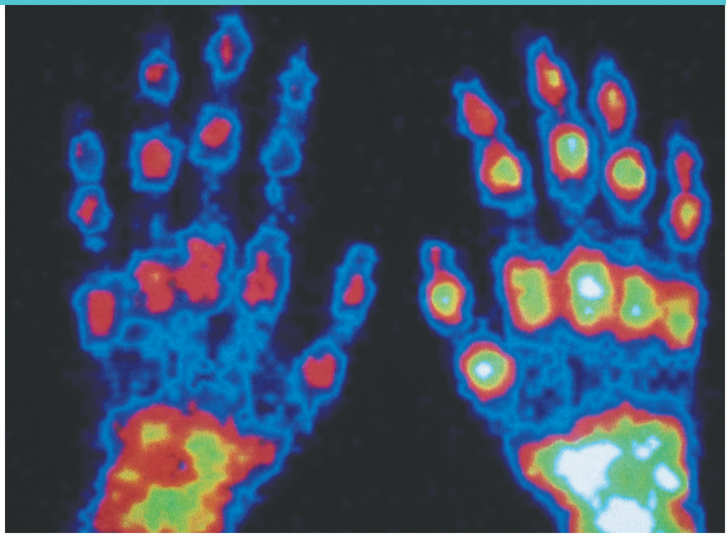
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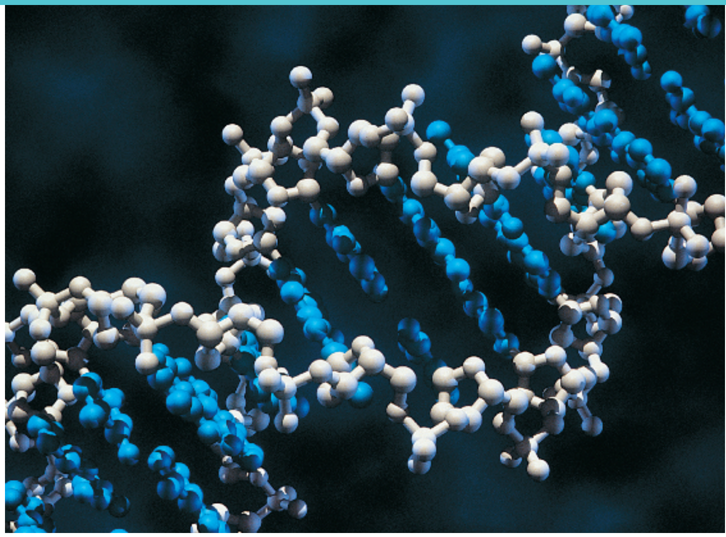

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Preface

Audience

The sixth edition of *Introductory Chemistry: An Active Learning Approach* is written for a college-level introductory or preparatory chemistry course for students who later will take a full-fledged general chemistry course. It can also be used for the first-term general portion of a two-term, general, organic, and biological chemistry course. It assumes that this is a student's first chemistry course, or if there has been a prior chemistry course, it has not adequately prepared the student for general chemistry.

Overarching Goals

Introductory Chemistry was written with the following broad-based goals. Upon completing the course while using this text, our hope is that students will be able to:

1. Read, write, and talk about chemistry, using a basic chemical vocabulary;

2. Write routine chemical formulas and equations;

3. Set up and solve chemistry problems;

4. Think about fundamental chemistry on an atomic or molecular level and visualize what happens in a chemical change.

To reach these goals, *Introductory Chemistry* helps students deal with three common problems: developing good learning skills, overcoming a weak background in mathematics, and overcoming difficulties in reading scientific material. The first problem is broached in Sections 1-4–1-5, which together make up an "introduction to active learning." These sections describe the pedagogical features of the text and how to use them effectively to learn chemistry in the least amount of time—that is, *efficiently.*

Introductory Chemistry deals with a weak quantitative problem-solving background in Chapter 3, "Measurement and Chemical Calculations." Algebra, including the use of conversion factors, is presented as a problem-solving method that can be used for nearly all of the quantitative problems in the book. The thought processes introduced in Chapter 3 are used in examples throughout the text, constantly reinforcing the student's ability to solve chemistry problems. These thought processes are featured in the examples found in Chapter 3, as well as in the main body of the text.

Active Learning Approach and Target Checks

The *Active Learning Approach* subtitle of the book refers in part to a question-and-answer presentation in which the student *actively learns* chemistry while studying an assignment, rather than studying now with the intent to learn later. A typical example leads students through a series of steps where they "listen" to the authors guide them to the solution, step-by-step, while simultaneously attempting the answer themselves. As students solve the problem, they actively write each

A sample Active Example: Students write in the right column, while guided by the authors in the left column.

answer step, covering the authors' answer with the shield provided in the book. This example feature turns the common passive "read the author's solution" approach into an active "work the problem" approach while guided by the authors' methodology.

Active Example 7-9 Percentage Composition by Mass III

How many grams of fluorine are in 216 g of calcium fluoride?

Think Before You Write The key concept is to use percentage as a conversion factor, grams of the element per 100 g of the compound.

Answers *Cover the left column with your tear-out shield. Reveal each answer only after you have written your own answer in the right column.*

Given: 216 g CaF_2 **Wanted:** g F 48.67 g F = 100 g CaF_2	In Active Example 7-7 you found that calcium fluoride is 48.67% fluorine. Use this percentage to solve the problem.
; the value of the answer is reasonable. You improved your skill at using percentage composition by mass as a conversion factor.	**Check** the solution. Is the value of the answer reasonable? What did you learn by solving this Active Example?

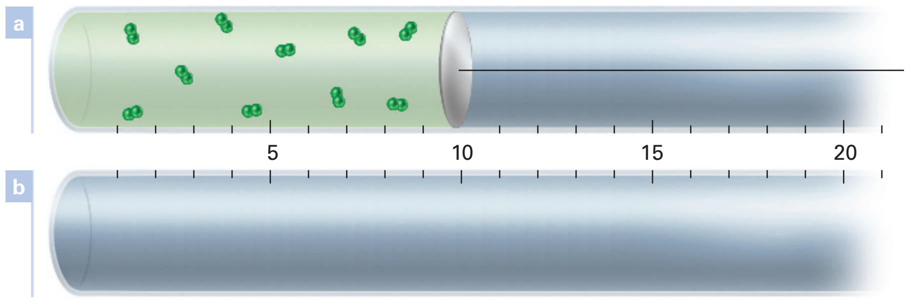
Practice Exercise 7-9

In Practice Exercise 7-7, you determined that aluminum chlorate is 38.35% chlorine. What mass of aluminum chlorate is needed as a source of 50.0 milligrams of chlorine?

We also provide *Target Check* questions for students to answer while studying the qualitative material. These just-in-time, fundamental questions help students to monitor their progress as they work instead of waiting for the end-of-chapter questions to discover incomplete understandings or misunderstandings.

A sample Target Check: A just-in-time check of students' understanding of the material.

Target Check 14-1



A horizontal cylinder (a) is closed at one end by a piston that moves freely left or right, depending on the pressure exerted by the enclosed gas. The gas consists of 10 two-atom molecules. A reaction occurs in which 5 of the molecules separate into one-atom particles. In cylinder (b), sketch the position to which the piston would move as a result of the reaction. Pressure and temperature remain constant throughout the process. (Hint: How many total particles would be present after the reaction? Include them in your sketch.)

Order of Coverage: A Flexible Format

Topics in a preparatory course or the general portion of a general–organic–biological chemistry course may be presented in several logical sequences, one of which is the order in which they appear in this textbook. However, it is common for individual instructors to prefer a different organization. *Introductory Chemistry* has been written to accommodate these different preferences by carefully writing each topic so that regardless of when it is assigned, it never assumes knowledge of any concept that an instructor might reasonably choose to assign later in the course. If some prior information is needed at a given point, it may be woven into the text as a ***Preview*** to the extent necessary to ensure continuity for students who have not seen it before, while affording a brief ***Review*** for those who have. (See the following P/Review.) At other times, margin notes are used to supply the needed information. Occasionally, digressions in small print are inserted for the same purpose. There is also an *Option* feature that actually identifies the alternatives for some topics. In essence, we have made a conscious effort to be sure that all students have all the background they need for any topic whenever they reach it.

P/Review Information and section references are provided in the narrative or as a note in the margin showing students were to find relevant information before or after a given section.

Introductory Chemistry also offers choices in how some topics are presented. The most noticeable example of this is the coverage of gases, which is spread over two chapters. Chapter 4 introduces the topic through the P-V-T combined gas laws. This allows application of the problem-solving principles from Chapter 3 immediately after they are taught. Then the topic is picked up again in Chapter 14, which uses the Ideal Gas Law. An instructor is free to move the Chapter 4 material to immediately precede Chapter 14, should a single “chapter” on gases be preferred.

We have a two-chapter treatment of chemical reactivity with a qualitative emphasis, preceding the quantitative chapter on stoichiometry. Chapter 8 provides an introduction to chemical reactivity, with an emphasis on writing and balancing chemical equations and recognizing reaction types based on the nature of the equation. After students have become confident with the fundamentals, we then increase the level of sophistication of our presentation on chemical change by introducing solutions of ionic compounds and net ionic equations. Chapter 9 on chemical change in solution may be postponed to any point after Chapter 8. Chapter 8 alone provides a sufficient background in chemical equation writing and balancing to allow students to successfully understand stoichiometry, the topic of Chapter 10. You may wish to combine Chapter 9 with Chapter 16 on solutions.

Chapter 14 features sections that offer *alternative* ways to solve gas stoichiometry problems at given temperatures and pressures. You can choose the section that you want to assign. Section 14-8 is based on what we call the molar volume method, where molar volume is used as a conversion factor to change between amount of substance in moles and volume. Section 14-9 is based on what we term the ideal gas equation method, where $PV = nRT$ and algebra is the method to make the amount–volume conversion.

On a smaller scale, there are minor concepts that are commonly taught in different ways. These may be identified specifically in the book, or mentioned only briefly, but always with the same advice to the student: *Learn the method that is presented in lecture. If your instructor’s method is different from anything in the book, learn it the way your instructor teaches it.* Our aim is to have the book support the classroom presentation, whatever it may be.

Features New to this Edition

MindTap™ Version A great deal of our effort in producing this edition was directed toward creating a MindTap™ version of the textbook. MindTap™ is an interactive online learning management system. The MindTap™ edition of this book has clickable answers for every Active Example problem, as well as clickable key terms and figure callouts. Students are able to create personalized Learning Paths with MindTap™ Reader that are flexible and easy to follow.

OWLv2 The OWL online learning system offers additional practice exercises and Personalized Study Plans (PSPs). All Test Yourself questions from the fifth edition have been altered to a multiple choice format in OWLv2, with more questions testing a broader range of course content. OWLv2 also contains a complete range of practice exercises to supplement the end-of-chapter problems found in the book. In addition, the chemical input tools have been improved to allow students to create more accurate chemical symbols, formulas, and equations. OWLv2 offers a range of study and planning tools that can be adjusted as a student progresses through the course topics.

Chapter Summaries Section The Chapter in Review cards from the fifth edition have been condensed into a single summary section that follows the last standard chapter (Chapter 22). This section effectively serves as a study guide for the textbook. It presents a list of the chapter goals, and each goal is followed with a summary of the key concepts associated with the goal, with key terms in bold. These summaries can be used as a preview to help students organize their learning before new material is introduced in the lecture portion of the course, and they serve as a review source during the term, as well as a comprehensive review source for the final exam.

Revised Approach to Measurement and Chemical Calculations (Chapter 3) Users of the fifth edition told us that the mathematical backgrounds of a significant fraction of their students were insufficient to fulfill the functional prerequisite for introductory chemistry. We therefore redesigned the calculations chapter to address this need. For example, we significantly revised what was Section 3-3 in the previous edition and split it into the new sixth edition Sections 3-2 and 3-3. Section 3-9 from the fifth edition is now integrated into the current Sections 3-2 and 3-3. This restructuring and revising provides a strengthened approach to teaching students how to solve quantitative problems. You will also notice that we have stopped using the term *dimensional analysis,* although we still use it as a problem-solving approach. Instead, we use the less daunting and more intuitive term *conversion factors.* All of the Active Examples have been revised to align with the revised approach, in both the calculations chapter and throughout the book.

Revised Approach to Nomenclature (Chapter 6) The users of the fifth edition also reported that the nomenclature chapter was a sticking point for a non-trivial fraction of their students. The faculty said that although they found the nomenclature chapter to be logical and well written, and they did not have specific suggestions for changes, they would appreciate it if we would try to come up with an improved pedagogy for teaching nomenclature. Accordingly, we decided to rewrite the nomenclature chapter with the goal of keeping it as simple as possible while still fully preparing students for the general chemistry sequence. If you feel that your students should know more nomenclature than we are now presenting, it will be a straightforward task to assign this additional responsibility.

The first change in the nomenclature chapter is the first section. Here, we provide a brief review of the topics that are prerequisite to learning nomenclature; plus, we give students a cross-referenced checklist to use for additional review, as necessary. We have reorganized the presentation of names and formulas of ions, and we have students writing the formula of ionic compounds earlier than we did in the previous edition. Then, as they learn new ions, they practice in context, writing formulas of those new ions as part of ionic compounds, reinforcing both the learning of the new ions and the procedure for writing ionic compounds. We've also broken oxoacid and oxoanion nomenclature into smaller chunks, which should make it easier to learn.

Increased Emphasis on Mental Arithmetic To further address the issue of insufficient mathematical preparation, we have increased our emphasis on estimating calculation results. All Active Examples that include a calculation now include an arithmetic check step. At a minimum, we aim to instill students with the philosophy that all results displayed on a calculator must be mentally challenged. Ideally, we hope they will embrace these estimation steps and improve their skill at doing mental arithmetic through practice. You may instruct students to omit these calculation verification steps, should your educational philosophy be such that you do not wish to require them in your course.

Merging of Dimensional Analysis and Algebra In previous editions, we have treated dimensional analysis and algebra as alternatives, where students should select one or the other as a problem solving approach. With this edition, we treat dimensional analysis as an application of algebra. In Section 3-2, we begin with an algebra refresher, and we introduce the concept that a quantity is the product of a value and a unit, where units can be cancelled just like common factors in the numerator and denominator of fractions. We then introduce dimensional analysis as a problem-solving method where equivalencies—two quantities that are equivalent in what they represent—can be written as two conversion factors. These concepts then become the basis of the strategy for solving quantitative problems in Section 3-3.

Simpler versus Precisely Correct Textbook authors continually battle with the issue of choosing between describing concepts simply versus giving a completely accurate and precise description. For example, the IUPAC definition of the mole is: "The mole is the amount of substance of a system which contains as many elementary entities as there are atoms in 0.012 kilogram of carbon-12; its symbol is 'mol.' When the mole is used, the elementary entities must be specified and may be atoms, molecules, ions, electrons, other particles, or specified groups of such particles." We have never seen a textbook that introduces the mole with its exact definition; there is literally unanimous agreement among the community of textbook authors and chemistry instructors that a simpler definition is a better pedagogical approach.

In this edition, we decided that we should lean toward the *simpler* choice a bit more heavily than in previous editions. The preparatory course is just that, preparatory, and any given concept can be described in more detail in the subsequent general chemistry course, if necessary. The GOB course is designed for students preparing for careers in the health professions, and these students need a firm foundation in fundamental chemistry in preparation for organic and biological chemistry; any necessary additional detail will be provided in the later part of the course sequence. For example, in previous editions, we used the terms exponential notation, standard exponential notation, exponential (scientific) notation, and scientific notation to describe what is essentially a single method for expressing numbers. Now we just use scientific notation. *Simpler.*

Everyday Chemistry Quick Quizzes Each Everyday Chemistry essay is now followed by two questions about the essay. Assignment of these questions is optional. Answers are provided in the Instructor's Manual.

Frequently Asked Questions This end-of-chapter feature has two main purposes: (1) to identify particularly important ideas and offer suggestions on how they can be mastered and (2) to alert students to some common mistakes so they can avoid making them.

Features Continuing in This Edition

Thinking About Your Thinking Boxes This feature helps students think about more than just the content of the chemical concepts; it gives them a broader view of the thinking skills used in chemistry. By focusing on how chemists think, students can not only learn the context in which material is presented but also improve their competence with the more general skill. These broad thinking skills can then be applied to new contexts in their future chemistry courses, in other academic disciplines, and throughout their lives.

Goals Learning objectives, identified simply as Goals, appear at the beginning of the section in which each topic is introduced. They focus attention on what students are expected to learn or the skill they are expected to develop while studying the section.

P/Review The flexible format of this book is designed so that any common sequence of topics will be supported. A cross-reference called P/Review refers to a topic already studied or one that is yet to be studied. Our aim is to provide a textbook that will work for your curriculum, as opposed to a book that dictates the curriculum design. We therefore assume that the chapters will not necessarily be assigned in numerical order. The P/Reviews allow flexibility in chapter order.

***a summary of…* and *how to…* Boxes** Clear in-chapter summaries and listings of steps that explain how to carry out a procedure appear throughout the text. These boxes allow students to reflect on what they've just studied and give them the structure for learning the chemistry.

Target Check Target Check questions enable students to test their understanding immediately after studying a topic. Target Checks are most prominent in the qualitative chapters, where the material does not fit well with Active Examples.

Everyday Chemistry All chapters have one or more Everyday Chemistry sections that move chemistry out of the textbook and classroom and into the daily experience of students. This feature gives students a concrete application of a principle within each chapter.

Concept-Linking Exercises An isolated concept in chemistry often lacks meaning to students until they understand how that concept is related to other concepts. Concept-Linking Exercises ask students to write a brief description of the relationships among a small group of terms or phrases. If they can express those relationships correctly in their own words, they understand the concepts.

Small-Group Discussion Questions A growing number of courses feature some sort of groupwork formally integrated within the curriculum. We believe that the end-of-chapter questions typically used as homework are best for individual study, so each chapter has a set of questions for that were designed with groupwork in mind. These questions are typically more conceptual, more challenging, and, potentially, more lengthy than the average end-of-chapter questions. We have not provided solutions to these questions in the hope of removing the temptation for students to give up too quickly and look at the solution as a method of learning how to answer the questions.

Questions, Exercises, and Problems Each chapter except Chapter 1 includes an abundant supply of questions, exercises, and problems arranged in three categories. There are questions grouped according to sections in the chapter, General Questions from any section in the chapter, and finally, More Challenging Problems. Answers for all blue-numbered questions appear at the end of the chapter. Interactive versions the questions are available in OWL (Online Web-Based Learning).

The Reference Pages Tear-out cards may be used as shields to cover step-by-step answers while solving Active Examples. One side of each card has a periodic table that gives students ready access to all the information that table provides. The reverse side of each card contains instructions, taken from Chapter 3, on how to use it in solving examples.

We also include a larger version of the Periodic Table and an alphabetical listing of the elements in another tear-out card. In addition, the information on the inside covers of the book comprises a summary of nomenclature rules, selected numbers and constants, definitions, and equations, and a mini-index of important text topics, all keyed to the appropriate section number in the text.

Appendices Appendixes I and II include a section on how to use a calculator in solving chemistry problems; a general review of arithmetic, exponential notation, algebra, and logarithms as they are used in this book; and a section on SI units and the metric system.

Glossary An important feature for a preparatory chemistry course is a glossary. With each end-of-chapter summary of Key Terms, we remind students to use their glossary regularly. The glossary provides definitions of many of the terms used in the textbook, and it is a convenient reference source to use to review vocabulary from past chapters.

Active Examples For many years, we have been following with great interest the research that utilizes magnetic resonance imaging as a technique to learn how the human brain works. One of the many findings from this line of research indicates that the brain continues to develop until people are in their late twenties. One way in which the pre–steady-state brain differs from the fully matured brain is in the nature of impulse control and decision making, where teenagers and people in their twenties tend to rely more on their impulses and are less adept at planning.

Given our personal observations of students often rushing to apply an algorithm immediately after reading a problem statement, matching the results of the brain research, we explicitly label the first frame in every Active Example as **Think Before You Write**. This is to encourage students to be less impulsive and to slow down and analyze the problem statement before working on the solution.

Active Examples are featured in two columns. The left column (the authors' answers) is to be covered by students while they write their own answers in the right column. As they actively work through and complete the solution in the right column, students can reveal the solution to each step in the left column, thereby receiving *immediate feedback* about their understanding of the concept as it is being formed.

Each example is titled so that students can better identify the concept or problem-solving skill they are learning. This should also be useful when reviewing for exams.

Practice Exercises Each Active Example is immediately followed by a parallel Practice Exercise designed to firm up the potentially fragile new knowledge that was just constructed during the process of completing the companion Active Example. The Practice Exercises cover the same concept as the Active Example, but they are typically slightly more challenging, leading students toward improved conceptual understanding and problem-solving skills. Solutions to the Practice Exercises are provided at the end of the chapter.

Art and Photography We have maintained the large number of photographs in the book, illustrating the chemistry that is also described in words. We have also retained high-quality art pieces, with an emphasis on simple color schemes, plentiful macro-to-micro art, and instructional descriptions.

End-of-Chapter Illustrations Well over 100 photographs and line drawings appear in the end-of-chapter Questions, Exercises, and Problems, primarily to better illustrate the macroscopic aspect of chemistry. Students will now be able to see physical and chemical changes and common forms of industrial manufacturing processes, as well as to better visualize the scenarios described in the questions.

Readability

We aim to help students overcome difficulties in reading scientific material by discussing chemistry in simple, direct, and user-friendly language. Maintaining the book's readability continues to be a primary focus in this edition. The book features relatively short sections and chapters to facilitate learning and to provide flexibility in ordering topics.

Alternate Versions

***Introductory Chemistry: An Active Learning Approach*, sixth edition Hybrid Version with Access (24 months) to OWLv2 with MindTap Reader**

ISBN: 9781305108981

This briefer, paperbound version of *Introductory Chemistry: An Active Learning Approach,* **sixth edition** does not contain the end-of-chapter problems, which can be assigned in OWL, the online homework and learning system for this book. Access to OWLv2 and the MindTap Reader eBook is included with the Hybrid version. The MindTap Reader is the full version of the text, with all end-of-chapter questions and problem sets.

Supporting Materials

Please visit **http://www.cengage.com/chemistry/cracolice/introchem6e** for information about student and instructor resources for this text, including custom versions and laboratory manuals.

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We continue to be very much interested in your opinions, comments, critiques, and suggestions about any feature or content in this book. Please feel free to write us directly or through Cengage, or contact us via e-mail.

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1

Introduction to Chemistry and Introduction to Active Learning

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◀ How many students in a typical Introductory Chemistry course are chemistry majors? Usually it is only a small fraction. How many students in a typical Introductory Chemistry course need chemistry for their major? All of them—that is why the students gathered around this table in their school library are studying chemistry together. In fact, all educated members of society need to know the fundamentals of chemistry to understand the natural world. In this chapter, we introduce you to the science and study of chemistry and all of the learning tools available to you, including this textbook.

CHAPTER CONTENTS

Welcome to your first college chemistry course! Chemistry is the gateway to careers in scientific research and human and animal health. You may be wondering why you, as a biology, premedicine, pharmacy, nursing, or engineering major—or as someone with any major other than chemistry—are required to take this course. The answer is that all matter is made up of molecules, and chemistry is the science that studies how molecules behave. If you need to understand matter, you need to know chemistry.

What lies before you is a fascinating new perspective on nature. You will learn to see the universe through the eyes of a chemist, as a place where you can think of all things large or small as being made up of extremely tiny **molecules** ▶. Let's start by taking a brief tour of some of the amazing variety of molecules in our world.

Key terms are indicated with **boldface print** throughout the textbook.

First consider the simple hydrogen molecules in **Figure 1-1(a)**. This shows you what you would see if you could take a molecular-level look at a cross section from a cylinder filled with pure hydrogen. The molecules are moving incredibly fast—more than 4,000 miles per hour when the gas is at room temperature! The individual molecule is two hydrogen atoms attached by the interaction between minute, oppositely charged particles within the molecule. Even though the hydrogen molecule is simple, it is the high-energy fuel that

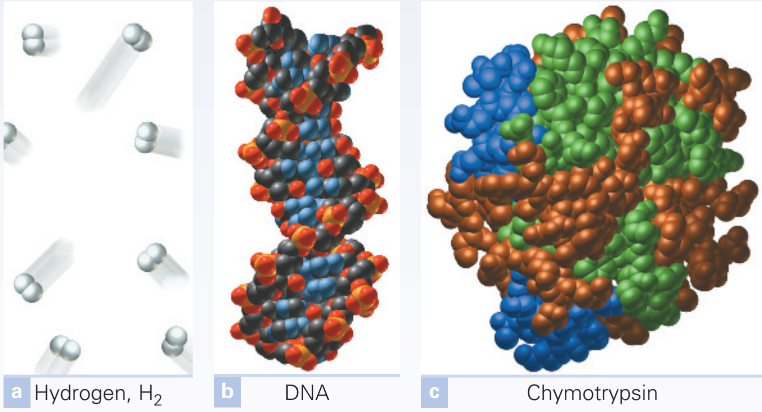

Figure 1-1 A sampling from the amazing variety of molecules. (a) A molecular-level view of a tiny sample of pure hydrogen. Each hydrogen molecule is made up of two hydrogen atoms. Hydrogen is a gas (unless pressurized and cooled to a very low temperature), so the molecules are independent of one another and traveling at very high speeds. (b) A molecule of deoxyribonucleic acid, more commonly known as DNA. Notice how the molecule twists around a central axis. Also observe the repeating units of the pattern within the molecule. (c) The protein chymotrypsin, which is one of approximately 100,000 different types of protein molecules in the human body. The function of this molecule is to speed up chemical reactions.

powers the sun and other stars. It is the ultimate source of most of the energy on earth. Hydrogen is found everywhere in the universe. It is part of many molecules in your body. Hydrogen is also the favorite molecule of theoretical chemists, who take advantage of its simplicity and use it to investigate the nature of molecules at the most fundamental level.

Now look at the DNA molecule (**Fig. 1-1[b]**). DNA is nature's way of storing instructions for the molecular makeup of living beings. At first glance, it seems complex, but on closer inspection you can see a simple pattern that repeats to make up the larger molecule. This illustrates one of the mechanisms by which nature works—a simple pattern repeats many times to make up a larger structure. DNA stands for deoxyribonucleic acid, a compound name that identifies the simpler patterns within the molecule.

Even this relatively large molecule is very, very tiny on the human scale. Five million DNA molecules can fit side-by-side across your smallest fingernail. (By the way, if you are a health or life sciences major, we think you'll agree that understanding the DNA molecule is a critical part of your education!)

Speaking of fingernails, they are made of the protein keratin. The human body contains about 100,000 different kinds of protein molecules. Some protein molecules in living organisms act to speed up chemical reactions. **Figure 1-1(c)** shows one such molecule, known as chymotrypsin. Proteins have many other essential biological functions, including being the primary components of skin, hair, and muscles, as well as serving as hormones.

Before you can truly understand the function of complex molecules such as DNA or proteins, you will have to understand and link together many fundamental concepts. This book and course are your first steps on the journey toward understanding the molecular nature of matter.

Now that you've had a look into the future of your chemistry studies, let's step briefly back to the past and consider the time when the science now called chemistry began.

1-1 Introduction to Chemistry: Lavoisier and the Beginning of Experimental Chemistry

Antoine Lavoisier (1743–1794) is often referred to as the father of modern chemistry (**Fig. 1-2**). His book *Traité Élémentaire de Chime,* published in 1789, marks the beginning of chemistry as we know it today, in the same way Darwin's *Origin of Species* forever changed the science of biology.

Lavoisier's experiments and theories revolutionized thinking that had been accepted since the time of the early Greeks. Throughout history, a simple observation defied explanation: When you burn a wooden log, all that remains is a small amount of ash. What happens to the rest of the log? Johann Becher (1635–1682) and Georg Stahl (1660–1734) proposed an answer to the question. They accounted for the "missing" weight of the log by saying that *phlogiston* was given off during burning. In essence, wood was made up of two things, phlogiston, which was lost in burning, and ash, which remained after. In general, Becher and Stahl proposed that *all* matter

The Metropolitan Museum of Art/Art Resource, NY

Figure 1-2 Antoine Lavoisier and his wife, Marie. They were married in 1771 when he was 28 and she was only 14. Marie was Antoine's laboratory assistant and secretary.

that had the ability to burn was able to do so because it contained phlogiston.

Lavoisier doubted the phlogiston theory. He knew that matter loses weight when it burns. He also knew that when a candle burns inside a sealed jar, the flame eventually goes out. The larger the jar, the longer it takes for the flame to disappear. How does the phlogiston theory account for these observable facts? If phlogiston is given off in burning, the air must absorb the phlogiston. Apparently a given amount of air can absorb only so much phlogiston. When that point is reached, the flame is extinguished. The more air that is available, the longer the flame burns.

So far, so good—no contradictions. Still, Lavoisier doubted. He tested the phlogiston theory with a new experiment. Instead of a piece of wood or a candle, he burned some phosphorus. Moreover, he burned it in a bottle that had a partially inflated balloon over its top (**Fig. 1-3[a]**). When the phosphorus burned, its ash appeared as smoke. The smoke was a finely divided powder, which Lavoisier collected and weighed. Curiously, the ash weighed more than the original phosphorus. What's more, the balloon collapsed; there was less air in the jar and balloon after burning than before (**Fig. 1-3[b]**).

Figure 1-3 Lavoisier's phosphorus-burning experiment. (a) The sample of phosphorus inside the jar is burning. (b) A fine dust of white ash remains after burning. The balloon has collapsed.

What happened to the phlogiston? What was the source of the additional weight? Why did the volume of air go down when it was supposed to be absorbing phlogiston? Is it possible that the phosphorus absorbed something from the air, instead of the air absorbing something (phlogiston) from the phosphorus? Whatever the explanation, something was very wrong with the theory of phlogiston.

Lavoisier needed new answers and new ideas. He sought them in the chemist's workshop: the laboratory. He devised a new experiment in which he burned liquid mercury in air. This formed a solid red substance (**Fig. 1-4**). The result resembled that of the phosphorus experiment. The red powder formed weighed more than the original mercury. Lavoisier then heated the red powder by itself. It decomposed, reforming the original mercury and a gas. The gas turned out to be oxygen, which had been discovered and identified just a few years earlier.

These experiments—burning phosphorus and mercury, both in the presence of air and both resulting in an increase in weight—disproved the phlogiston theory. A new hypothesis took its place: When a substance burns, it combines with oxygen in the air. This hypothesis has been confirmed many times. It is now accepted as the correct explanation of the process known as burning.

But wait a moment. What about the ash left after a log burns? It does weigh less than the log. What happened to the lost weight? We'll leave that to you to think about for a while. You probably have a good idea about it already, but (also

Figure 1-4 Lavoisier's apparatus for investigating the reaction of mercury and oxygen, as illustrated in his book *Traité Élémentaire de Chime.*

probably) you aren't really sure. If you were Lavoisier, and you wondered about the same thing, what would you have done? Another experiment, perhaps? We won't ask you to perform an experiment to find out what happens to the lost weight. We'll tell you—but not now. The answer is explained in Chapter 9.

Before leaving Lavoisier, let's briefly visit a spin-off of his phosphorus experiment. Lavoisier was the first chemist to measure the weights of chemicals in a reaction. The concept of measuring weight may seem obvious to you today, but it was revolutionary in the 1700s. We have already noted that the phosphorus gained weight. The weight gained by the phosphorus was "exactly" the same as the weight lost by the air. "Exactly" is in quotation marks because the weighing was only as exact as Lavoisier's scales and balances were able to measure. As you will see in Chapter 3, no measurement can be said to be "exact." In Chapter 2, you will see the modern-day conclusion of Lavoisier's weight observations. It is commonly known as the Law of Conservation of Mass. It says that mass is neither gained nor lost in a chemical change.

1-2 Introduction to Chemistry: Science and the Scientific Method

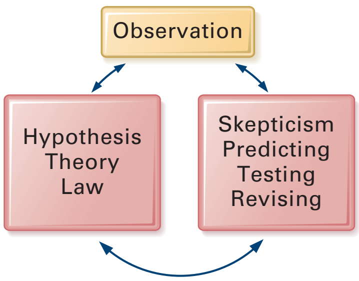

Figure 1-5 The scientific method.

We have selected a few of Antoine Lavoisier's early experiments to illustrate what has become known as the **scientific method** (**Fig. 1-5**). Examining the history of physical and biological sciences reveals features that occur repeatedly. They show how science works, develops, and progresses. They include the following:

1. *Observing.* A wooden log loses weight when it burns.
2. *Proposing a hypothesis.* A **hypothesis** is a tentative *explanation* for observations. The initial hypothesis posed by scientists before Lavoisier was that wood—and everything else that burns—contains phlogiston. When something burns, it loses phlogiston.
3. *Being skeptical.* Lavoisier was skeptical of the phlogiston hypothesis because metals gained weight when strongly heated. If this process was similar to burning wood, why was the phlogiston not lost?
4. *Predicting an outcome that should result if the hypothesis is true.* When phosphorus burns, it should lose weight.
5. *Testing the prediction by an experiment.* Lavoisier burned phosphorus. It gained weight instead of losing it. The new observation required. . . .
6. *Revising or changing the hypothesis.* Lavoisier proposed that burning combines the substance burned and oxygen from the air. (How did Lavoisier know about oxygen?)
7. *Testing the revised or new hypothesis and predicting a new experimental outcome.* The new hypothesis was supported when Lavoisier burned mercury and it gained weight.
8. *Upgrading the hypothesis to a theory by more experiments.* Lavoisier and others performed many more experiments. (How did others get into the process?) All the experiments supported the explanation that burning involves combining with oxygen in the air. When a hypothesis is tested and confirmed by many experiments under varying conditions, without contradiction, it becomes a **theory** or **scientific model**.

The scientific method is not a rigid set of rules or procedures. When scientists get ideas, they most often try to determine if anyone else has had the same idea or perhaps has done some research on it. They do this by reading the many scientific journals in which researchers report the results of their work. Modern scientists communicate with each other through technical literature. Scientific periodicals

Figure 1-6 Chemical Abstracts Service, a division of the American Chemical Society, is located in Columbus, Ohio. They maintain a database of chemical substances. You can search about 7,900 common chemicals at http://commonchemistry.org/. Your college or university library may have subscriptions to more powerful database searching tools.

are also a major source of new ideas, as well as talks and presentations at scientific professional meetings.

Communication is not usually included in the scientific method, but it should be. Lavoisier knew about oxygen because he read the published reports of Joseph Priestley and Carl Wilhelm Scheele, who discovered oxygen independently in the early 1770s. In turn, other scientists learned of Lavoisier's work and confirmed it with their own experiments. Today, communication is responsible for the explosive growth in scientific knowledge (**Fig. 1-6**). It is estimated that the total volume of published scientific literature in the world doubles every 8 to 10 years.

Another term used to describe patterns in nature in a general way is *law.* In science, a **law** is a summary of a pattern of regularity detected in nature. Probably the best known is the law of gravity: objects are attracted to one another. If you release a rock above the surface of the earth, it will fall to the earth. No rock has ever "fallen" upward.

A scientific law does not explain anything, as a hypothesis, theory, or scientific model might. A law simply expresses a pattern. Although laws cannot be proved, we do rely on them. The only justification for such faith is that in order for a law to be so classified, it must have no known exceptions. Water never runs uphill.

1-3 Introduction to Chemistry: The Science of Chemistry Today

Chemists study matter and its changes from one substance to another by probing the smallest basic particles of matter to understand how these changes occur. Chemists also investigate energy gained or released in chemical change—heat, electrical, mechanical, and other forms of energy.

Chemistry has a unique, central position among the sciences (**Fig. 1-7**). It is so central that much research in chemistry today overlaps physics, biology, geology, and other sciences. You will frequently find both chemists and physicists, or chemists and biologists, working on the same research problems. Scientists often refer to themselves with compound words or phrases that include the suffix or word *chemist:* biochemist, geochemist, physical chemist, medicinal chemist, and so on.

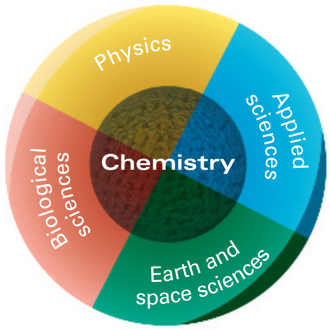

Figure 1-7 Chemistry is the central science. Imagine all sciences as a sphere. This cross section of the science sphere shows chemistry at the core. If you view the other sciences as surface-to-center samples, each contains a chemistry core.

Chemistry has traditionally been classified into five subdivisions: analytical, biological, organic, inorganic, and physical. Analytical chemistry is the study of what (qualitative analysis) and how much (quantitative analysis) are in a sample of matter. Biological chemistry—biochemistry—is concerned with living systems and is by far the most active area of chemical research today. Organic chemistry

Fancy/Jupiter Images

Figure 1-8 Chemists at work.

Alexey Nikolsky/AFP/Getty Images/Newscom

Figure 1-9 Polypropylene plant. Plastics are the substances produced in the greatest quantity by the chemical industry. This plastic manufacturing facility is located in Tobolsk, Russia (a historic capital of Siberia).

is the study of the properties and reactions of compounds that contain carbon. Inorganic chemistry is the study of all substances that are not organic. Physical chemistry examines the physics of chemical change.

You will find chemists—the people who practice chemistry—in many fields. Probably the chemists most familiar to you are those who teach and do chemical research in colleges and universities. Many industries employ chemists for research, product development, quality control, production supervision, sales, and other tasks. The petroleum industry is the largest single employer of chemists, but chemists are also highly visible in medicine, government, chemical manufacturing, the food industry, and mining (**Fig. 1-8**).

Chemical manufacturers produce many things we buy and take for granted today. They convert raw materials available in nature, such as oil, coal, and natural gas, into products such as plastics, fertilizers, and pharmaceutical drugs. The most commonly produced products are plastics, such as plastic bags, bottles, and packaging (**Fig. 1-9**). Another familiar and important category of manufactured goods from the chemical industry is health products, such as pharmaceuticals and nutritional supplements. Millions of people are employed worldwide by the chemical industry. The German-based company BASF is the largest chemical company in the world. The chemical company in the United States with the greatest dollar amount of sales currently is Dow Chemical.

1-4 Introduction to Active Learning: Learning How to Learn Chemistry

Here is your first chemistry "test" question:

Which of the following is your primary goal in this introductory chemistry course?

A. To learn all the chemistry that I can in the coming term.

B. To spend as little time as possible studying chemistry

C. To get a good grade in chemistry.

D. All of the above.

If you answered A, you have the ideal motive for studying chemistry—and any other course for which you have the same goal. Nevertheless, this is not the best answer.

If you answered B, we have a simple suggestion: Drop the course. Mission accomplished.

If you answered C, you have acknowledged the greatest short-term motivator of many college students.

Fortunately, most students have a more meaningful purpose for taking a course.

If you answered D, you have chosen the best answer.

Let's examine answers A, B, and C in reverse order.

C: There is nothing wrong in striving for a good grade in any course, just as long as it is not your major objective. A student who has developed a high level of skill in cramming for and taking tests can get a good grade even though he or she has not learned much. That helps the grade point average, but it can lead to trouble in the next course of a sequence, not to mention the trouble it can cause when you graduate and aren't prepared for your career. It is better to regard a good grade as a reward earned for good work.

B: There is nothing wrong with spending "as little time as possible studying chemistry" as long as you *learn* the needed amount of chemistry in the time spent. Soon we'll show why the amount of time required to *learn* (not just study) chemistry depends on *when* you study *and* learn. They should occur simultaneously. Reducing the time required to complete any task satisfactorily is a worthy objective. It even has a name: *efficiency.*

A: There is nothing wrong with learning all the chemistry you can learn in the coming term, as long as it doesn't interfere with the rest of your schoolwork and the rest of your life. The more time you spend studying chemistry, the more you will learn. College is the last period in the lives of most people in which the majority of their time can be devoted to intellectual development and the acquisition of knowledge, and they should take advantage of the opportunity. But maintain some balance. Mix some of answer B in your endeavor to learn. Again, the key is efficiency.

To summarize, the best goal for this chemistry course—and for all courses—is to learn as much as you can possibly learn in the smallest *reasonable* amount of time.

The rest of this section identifies choices that you need to make to ensure that you will reach your goal.

Choice 1: Commit to Sufficient Time Outside of Class

A rule of thumb for college coursework is that an average student in an average course should spend two hours outside of class for every hour in class. Are you ready to *choose* to make this commitment? You may have to spend more time outside of class if your math skills are weak, if you have not recently had a good high school chemistry course, if English is not your native language, or if you have been out of school for some time. To keep your out-of-class time to an efficient minimum, you must study regularly, doing each assignment before the next class meeting. Chemistry builds on itself. If you don't complete today's assignment before the next class meeting, you will not be ready to learn the new material. Many successful students schedule regular study time, just as they would schedule a class. *Failure to commit sufficient time outside of class is the biggest problem when it comes to learning chemistry.*

Choice 2: Commit to Quality Time When Studying

Efficient learning means learning at the time you are studying. It does not mean just reading your notes or the book and deciding to come back and learn the material later. It takes longer to *learn now* than it does to passively read the textbook, but the payoff comes with all the time you save by not having to learn later. This is so important that we have special *Learn It Now!* reminders throughout the textbook. Are you ready to *choose* to commit to making your study time high quality? If so, you should also commit to studying without distractions—without sounds, sights, people, or thoughts that take your attention away from learning. Turn your cell phone off for at least an hour at a time while studying. Every minute your mind wanders while you study must be added to your total study time. Your time is limited, and that wasted minute is lost forever.

Choice 3: Commit to Utilizing All Learning Resources

College chemistry courses typically have a multitude of learning resources, which may include lecture, this textbook and its accompanying online learning tools, laboratory exercises, discussion sections, help centers, tutors, instructor office hours, Internet resources, and your school library. Are you ready to *choose* to commit to taking advantage of all of the learning tools provided in your course? Let's consider some of these tools in more detail.

Lecture Although it is obviously the wrong way to learn, some students choose to skip lectures occasionally. Don't be one of those students. *Attend every lecture* (**Fig. 1-10**). If you miss just one lecture per month in a semester course, you will probably miss 10% of the material. That is a reduction of one letter grade worth of content in a typical course. You need to learn the role of lecture in your course. If your instructor expects you to listen to his or her discussion and watch presentation slides and/or material written on the board or an overhead projector, you will need to take notes. We recommend that your note-taking procedure follow these general steps: (1) Preview the material by skimming the textbook. Usually, this only needs to be done every few lectures as a new chapter is about to be introduced. Look in particular for new words and the major concepts so that you are not caught unprepared when they are introduced in lecture. (2) Concentrate during lecture and take notes. Don't fool yourself; concentrating over an extended period of time is hard work. Focus on what is being shown and said, and work to transcribe as much material as accurately and quickly as you can. Use a notebook that is exclusively for chemistry lecture. (3) Organize your notes as soon as possible after lecture. Organization is the key. During a classic lecture, you often are mostly working to transcribe the material. True learning occurs when you work to make sense of the material and try to analyze the relationships among the concepts that were discussed. (4) Study the textbook, work the assigned problems, and look for connections between the lecture and the textbook. You will often find that seeing the material presented in a slightly different way is the key to helping you make sense of a concept. Combining your organized lecture notes with the textbook presentation of the same topic is a powerful learning technique.

Figure 1-10 Introductory chemistry is often taught in large lecture halls. Attendance at every lecture is important, even if roll is not taken.

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Textbook This book is a central learning resource in your chemistry course. We will help you to become familiar with its structure in the next section.

MindTap This highly interactive, fully online version of the book combines multimedia, activities, and assessments to further engage your active learning of chemistry.

Laboratory If your course includes a laboratory, learn what each experiment is designed to teach. Relate the experiment to the lecture and textbook coverage of the same topic. Seeing something in the laboratory and getting a hands-on experience is often just what you need to fully understand what you read in the textbook and see and hear in the lecture.

Instructor Office Hours Many chemistry instructors are available for help outside of class. If your instructor is not, you likely have a teaching assistant with office hours or a tutoring center that you can visit instead. No matter the quality of print or electronic instructional resources available to you, human help is occasionally needed to accomplish your learning goals. We recommend that you develop a list of questions and/or sample problems that you cannot solve before you attend office hours.

Internet The Internet provides you with an abundance of information related to introductory chemistry. When a topic presented in class or this textbook is unclear, clarification may be available by doing a search for the topic to see if an alternative perspective helps you learn. A well-written website can often have the information you need to solidify your understanding of a concept. However, you should use the Internet with a healthy dose of skepticism. Most websites lack the sequencing, structure, and integration of topics that your instructor, your course curriculum, and this textbook provide. Also be sure that you choose reputable websites to ensure that you are not led astray by incorrect or incomplete information.

Library or Learning Center Many college libraries and learning centers have Internet resources, computer programs, workbooks, and other learning aids that are helpful for practice with using chemical formulas, balancing equations, solving problems, and other routine skills. Find out what is available for your course and use it as needed. Some instructors will also put supplementary materials on reserve. Take advantage of these, if provided.

Choice 4: Commit to Improvement

By definition, you are changed as a result of learning. You need to be willing to open your mind to new, more powerful ways of thinking about the natural world and the process of personal intellectual development. The purpose of your college education is to make you a better person. Are you willing to *choose* to commit to improving the way you understand nature, becoming a better learner, and developing your intellect? Let's look at some ways to do this within the framework of this chemistry course.

Think Like a Chemist The perspective of the chemist is unique, as is the perspective of the philosopher, the mathematician, the geographer, or the linguist. Each course you take in college will expose you to a different way of thinking about the world. In this chemistry course, you should work to understand the distinctive viewpoint of a chemist. In particular, focus on the relationships among the macroscopic, directly observable natural world; the abstract, particulate makeup of those macroscopic materials; and the symbols that chemists use to represent both the macroscopic and particulate world, as illustrated in **Figure 1-11**.