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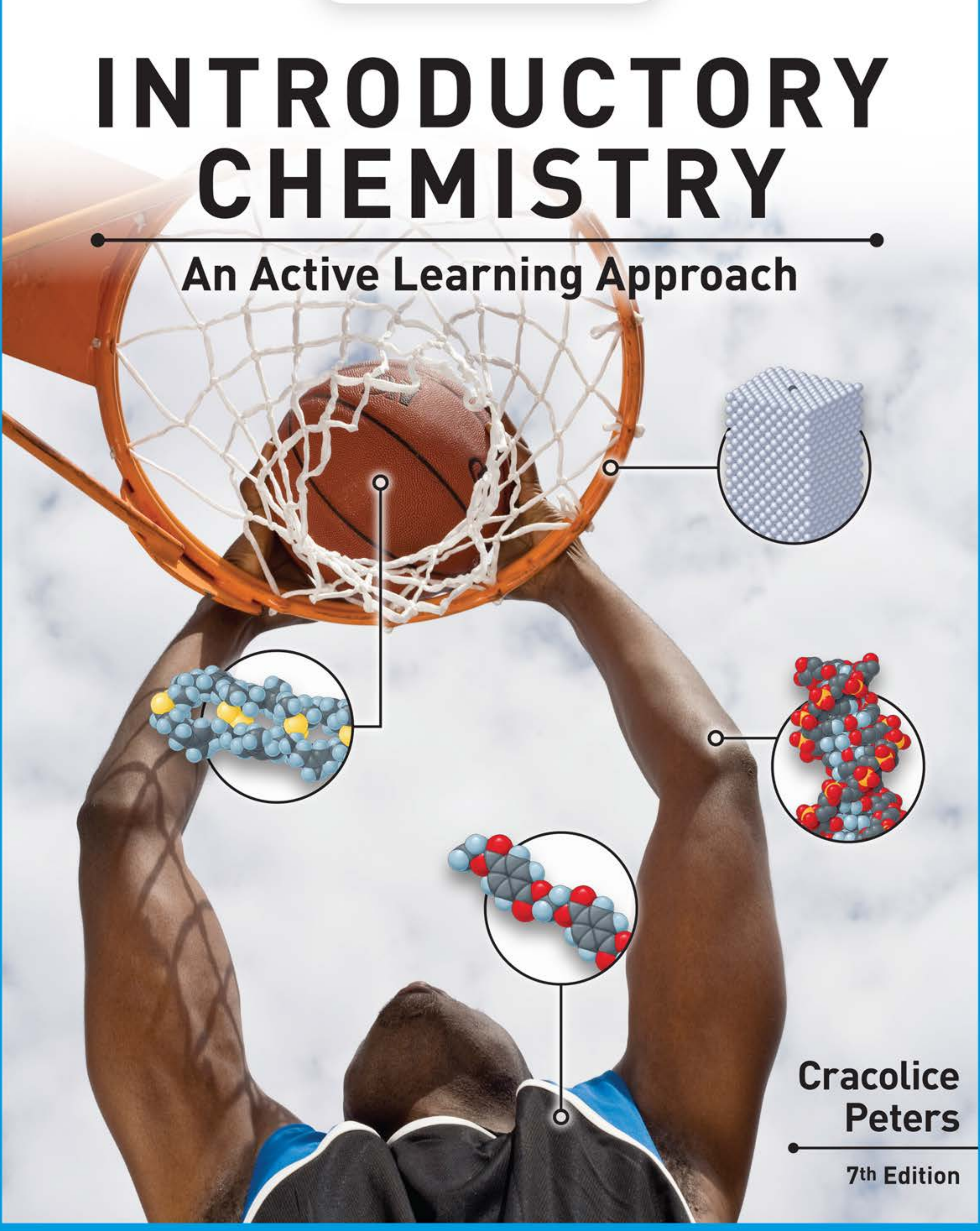
INTRODUCTORY CHEMISTRY

An Active Learning Approach



Cracolice
Peters

7th Edition

Introductory Chemistry

SEVENTH EDITION

An Active Learning Approach

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Mark S. Cracolice
University of Montana

Edward I. Peters

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***Introductory Chemistry: An Active Learning Approach*, Seventh Edition**
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Library of Congress Control Number: 2019917479

Student Edition
ISBN: 978-0-357-36366-9

Loose-leaf Edition
ISBN: 978-0-357-36391-1

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200 Pier 4 Boulevard
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Printed in the United States of America
Print Number: 01 Print Year: 2020

Dedication

This book is dedicated to the memory of my late mother, Marjorie Sharp, the Worthy Advisor.

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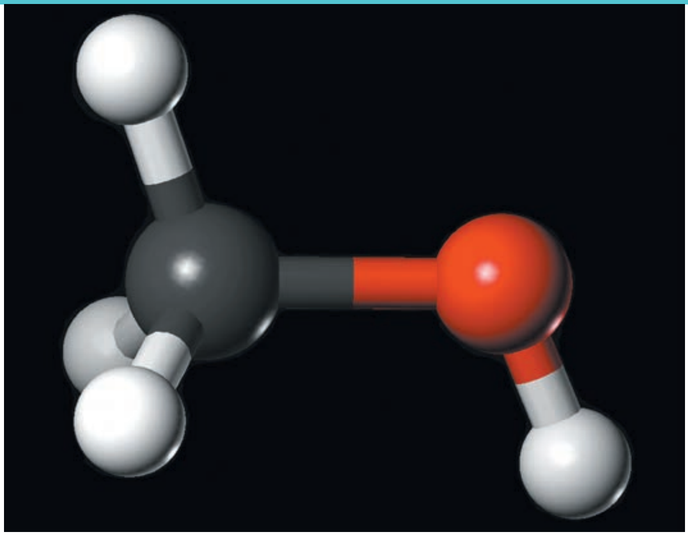

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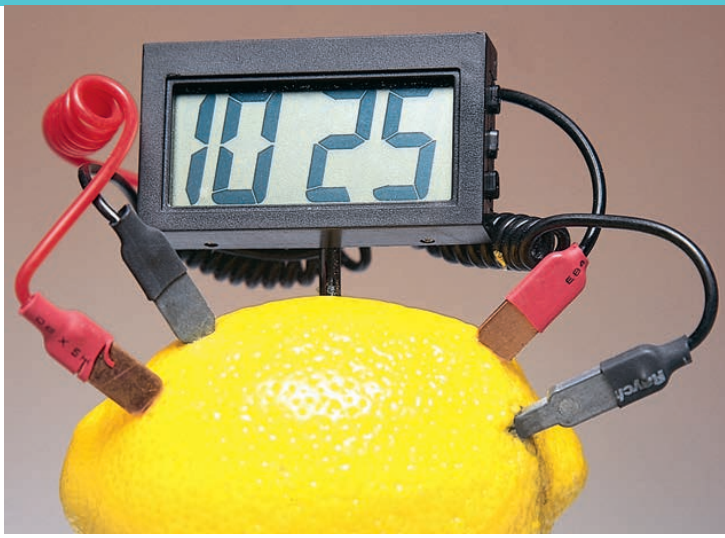

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Preface

Audience

The seventh edition of *Introductory Chemistry: An Active Learning Approach* is written for a college-level introductory or preparatory chemistry course for students who next will take a college general chemistry course. It is also appropriate for the first-term general portion of a two-term general, organic, and biological chemistry (GOB) course. The textbook is written with the assumption 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 or GOB chemistry.

Overarching Goals

Introductory Chemistry was written with the following broad-based goals. Upon completing the course while using this textbook, our aim 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 addressed beginning in Sections 1.4–1.6, which together make up an "Introduction to Active Learning." These sections describe the pedagogical features of the textbook and how to use them effectively to learn chemistry as efficiently as possible.

Introductory Chemistry deals with a weak quantitative problem-solving background beginning in Chapter 3. 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 textbook. The thought processes introduced in Chapter 3 are used throughout the text, constantly reinforcing the student's ability to solve quantitative problems.

We address difficulties in reading scientific material via many of the features of the textbook. Clearly stated learning goals lead to carefully written narratives, which are then often summarized in a numbered list. Key words are printed in bold, summarized at the end of each chapter, and collected into a glossary. Chapter summaries are used to help students review as they complete each chapter. Active learning techniques are used throughout to keep students engaged in learning while they are reading.

Active Learning

The *An Active Learning Approach* portion of the title of the textbook refers to what general cognitive science and applied chemistry education research indicate is the best curricular approach to facilitate construction of *procedural* knowledge.

When we use the term *procedural* knowledge, we are referring to knowledge of how to do something, such as solve quantitative chemistry problems, as opposed to *declarative* knowledge, which is knowledge of facts. Both types of knowledge are important in an introductory chemistry course; students must learn facts such as the symbol for the element hydrogen is H, *and* they should learn how to calculate the amount of water that will be produced when a given mass of hydrogen is reacted with excess oxygen. However, declarative knowledge is relatively straightforward to teach; it is mostly a matter of organization and making connections. Procedural knowledge is relatively difficult to teach. It requires a curriculum centered on active learning.

Evidence in support of our claim about active learning is strong. The work of Scott Freeman of the University of Washington and associates provides an excellent example.* They used a statistical approach called a *meta-analysis* that combines results from many individual studies. This technique provides stronger evidence than any given individual study. They compared active-learning-centered classrooms with those that primarily relied on expository teaching, finding that the active learning classrooms produced both better exam performance *and* lower failure rates. Specifically, student performance on exams was about one-half standard deviation higher in active learning classrooms and failure rates in expository courses were 1.5 times the rate in active learning courses.

Active learning means that the student spends as much of his or her time as possible invested into studying actively, working to construct knowledge. Most textbooks engage students in active learning only while answering end-of-chapter questions. Our book engages students in active learning while answering end-of-chapter questions *and* studying the body of the chapter. We next examine how we accomplish this goal.

Active Examples

The examples in our textbook are written in a question-and-answer format 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 tutor them as they work the solution, step-by-step. As students solve the example problem, they actively write for themselves each step in the solution, covering the authors' answer with the shield provided in the book. This example format turns the common passive "read the authors' solution" approach to an active "you solve the problem while we tutor you" methodology.

To serve as an example of and explanation about this methodology, let's break down Active Example 10.4, the first mass-to-mass stoichiometry example in the textbook. The problem statement comes first. The examples are numbered and titled for easy reference.

Active Example 10.4 **Mass–Mass Stoichiometry II**

What is the mass in grams of CO_2 that will be produced by burning 66.0 g C_7H_{16} by the same reaction as in Active Example 10.3, $C_7H_{16}(\ell) + 11\ O_2(g) \rightarrow 7\ CO_2(g) + 8\ H_2O(\ell)$?

The next portion of the Active Example is titled Think Before You Write. This feature has two purposes. One is to teach students to engage the portion of the

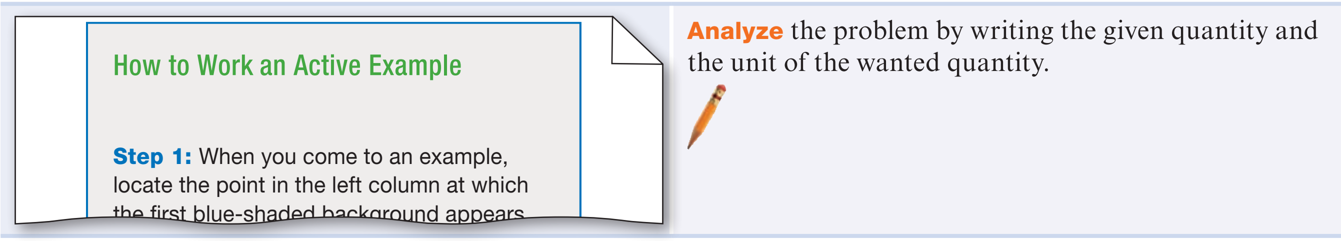
*Freeman, S., Eddy, S. L., McDonough, M., Smith, M. K., Okoroafor, N., Jordt, H., & Wenderoth, M. P. (2014). Active learning increases student performance in science, engineering, and mathematics. *Proceedings of the National Academy of Sciences of the United States of America, 111*(23), 8410–8415.

brain used for higher-order thinking, avoiding reacting impulsively.* The other purpose is to help students learn how to extract the relevant information from a problem statement, focusing on the deep structure rather than on the surface features.† Here, we begin by discussing how to analyze the problem statement from the deep structure perspective. We then discuss the problem-solving approach from the general perspective, divorced from the context of this specific problem. At the end of the box, students are reminded to actively work the example for themselves, covering our answers until they have produced their own.

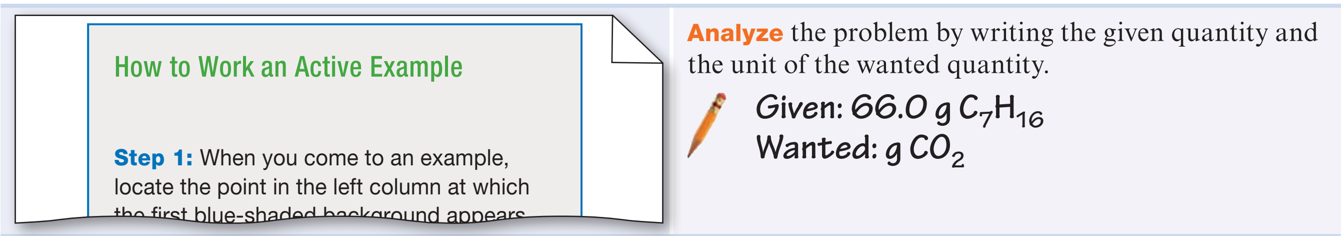
Think Before You Write You are given the mass of one species in a chemical change, and you are asked to determine the mass of another species. Thus, you will switch from the macroscopic mass quantity to the particulate number of moles, use the mole ratio in the chemical equation to determine the amount in moles of the wanted quantity, and then switch back to the macroscopic level and determine the mass of that amount in grams. This is illustrated in Figure 10.4.

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

When appropriate, quantitative Active Examples are solved using a four-step problem-solving approach: analyze, identify, construct, and check. In the *analyze* step, students identify the given quantity and the unit of the wanted quantity. Space is provided for students to write under the pencil icon.



Students literally write their responses, making a commitment to reveal their present state of understanding and recording it.



They then reveal the authors' answer, comparing their answer to that of an expert. If the answers match, their correct thinking is reinforced. If the answers don't match, students get immediate feedback at the specific point at which they don't correctly understand the problem-solving process. Earlier in the textbook, we gave overarching guidance to students to go back to the narrative before the Active Example when this occurs and figure out what is wrong.

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*Wright, S. B., Matlen, B. J., Baym, C. L., Ferrer, E., & Bunge, S. (2007). Neural correlates of fluid reasoning in children and adults. *Frontiers in Human Neuroscience, 1*(8), doi: 10.3389/neuro.09.008.2007.

†Chi, M. T. H., & VanLehn, K. A., (2012). Seeing deep structure from the interactions of surface features. *Educational Psychologist, 47*(3), 177–188.

Given: 66.0 g C_7H_{16}
Wanted: g CO_2

Analyze the problem by writing the given quantity and the unit of the wanted quantity.

Given: 66.0 g C_7H_{16}
Wanted: g CO_2

The second step in our four-step approach is the *identify* step. Here we introduce the unit path approach, where students first write the units for each step in the solution setup. We then instruct them to identify the equivalency that connects each pair of units. After that, the equivalencies are changed to conversion factors. Equivalency and conversion factors are introduced in Section 3.3 and used continuously from that point forward.

$$\text{g } C_7H_{16} \rightarrow \text{mol } C_7H_{16} \rightarrow \text{mol } CO_2 \rightarrow \text{g } CO_2$$

$$1 \text{ mol } C_7H_{16} = 100.20 \text{ g } C_7H_{16}$$

$$7 \text{ mol } CO_2 = 1 \text{ mol } C_7H_{16}$$

$$44.01 \text{ g } CO_2 = 1 \text{ mol } CO_2$$

$$\frac{1 \text{ mol } C_7H_{16}}{100.20 \text{ g } C_7H_{16}} \quad \frac{7 \text{ mol } CO_2}{1 \text{ mol } C_7H_{16}} \quad \frac{44.01 \text{ g } CO_2}{1 \text{ mol } CO_2}$$

The next step is to **identify** the equivalencies. With multiple-step problems such as this, it can be helpful to write the units for each step before you write the equivalencies:

$$\text{g } C_7H_{16} \rightarrow \text{mol } C_7H_{16} \rightarrow \text{mol } CO_2 \rightarrow \text{g } CO_2$$

Each arrow in this **unit path** requires an equivalency. Change the equivalencies to conversion factors.

$$\text{g } C_7H_{16} \rightarrow \text{mol } C_7H_{16} \rightarrow \text{mol } CO_2 \rightarrow \text{g } CO_2$$

$$1 \text{ mol } C_7H_{16} = 100.20 \text{ g } C_7H_{16}$$

$$7 \text{ mol } CO_2 = 1 \text{ mol } C_7H_{16}$$

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The majority of the challenging part of problem solving is complete at this point. Through our Active Example approach, students learn that identification of the given and wanted and deduction of equivalencies that link pairs of units are the keys to quantitative problem solving in introductory chemistry. The third step of the four-step approach is to *construct* the solution setup. Here, students confirm that the units cancel correctly, and we literally show the cancellation lines in the textbook and encourage students to do the same, and then they calculate the value (quantity × unit) of the answer.

$$66.0 \cancel{\text{g } C_7H_{16}} \times \frac{1 \cancel{\text{mol } C_7H_{16}}}{100.20 \cancel{\text{g } C_7H_{16}}} \times \frac{7 \cancel{\text{mol } CO_2}}{1 \cancel{\text{mol } C_7H_{16}}} \times \frac{44.01 \text{ g } CO_2}{1 \cancel{\text{mol } CO_2}} = 203 \text{ g } CO_2$$

Construct the solution setup and determine the answer.

$$66.0 \cancel{\text{g } C_7H_{16}} \times \frac{1 \cancel{\text{mol } C_7H_{16}}}{100.20 \cancel{\text{g } C_7H_{16}}} \times \frac{7 \cancel{\text{mol } CO_2}}{1 \cancel{\text{mol } C_7H_{16}}} \times \frac{44.01 \text{ g } CO_2}{1 \cancel{\text{mol } CO_2}} = 203 \text{ g } CO_2$$

The fourth step in the four-step approach has two parts. One aim is to have students do mental arithmetic to the point where the answer obtained from a calculator is verified as reasonable, and a second aim is to teach students to reflect on how they have improved their problem-solving skills. Here, we guide students to be flexible in their choices in doing the calculation *check*.

$(60 \times 7) \times 50 \div 100 = 420 \times (50 \div 100) = 420 \times 0.5 = 210$, OK. $(70 \times 7) \times 40 \div 100 = 490 \times (40 \div 100) \approx 500 \times 0.4 = 200$, OK.	The **check** of a setup with a large number of values becomes a bit challenging. You have to round the numbers, aiming to round in opposite directions. For example, this setup could be estimated as 60 (round down) $\times$ 7 $\times$ 50 (round up) $\div$ 100 or 70 (round up) $\times$ 7 $\times$ 40 (round down) $\div$ 100. Remember that the goal is to be sure you in are in the ballpark, not to calculate the *exact* answer in your head. $(60 \times 7) \times 50 \div 100 = 420 \times (50 \div 100) = 420 \times 0.5 = 210$, OK.

The second part of the fourth step is to encourage students to think about the purpose of the Active Example and to contemplate if they have successfully achieved that purpose. This step is designed to invoke metacognition* so that students become explicitly aware of and make conscious the thought processes that they just learned.

You improved your skill at solving mass–mass stoichiometry problems.	What did you learn by solving this Active Example? I am beginning to understand the mass given $\rightarrow$ amount given $\rightarrow$ amount wanted $\rightarrow$ mass wanted problem solving strategy.

Finally, each Active Example is followed by a practice exercise that is based on the deep structure of the example that comes immediately before it. This allows the student who correctly solved the example to receive reinforcement and the student who did not solve the example correctly an opportunity to solve a parallel problem correctly before moving to the next topic. Solutions to the practice exercises are at the end of each chapter.

Practice Exercise 10.4

What mass of fluorine is formed when 3.0 grams of bromine trifluoride decomposes into its elements?

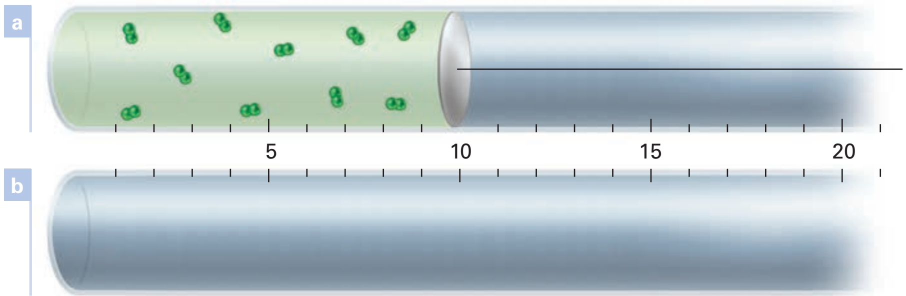
*Flavell, J. H. (1979). Metacognition and cognitive monitoring: A new area of cognitive-developmental inquiry. *American Psychologist, 34*(10), 906–911.

Rickey, D., & Stacy, A. M. (2000). The role of metacognition in learning chemistry. *Journal of Chemical Education, 77*(7), 915–920.

Target Checks

When a multistep Active Example is not warranted, we use another active learning feature termed *Target Checks.* These are just-in-time, fundamental questions, primarily utilized with nonquantitative topics, that help students monitor their progress as they work instead of waiting for the end-of-chapter questions so that they can identify and diagnose incomplete understandings or misunderstandings *as they study.* As an example, Target Check 14.1 is from the "Avogadro's Law" section:

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 five 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 ***P****review* to the extent necessary to ensure continuity for students who have not seen it before, while affording a brief ***R****eview* 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 where 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 introduces the Ideal Gas Law. An instructor is free to move Chapter 4 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 14.9 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 14.10 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.

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.

Features

Active Examples Active Examples were described in detail previously. An Active Example is an active learning feature that is formatted in two columns. The left column (the authors' answers) is to be covered by students while they write their own answers in the space provided in the right column. As students actively work through and complete the solution in the right column, they 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 will be useful when reviewing for exams.

Practice Exercises Each Active Example is followed immediately 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 Examples, 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 each chapter.

Target Checks Target Checks were described in detail previously. Target Check questions are an active learning feature that enable students to test their understanding immediately after studying a topic. Target Checks are most prominent in the qualitative chapters where the material often does not align well with Active Examples.

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

We also include a larger, complete version of the Periodic Table and an alphabetical listing of the elements in another cut-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.

Section 1 Each chapter except for Chapter 1 begins with an introductory section designed to *engage* students in thinking about an issue related to the major topic of the chapter. Our goal here is to pique students' curiosity and generate interest. We sometimes discuss topics that are being actively researched at the moment. We seek to convey some of the excitement that comes from using the scientific method to seek the creation of new knowledge about the natural world. We do not include end-of-chapter questions for these sections in order to keep the focus on engagement of student interest.

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.

Emphasis on Mental Arithmetic To address the issue of insufficient mathematical preparation, we have an emphasis on estimating and verifying the reasonableness of calculation results. All Active Examples that include a calculation 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.

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 cannot 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.

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 help to 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 supplementary structure for learning in their first college chemistry course.

Everyday Chemistry All chapters have an Everyday Chemistry section that moves 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.

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

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 and revised high-quality art pieces, with an emphasis on simple color schemes, plentiful macro-to-micro art, and instructional descriptions.

Chapter Summaries Each chapter includes a summary immediately following the last narrative section. It presents a list of the chapter goals, and each goal is matched to 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.

The chapter summaries, when combined with worked examples and some end-of-chapter questions, would constitute a study guide for the textbook. Our aim is for the book to effectively serve as a combined study guide and textbook integrated into a single package.

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.

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.

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 of phrases. If they can express those relationships correctly in their own words, they understand the concepts. Explicitly writing these connections also helps with long-term retention of the concepts.

Small-Group Discussion Questions A growing number of courses feature some sort of group work 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 group work 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 includes an abundant supply of questions, exercises, and except for Chapter 1, the 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. Complete solutions (not just answers) for all blue-numbered questions appear at the end of the chapter. Solutions for to the black-numbered questions are in the Instructor's Manual.

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 aspects of chemistry. Students will be able to see physical and chemical changes and common forms of industrial manufacturing processes, as well as better visualize the scenarios described in the questions.

Appendices Appendix I includes a general review of arithmetic, scientific notation, algebra, and logarithms as they are used in this book. Appendix II gives a more complete treatment of the SI system than in Chapter 3.

New to This Edition

Revised Approach to Biochemistry (Chapter 22) We believe that previous editions of this chapter had a mismatch between the level of coverage that is appropriate for an *Introductory Chemistry* course and the presentation in Chapter 22. Thus, we rewrote the chapter with the intention of keeping an emphasis on only the major concepts. All of the minor details have been removed. To accomplish this, the chapter narrative was nearly completely rewritten. In addition to the revised level of coverage, we believe that the narrative is now more appropriately sequential and therefore more pedagogically suitable for a student who has not yet taken a general chemistry course.

Revision to Accommodate the Revised International System of Units (SI) In November 2018, the Member States of the Bureau International des Poids et Mesures unanimously voted to adopt a revised SI, changing the definitions of three units central to introductory chemistry, the mole, the kilogram, and the kelvin, and one unit usually not included in an introductory chemistry course, the ampere, effective on May 20, 2019. All of the SI revisions are integrated throughout the textbook and Appendix II on the SI System of Units.

Section 1 We have added a new first section to each chapter that emphasizes big picture topics that have a connection to a topic in each chapter. These sections were written with the philosophy that the first step in each topical cycle of learning should be to intellectually and emotionally engage the student. Thus, we give a chemist's perspective on big picture questions on topics such as the origins of the elements, the universal nature of chemical change, the existence of water on other planets, and the origins of life. No Target Check or end-of-chapter questions are associated with these sections to clearly convey to students that the sections are meant to help inspire them to wonder about the nature of the universe, with no pressure to be responsible for related textbook questions.

Improved Photography Program We sought to improve the quality of as many of the hundreds of photographs in the book as possible. We were actually surprised to come to the realization that many photos from the previous edition were quite good! Nonetheless, we looked at numerous alternatives for many photos, changing to images that more clearly illustrated a concept or reflected a more modern perspective when possible.

Video Solutions to Active Examples (eBook Only) Students at the University of Montana have been featured in dozens of videos that mirror what an in-person tutor would do if a student asked for help with understanding an Active Example. With the assistance of the editorial and production teams, textbook author Mark

Cracolice wrote scripts and directed students as they performed in these short audiovisual performances. We believe that many students will find these videos more engaging than the print programmed examples used in the book, but the print examples are still available for students who prefer learning via this format. The content of the video solutions and the Active Examples are equivalent, providing no disadvantage to students who prefer one format to the other.

Looseleaf Edition

Loose-Leaf Edition for Introductory Chemistry: An Active Learning Approach, 7e.

ISBN: 9780357363911

A loose-leaf (unbound, three-hole-punched) version of *Introductory Chemistry: An Active Learning Approach 7e,* which can be inserted in a binder, is also available.

OWLv2

The OWL online learning system offers additional practice exercises. 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.

Students can use this ISBN at www.CENGAGEbrain.com to purchase instant access to OWLv2, the most trusted online learning solution for chemistry. Featuring chemist-developed content, OWLv2 is the only system designed to elevate thinking through Mastery Learning, allowing students to work at their own pace until they understand each concept and skill. Each time a student tries a problem, OWLv2 changes the chemicals, values, and sometimes even the wordings of the question to ensure students are learning the concepts and not cheating the system. With detailed, instant feedback and interactive learning resources, students get the help they need when they need it. Now with improved student and instructor tools and greater functionality, OWLv2 is more robust than ever. Visit www.CENGAGE.com/owlv2 to learn more.

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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.

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- **PowerPoint® lecture slides** written for this text that instructors can customize by importing their own slides or other materials.
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- The **Instructor's Manual** provides for each chapter authors' comments, answers to Everyday Chemistry Quick Quiz questions, and solutions to black-numbered end of chapter questions.

- **Test bank questions** including dozens of multiple choice questions per chapter.
- **Chemistry Multimedia Library** of lecture-ready animations, simulations, and movies.

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Acknowledgments

At Cengage, we appreciate Maureen McLaughlin, former Senior Product Manager for Chemistry, for supporting the production of a new edition. Liz Woods, who worked her way up through the ranks at Cengage, serving in various roles in previous editions, was the Learning Designer who solicited reviews, worked with us to develop a revision plan, and created the initial schedule. We are thankful for her valuable contributions. Peter McGahey took over as Learning Designer early in the project, and we are grateful for his efforts, particularly in helping to make the print and online versions integrate so well. We also thank Meaghan Tomaso, Senior Content Manager, for all of her work in coordination of all of the people who collaborate to produce a modern textbook.

At Lumina Datamatics, we are appreciative of the work of Arul Joseph Raj, who was instrumental in transforming a series of word processing files, art renderings, and photographs into the beautiful book you are reading.

Our accuracy reviewer was Dr. David Shinn, Associate Professor in the Department of Math and Science at the United States Merchant Marine Academy. David had the challenging task of reviewing every word, every number, every photograph, and every illustration in the textbook while under considerable time pressure. We appreciate his attention to detail. David's suggestions led to a number of improvements to the initial draft of the textbook.

The reviewers of the seventh edition helped to shape our thinking, and for that, we are most appreciative. They include:

Chester Dabalos, University of Hawaii at Manoa

Michael Hauser, St. Louis Community College–Meramec

Ling Huang, Sacramento City College

Tara Hurt, East Mississippi Community College

E. Kay Sutton, Campbellsville University

We are also grateful to the faculty and student users of the first through sixth editions of *Introductory Chemistry.* Their comments and suggestions over the past 20 years have led to significant improvements in this book.

We thank the reviewers of the previous editions:

Melvin T. Arnold, Adams State College

Joe Asire, Cuesta College

Caroline Ayers, East Carolina University

Bob Blake, Texas Tech University

Juliette A. Bryson, Las Positas College

Sharmaine Cady, East Stroudsburg State College

K. Kenneth Caswell, University of South Florida

Bill Cleaver, University of Vermont
Pam Coffin, University of Michigan–Flint
Claire Cohen-Schmidt, The University of Toledo
Mapi Cuevas, Santa Fe Community College
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Andrew Wells, Chabot College
Linda Wilson, Middle Tennessee State University
David L. Zellmer, California State University, Fresno

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

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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 the 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.

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 4000 miles

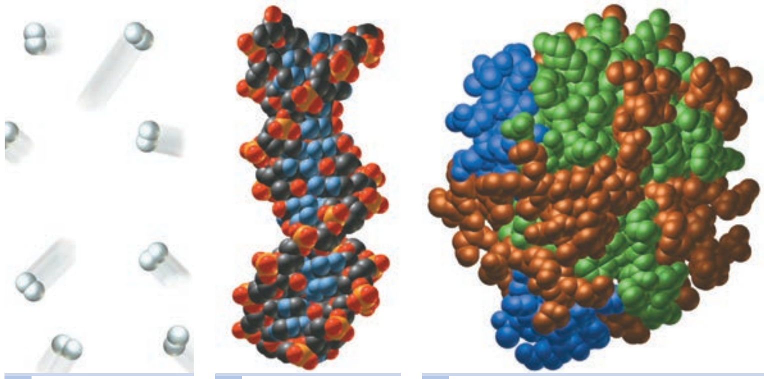

Figure 1.1 A sampling from the amazing variety of molecules. (a) A molecular-level view of a tiny sample of pure hydrogen. Each hydrogen molecule is made up of two hydrogen atoms. Hydrogen is a gas (unless pressurized and cooled to a very low temperature), so the molecules are independent of one another and travel 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.

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 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 (**Figure 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 a 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 is an abbreviation for **d**eoxyribo**n**ucleic **a**cid, a compound name that identifies the simpler patterns within a molecule.

Even this relatively large molecule is very tiny in comparison with objects that can be directly observed. 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.

ACTIVE MUSEUM/Alamy Stock Photo

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.

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 (**Figure 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 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.

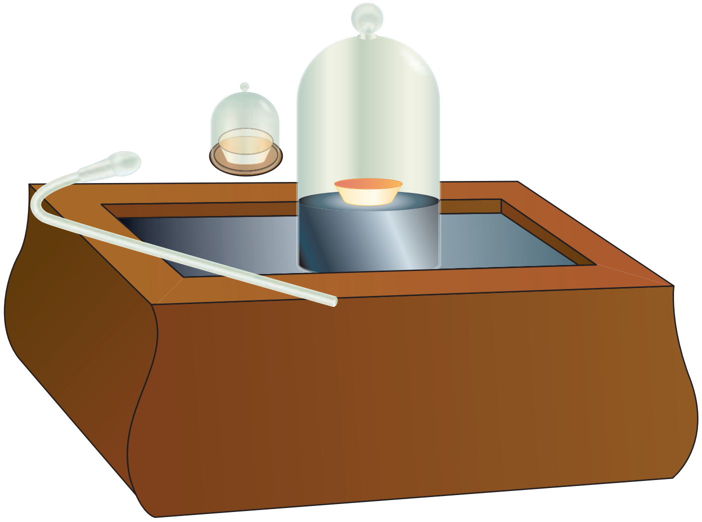

Figure 1.3 Lavoisier's phosphorus-burning experiment, as illustrated in his book *Traité Élémentaire de Chime*. A sample of solid phosphorus was placed in the dish inside the bell jar and ignited. The ash that remained after burning weighed more than the original sample. The quantity of oxygen gas in the bell jar decreased. How could phosphorus lose phlogiston but weigh more?

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 bell jar filled with oxygen (**Figure 1.3**). 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 liquid level in the bell jar increased in height, indicating that there was less oxygen in the jar after burning than before.

What happened to the phlogiston? What was the source of the additional weight? Why did the volume of oxygen in the jar decrease when it was supposed to be absorbing phlogiston? Is it possible that the phosphorus absorbed something from the oxygen, instead of the oxygen 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 (**Figure 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 oxygen 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. 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 oxygen. "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

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

We have selected a few of Antoine Lavoisier's early experiments to illustrate what has become known as the **scientific method** (**Figure 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:

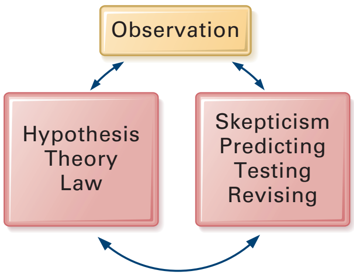

Figure 1.5 The scientific method.

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. *Divorcing yourself from bias and personal beliefs.* You must also minimize the role of bias in evaluating the work of others. 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 hypothesis is refuted. A new hypothesis is required.
6. *Revising or changing the hypothesis.* Lavoisier proposed that burning combines the substance burned and oxygen. (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 relevant articles in the many scientific journals in which researchers report the results of their work. Modern scientists communicate with each other through technical literature. Scientific periodicals are also a major source of new ideas, as well as talks and presentations at scientific professional meetings.

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.

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 (**Figure 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, they form the foundation of scientific knowledge. The only justification for such confidence is that in order for a law to be so classified, it must have no known exceptions.

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 transferred in chemical change—heat, electrical, mechanical, and other forms of energy.

Chemistry has a unique, central position among the sciences (**Figure 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.

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 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.

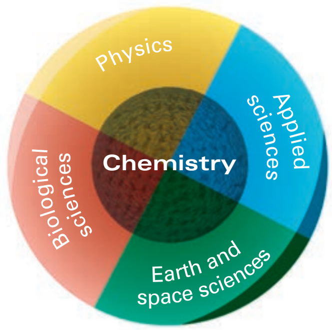

Figure 1.7 Chemistry is the central science. Imagine all sciences as a sphere. This cross section of the science sphere shows chemistry at the core. If you view the other sciences as surface-to-center samples, each contains a chemistry core.

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).

You will find chemists—the people who practice chemistry—in many fields (**Figure 1.8**). 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.

Chemical manufacturers produce many things that 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 (**Figure 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, with well over 70 billion dollars in annual sales, and employing more than 100,000 people.

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 you should take advantage of the opportunity. But maintain 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 a half 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* (**Figure 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.

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.

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

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Figure 1.10 Introductory chemistry is often taught in large lecture halls. Attendance at every lecture is important, even if roll is not taken.

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 digital or print 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-designed 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**.

Think Conceptually A trap that some students fall into while solving quantitative chemistry problems is to mindlessly crunch numbers without thinking about the underlying concept. Almost certainly, there will be a few routine types of quantitative problem setups that you should master without the need to reinvent the procedure each time you solve such a problem. But many other problems will be more complex. With these more complex problems, it is critical to understand the underlying concept. If you can imagine the particulate-level process described in the problem statement, do so. Remember that it is not the answer that is important when you tackle difficult problems but rather the process that should be your focus.

Embrace Multiple Ways of Knowing This chemistry course will expose you to many ways of obtaining new knowledge. You will likely need to learn (in order of increasing