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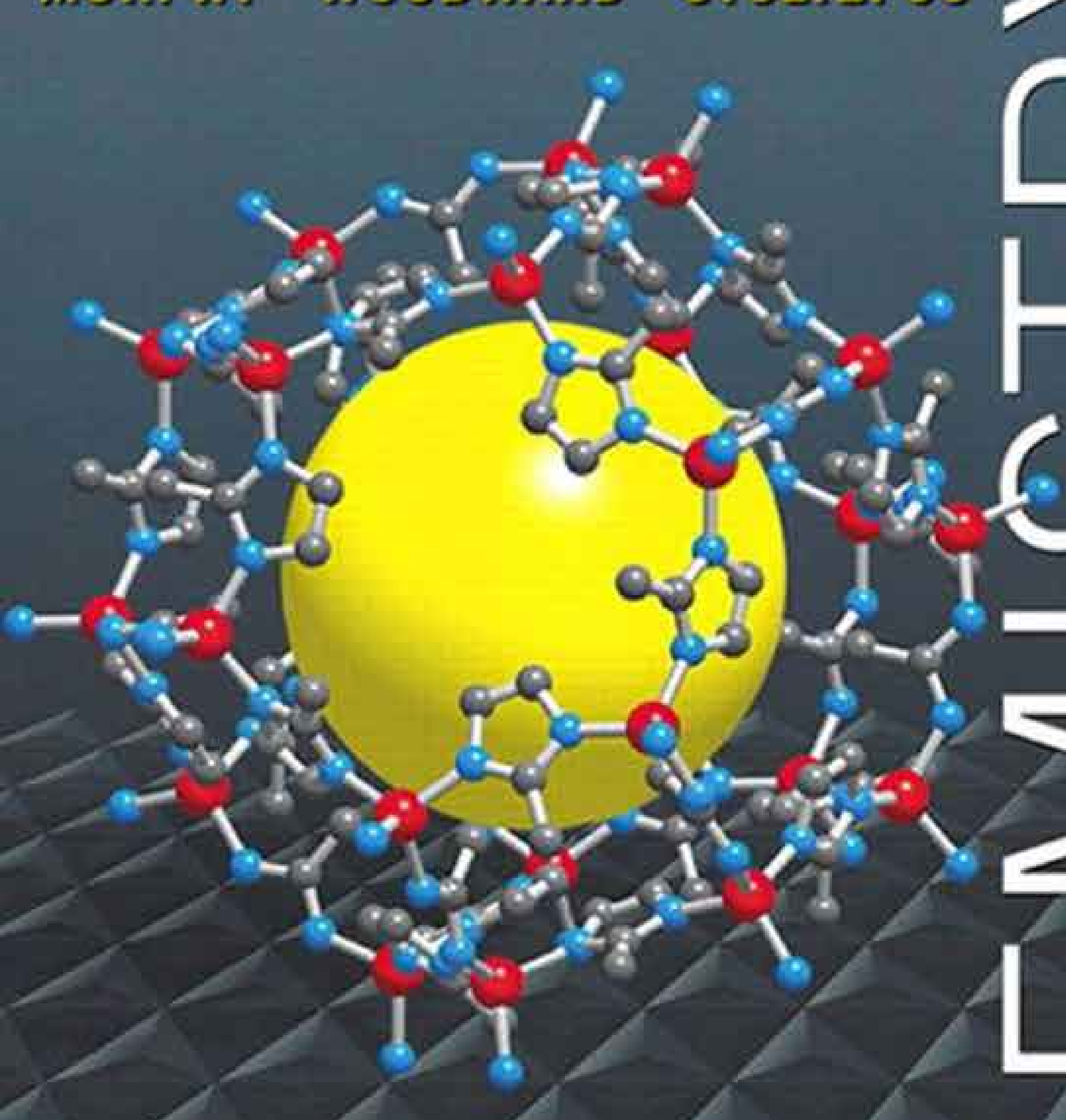
CHEMISTRY

THE CENTRAL SCIENCE

13TH EDITION



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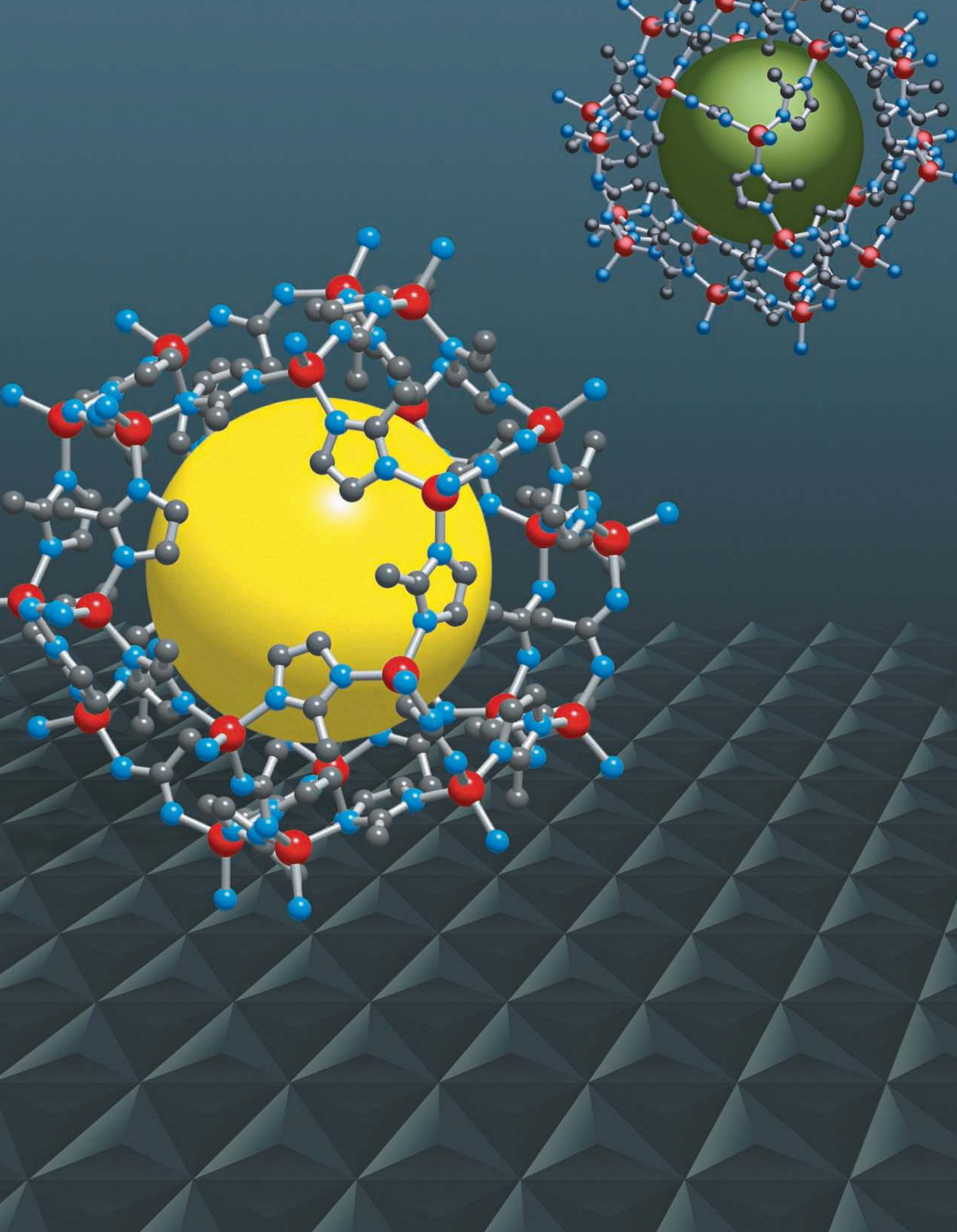

CHEMISTRY

THE CENTRAL SCIENCE 13TH EDITION

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To our students,
whose enthusiasm and curiosity
have often inspired us,
and whose questions and suggestions
have sometimes taught us.

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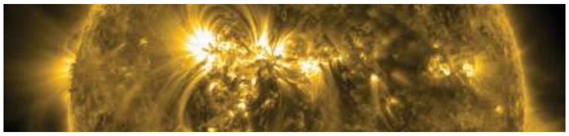

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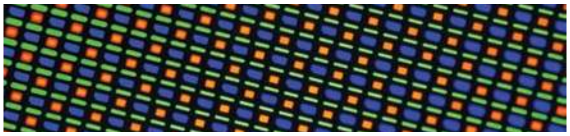

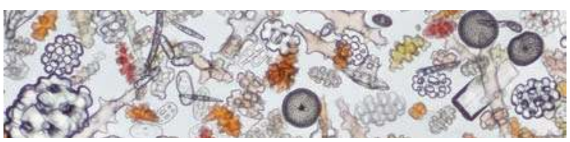

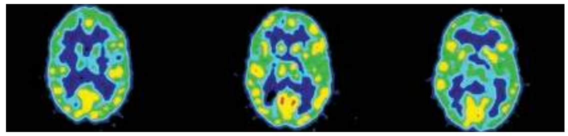

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PREFACE

To the Instructor

Philosophy

We authors of *Chemistry: The Central Science* are delighted and honored that you have chosen us as your instructional partners for your general chemistry class. We have all been active researchers who appreciate both the learning and the discovery aspects of the chemical sciences. We have also all taught general chemistry many times. Our varied, wide-ranging experiences have formed the basis of the close collaborations we have enjoyed as coauthors. In writing our book, our focus is on the students: we try to ensure that the text is not only accurate and up-to-date but also clear and readable. We strive to convey the breadth of chemistry and the excitement that scientists experience in making new discoveries that contribute to our understanding of the physical world. We want the student to appreciate that chemistry is not a body of specialized knowledge that is separate from most aspects of modern life, but central to any attempt to address a host of societal concerns, including renewable energy, environmental sustainability, and improved human health.

Publishing the thirteenth edition of this text bespeaks an exceptionally long record of successful textbook writing. We are appreciative of the loyalty and support the book has received over the years, and mindful of our obligation to justify each new edition. We begin our approach to each new edition with an intensive author retreat, in which we ask ourselves the deep questions that we must answer before we can move forward. What justifies yet another edition? What is changing in the world not only of chemistry, but with respect to science education and the qualities of the students we serve? The answer lies only partly in the changing face of chemistry itself. The introduction of many new technologies has changed the landscape in the teaching of sciences at all levels. The use of the Internet in accessing information and presenting learning materials has markedly changed the role of the textbook as one element among many tools for student learning. Our challenge as authors is to maintain the text as the primary source of chemical knowledge and practice, while at the same time integrating it with the new avenues for learning made possible by technology and the Internet. This edition incorporates links to a number of those new methodologies, including use of the Internet, computer-based classroom tools, such as Learning Catalytics™, a cloud-based active learning analytics and assessment system, and web-based tools, particularly MasteringChemistry®, which is continually evolving to provide more effective means of testing and evaluating student performance, while giving the student immediate and helpful feedback. In past versions, MasteringChemistry® provided feedback only on a question level. Now with Knewton-enhanced adaptive follow-up assignments, and Dynamic Study Modules, MasteringChemistry® continually adapts to each student, offering a personalized learning experience.

As authors, we want this text to be a central, indispensable learning tool for students. Whether as a physical book or in electronic form, it can be carried everywhere and used at any time. It is the one place students can go to obtain the information outside of the classroom needed for learning, skill development, reference, and test preparation. The text, more effectively than any other instrument, provides the depth of coverage and coherent background in modern chemistry that students need to serve their professional interests and, as appropriate, to prepare for more advanced chemistry courses.

If the text is to be effective in supporting your role as instructor, it must be addressed to the students. We have done our best to keep our writing clear and interesting and the book attractive and well illustrated. The book has numerous in-text study aids for students, including carefully placed descriptions of problem-solving strategies. We hope that our cumulative experiences as teachers is evident in our pacing, choice of examples, and the kinds of study aids and motivational tools we have employed. We believe students are more enthusiastic about learning chemistry when they see its importance relative to their own goals and interests; therefore, we have highlighted many important applications of chemistry in everyday life. We hope you make use of this material.

It is our philosophy, as authors, that the text and all the supplementary materials provided to support its use must work in concert with you, the instructor. A textbook is only as useful to students as the instructor permits it to be. This book is replete with features that can help students learn and that can guide them as they acquire both conceptual understanding and problem-solving skills. There is a great deal here for the students to use, too much for all of it to be absorbed by any one student. You will be the guide to the best use of the book. Only with your active help will the students be able to utilize most effectively all that the text and its supplements offer. Students care about grades, of course, and with encouragement they will also become interested in the subject matter and care about learning. Please consider emphasizing features of the book that can enhance student appreciation of chemistry, such as the *Chemistry Put to Work* and *Chemistry and Life* boxes that show how chemistry impacts modern life and its relationship to health and life processes. Learn to use, and urge students to use, the rich online resources available. Emphasize conceptual understanding and place less emphasis on simple manipulative, algorithmic problem solving.

What Is New in This Edition?

A great many changes have been made in producing this thirteenth edition. We have continued to improve upon the art program, and new features connected with the art have been introduced. Many figures in the book have undergone modification, and dozens of new figures have been introduced.

A systematic effort has been made to place explanatory labels directly into figures to guide the student. New designs have been employed to more closely integrate photographic materials into figures that convey chemical principles.

We have continued to explore means for more clearly and directly addressing the issue of concept learning. It is well established that conceptual misunderstandings, which impede student learning in many areas, are difficult to correct. We have looked for ways to identify and correct misconceptions via the worked examples in the book, and in the accompanying practice exercises. Among the more important changes made in the new edition, with this in mind, are:

- A major new feature of this edition is the addition of a second Practice Exercise to accompany each Sample Exercise within the chapters. The majority of new *Practice Exercises* are of the multiple-choice variety, which enable feedback via MasteringChemistry®. The correct answers to select Practice Exercises are given in an appendix, and guidance for correcting wrong answers is provided in MasteringChemistry®. The new Practice Exercise feature adds to the aids provided to students for mastering the concepts advanced in the text and rectifying conceptual misunderstandings. The enlarged practice exercise materials also further cement the relationship of the text to the online learning materials. At the same time, they offer a new supportive learning experience for all students, regardless of whether the MasteringChemistry® program is used.
- A second major innovation in this edition is the *Design An Experiment* feature, which appears as a final exercise in all chapters beginning with Chapter 3, as well as in MasteringChemistry®. The *Design an Experiment* exercise is a departure from the usual kinds of end-of-chapter exercises in that it is inquiry based, open ended, and tries to stimulate the student to "think like a scientist." Each exercise presents the student with a scenario in which various unknowns require investigation. The student is called upon to ponder how experiments might be set up to provide answers to particular questions about a system, and/or test plausible hypotheses that might account for a set of observations. The aim of the *Design an Experiment* exercises is to foster critical thinking. We hope that they will be effective in active learning environments, which include classroom-based work and discussions, but they are also suitable for individual student work. There is no one right way to solve these exercises, but we authors offer some ideas in an online Instructor's Resource Manual, which will include results from class testing and analysis of student responses.
- The *Go Figure* exercises introduced in the twelfth edition proved to be a popular innovation, and we have expanded on its use. This feature poses a question that students can answer by examining the figure. These questions encourage students to actually study the figure and understand its primary message. Answers to the *Go Figure* questions are provided in the back of the text.
- The popular *Give It Some Thought (GIST)* questions embedded in the text have been expanded by improvements in some of the existing questions and addition of new ones. The answers to all the GIST items are provided in the back of the text.
- New end-of-chapter exercises have been added, and many of those carried over from the twelfth edition have been significantly revised. Analysis of student responses to the twelfth edition questions in MasteringChemistry® helped us identify and revise or create new questions, prompting improvements and eliminations of some questions. Additionally, analysis of usage of MasteringChemistry® has enhanced our understanding of the ways in which instructors and students have used the end-of-chapter and MasteringChemistry® materials. This, in turn, has led to additional improvements to the content within the text and in the MasteringChemistry® item library. At the end of each chapter, we list the *Learning Outcomes* that students should be able to perform after studying each section. End-of-chapter exercises, both in the text and in MasteringChemistry® offer ample opportunities for students to assess mastery of learning outcomes. We trust the *Learning Outcomes* will help you organize your lectures and tests as the course proceeds.

Organization and Contents

The first five chapters give a largely macroscopic, phenomenological view of chemistry. The basic concepts introduced—such as nomenclature, stoichiometry, and thermochemistry—provide necessary background for many of the laboratory experiments usually performed in general chemistry. We believe that an early introduction to thermochemistry is desirable because so much of our understanding of chemical processes is based on considerations of energy changes. Thermochemistry is also important when we come to a discussion of bond enthalpies. We believe we have produced an effective, balanced approach to teaching thermodynamics in general chemistry, as well as providing students with an introduction to some of the global issues involving energy production and consumption. It is no easy matter to walk the narrow pathway between—on the one hand—trying to teach too much at too high a level and—on the other hand—resorting to oversimplifications. As with the book as a whole, the emphasis has been on imparting *conceptual* understanding, as opposed to presenting equations into which students are supposed to plug numbers.

The next four chapters (Chapters 6–9) deal with electronic structure and bonding. We have largely retained our presentation of atomic orbitals. For more advanced students, *Closer Look* boxes in Chapters 6 and 9 highlight radial probability functions and the phases of orbitals. Our approach of placing this latter discussion in a *Closer Look* box in Chapter 9 enables those who wish to cover this topic to do so, while others may wish to bypass it. In treating this topic and others in Chapters 7 and 9, we have materially enhanced the accompanying figures to more effectively bring home their central messages.

In Chapters 10–13, the focus of the text changes to the next level of the organization of matter: examining the states of matter. Chapters 10 and 11 deal with gases, liquids, and intermolecular forces, as in earlier editions. Chapter 12 is devoted to solids, presenting an enlarged and more contemporary view of the solid state as well as of modern materials. The chapter provides an opportunity to show how abstract chemical bonding concepts impact real-world applications. The modular organization of the chapter allows you to tailor your coverage to focus on materials (semiconductors, polymers, nanomaterials, and so forth) that are most relevant to your students and your own interests. Chapter 13 treats the formation and properties of solutions in much the same manner as the previous edition.

The next several chapters examine the factors that determine the speed and extent of chemical reactions: kinetics (Chapter 14), equilibria (Chapters 15–17), thermodynamics (Chapter 19), and electrochemistry (Chapter 20). Also in this section is a chapter on environmental chemistry (Chapter 18), in which the concepts developed in preceding chapters are applied to a discussion of the atmosphere and hydrosphere. This chapter has increasingly come to be focused on green chemistry and the impacts of human activities on Earth's water and atmosphere.

After a discussion of nuclear chemistry (Chapter 21), the book ends with three survey chapters. Chapter 22 deals with nonmetals, Chapter 23 with the chemistry of transition metals, including coordination compounds, and Chapter 24 with the chemistry of organic compounds and elementary biochemical themes. These final four chapters are developed in a parallel fashion and can be covered in any order.

Our chapter sequence provides a fairly standard organization, but we recognize that not everyone teaches all the topics in the order we have chosen. We have therefore made sure that instructors can make common changes in teaching sequence with no loss in student comprehension. In particular, many instructors prefer to introduce gases (Chapter 10) after stoichiometry (Chapter 3) rather than with states of matter. The chapter on gases has been written to permit this change with *no* disruption in the flow of material. It is also possible to treat balancing redox equations (Sections 20.1 and 20.2) earlier, after the introduction of redox reactions in Section 4.4. Finally, some instructors like to cover organic chemistry (Chapter 24) right after bonding (Chapters 8 and 9). This, too, is a largely seamless move.

We have brought students into greater contact with descriptive organic and inorganic chemistry by integrating examples throughout the text. You will find pertinent and relevant examples of "real" chemistry woven into all the chapters to illustrate principles and applications. Some chapters, of course, more directly address the "descriptive" properties of elements and their compounds, especially Chapters 4, 7, 11, 18, and 22–24. We also incorporate descriptive organic and inorganic chemistry in the end-of-chapter exercises.

Changes in This Edition

The **What is New in This Edition** section on pp. xx–xxi details changes made throughout the new edition. Beyond a mere listing, however, it is worth dwelling on the general goals we set forth in formulating this new edition. *Chemistry: The Central Science* has traditionally been valued for its clarity of writing, its scientific accuracy and currency, its strong end-of-chapter exercises, and its consistency in level of coverage. In making changes, we have made sure not to compromise these characteristics, and we have also continued to employ an open, clean design in the layout of the book.

The art program for this thirteenth edition has continued the trajectory set in the twelfth edition: to make greater and more effective use of the figures as learning tools, by drawing the reader more directly into the figure. The art itself has continued to evolve, with modifications of many figures and additions or replacements that teach more effectively. The *Go Figure* feature has been expanded greatly to include a larger number of figures. In the same vein, we have added to the *Give it Some Thought* feature, which stimulates more thoughtful reading of the text and fosters critical thinking.

We provide a valuable overview of each chapter under the *What's Ahead* banner. *Concept links* ( ) continue to provide easy-to-see cross-references to pertinent material covered earlier in the text. The essays titled *Strategies in Chemistry*, which provide advice to students on problem solving and "thinking like a chemist," continue to be an important feature. For example, the new *Strategies in Chemistry* essay at the end of Chapter 3 introduces the new *Design an Experiment* feature and provides a worked out example as guidance.

We have continued to emphasize conceptual exercises in the end-of-chapter exercise materials. The well-received *Visualizing Concepts* exercise category has been continued in this edition. These exercises are designed to facilitate concept understanding through use of models, graphs, and other visual materials. They precede the regular end-of-chapter exercises and are identified in each case with the relevant chapter section number. A generous selection of *Integrative Exercises*, which give students the opportunity to solve problems that integrate concepts from the present chapter with those of previous chapters, is included at the end of each chapter. The importance of integrative problem solving is highlighted by the *Sample Integrative Exercise*, which ends each chapter beginning with Chapter 4. In general, we have included more conceptual end-of-chapter exercises and have made sure that there is a good representation of somewhat more difficult exercises to provide a better mix in terms of topic and level of difficulty. Many of the exercises have been restructured to facilitate their use in MasteringChemistry®. We have made extensive use of the metadata from student use of MasteringChemistry® to analyze end-of-chapter exercises and make appropriate changes, as well as to develop *Learning Outcomes* for each chapter.

New essays in our well-received *Chemistry Put to Work* and *Chemistry and Life* series emphasize world events, scientific discoveries, and medical breakthroughs that bear on topics developed in each chapter. We maintain our focus on the positive aspects of chemistry without neglecting the problems that can arise in an increasingly technological world. Our goal is to help students appreciate the real-world perspective of chemistry and the ways in which chemistry affects their lives.

It is perhaps a natural tendency for chemistry textbooks to grow in length with succeeding editions, but it is one that we have resisted. There are, nonetheless, many new items in this edition, mostly ones that replace other material considered less pertinent. Here is a list of several significant changes in content:

In Chapter 1, the *Closer Look* box on the scientific method has been rewritten. The *Chemistry Put to Work* box, dealing with *Chemistry in the News*, has been completely rewritten, with items that describe diverse ways in which chemistry intersects with the affairs of modern society. The *Chapter Summary* and *Learning Outcomes* sections at the end of the chapter have been rewritten for ease of use by both instructor and student, in this and all chapters in the text. Similarly, the exercises have been thoroughly vetted, modified where this was called for and replaced or added to, here and in all succeeding chapters.

In Chapter 3, graphic elements highlighting the correct approach to problem solving have been added to *Sample Exercises* on calculating an empirical formula from mass percent of the elements present, combustion analysis, and calculating a theoretical yield.

Chapter 5 now presents a more explicit discussion of combined units of measurement, an improved introduction to enthalpy, and more consistent use of color in art.

Changes in Chapter 6 include a significant revision of the discussion of the energy levels of the hydrogen atom, including greater clarity on absorption versus emission processes. There is also a new *Closer Look* box on *Thought Experiments and Schrödinger's Cat*, which gives students a brief glimpse of some of the philosophical issues in quantum mechanics and also connects to the 2012 Nobel Prize in Physics.

In Chapter 7, the emphasis on conceptual thinking was enhanced in several ways: the section on effective nuclear charge was significantly revised to include a classroom-tested analogy, the number of *Go Figure* features was increased substantially, and new end-of-chapter exercises emphasize critical thinking and understanding concepts. In addition, the *Chemistry Put to Work* box on lithium-ion batteries was updated and revised to include discussion of current issues in using these batteries. Finally, the values of ionic radii were revised to be consistent with a recent research study of the best values for these radii.

In Chapter 9, which is one of the most challenging for students, we continue to refine our presentation based on our classroom experience. Twelve new *Go Figure* exercises will stimulate more student thought in a chapter with a large amount of graphic material. The discussion of molecular geometry was made more conceptually oriented. The section on delocalized bonding was completely revised to provide what we believe will be a better introduction that students will find useful in organic chemistry. The *Closer Look* box on phases in orbitals was revamped with improved artwork. We also increased the number of end-of-chapter exercises, especially in the area of molecular orbital theory. The *Design an Experiment* feature in this chapter gives the students the opportunity to explore color and conjugated π systems.

Chapter 10 contains a new *Sample Exercise* that walks the student through the calculations that are needed to understand Torricelli's barometer. Chapter 11 includes an improved definition of hydrogen bonding and updated data for the strengths of intermolecular attractions. Chapter 12 includes the latest updates to materials chemistry, including plastic electronics. New material on the diffusion and mean free path of colloids in solution is added to Chapter 13, making a connection to the diffusion of gas molecules from Chapter 10.

In Chapter 14, ten new *Go Figure* exercises have been added to reinforce many of the concepts presented as figures and graphs in the chapter. The *Design an Experiment* exercise in the chapter connects strongly to the *Closer Look* box on Beer's Law, which is often the basis for spectrometric kinetics experiments performed in the general chemistry laboratory.

The presentation in Chapter 16 was made more closely tied to that in Chapter 15, especially through the use of more initial/change/equilibrium (ICE) charts. The number of conceptual end-of-chapter exercises, including *Visualizing Concepts* features, was increased significantly.

Chapter 17 offers improved clarity on how to make buffers, and when the Henderson–Hasselbalch equation may not be accurate. Chapter 18 has been extensively updated to reflect changes in this rapidly evolving area of chemistry. Two *Closer Look* boxes have been added; one dealing with the shrinking level of water in the Ogallala aquifer and a second with the potential environmental consequences of hydraulic fracking. In Chapter 20, the description of Li-ion batteries has been significantly expanded to reflect the growing importance of these batteries, and a new *Chemistry Put to Work* box on batteries for hybrid and electric vehicles has been added.

Chapter 21 was updated to reflect some of the current issues in nuclear chemistry and more commonly used nomenclature for forms of radiation are now used. Chapter 22 includes an improved discussion of silicates.

In Chapter 23, the section on crystal-field theory (Section 23.6) has undergone considerable revision. The description of how the *d*-orbital energies of a metal ion split in a tetrahedral crystal field has been expanded to put it on par with our treatment of the octahedral geometry, and a new *Sample Exercise* that effectively integrates the links between color, magnetism, and the spectrochemical series has been added. Chapter 24's coverage of organic chemistry and biochemistry now includes oxidation–reduction reactions that organic chemists find most relevant.

To the Student

Chemistry: The Central Science, Thirteenth Edition, has been written to introduce you to modern chemistry. As authors, we have, in effect, been engaged by your instructor to help you learn chemistry. Based on the comments of students and instructors who have used this book in its previous editions, we believe that we have done that job well. Of course, we expect the text to continue to evolve through future editions. We invite you to write to tell us what you like about the book so that we will know where we have helped you most. Also, we would like to learn of any shortcomings so that we might further improve the book in subsequent editions. Our addresses are given at the end of the Preface.

Advice for Learning and Studying Chemistry

Learning chemistry requires both the assimilation of many concepts and the development of analytical skills. In this text, we have provided you with numerous tools to help you succeed in both tasks. If you are going to succeed in your chemistry course, you will have to develop good study habits. Science courses, and chemistry in particular, make different demands on your learning skills than do other types of courses. We offer the following tips for success in your study of chemistry:

Don't fall behind! As the course moves along, new topics will build on material already presented. If you don't keep up in your reading and problem solving, you will find it much harder to follow the lectures and discussions on current topics. Experienced teachers know that students who read the relevant sections of the text *before* coming to a class learn more from the class and retain greater recall. "Cramming" just before an exam has been shown to be an ineffective way to study any subject, chemistry included. So now you know. How important to you, in this competitive world, is a good grade in chemistry?

Focus your study. The amount of information you will be expected to learn can sometimes seem overwhelming. It is essential to recognize those concepts and skills that are particularly important. Pay attention to what your instructor is emphasizing. As you work through the *Sample Exercises* and homework assignments, try to see what general principles and skills they employ. Use the *What's Ahead* feature at the beginning of each chapter to help orient yourself to what is important in each chapter. A single reading of a chapter will simply not be enough for successful learning of chapter concepts and problem-solving skills. You will need to go over assigned materials more than once. Don't skip the *Give It Some Thought* and *Go Figure* features, *Sample Exercises*, and *Practice Exercises*. They are your guides to whether you are learning the material. They are also good preparation for test-taking. The *Learning Outcomes* and *Key Equations* at the end of the chapter should help you focus your study.

Keep good lecture notes. Your lecture notes will provide you with a clear and concise record of what your instructor regards as the most important material to learn. Using your lecture notes in conjunction with this text is the best way to determine which material to study.

Skim topics in the text before they are covered in lecture. Reviewing a topic before lecture will make it easier for you to take good notes. First read the *What's Ahead* points and the end-of-chapter *Summary*; then quickly read through the chapter, skipping Sample Exercises and supplemental sections. Paying attention to the titles of sections and subsections gives you a feeling for the scope of topics. Try to avoid thinking that you must learn and understand everything right away.

You need to do a certain amount of preparation before lecture. More than ever, instructors are using the lecture period not simply as a one-way channel of communication from teacher to student. Rather, they expect students to come to class ready to work on problem solving and critical thinking. Coming to class unprepared is not a good idea for any lecture environment, but it certainly is not an option for an active learning classroom if you aim to do well in the course.

After lecture, carefully read the topics covered in class. As you read, pay attention to the concepts presented and to the application of these concepts in the *Sample Exercises*. Once you think you understand a *Sample Exercise*, test your understanding by working the accompanying *Practice Exercise*.

Learn the language of chemistry. As you study chemistry, you will encounter many new words. It is important to pay attention to these words and to know their meanings or the entities to which they refer. Knowing how to identify chemical substances from their names is an important skill; it can help you avoid painful mistakes on examinations. For example, "chlorine" and "chloride" refer to very different things.

Attempt the assigned end-of-chapter exercises. Working the exercises selected by your instructor provides necessary practice in recalling and using the essential ideas of the chapter. You cannot learn merely by observing; you must be a participant. In particular, try to resist checking the *Student Solutions Manual* (if you have one) until you have made a sincere effort to solve the exercise yourself. If you get stuck on an exercise, however, get help from your instructor, your teaching assistant, or another student. Spending more than 20 minutes on a single exercise is rarely effective unless you know that it is particularly challenging.

Learn to think like a scientist. This book is written by scientists who love chemistry. We encourage you to develop your critical thinking skills by taking advantage of new features in this edition, such as exercises that focus on conceptual learning, and the *Design an Experiment* exercises.

Use online resources. Some things are more easily learned by discovery, and others are best shown in three dimensions. If your instructor has included MasteringChemistry® with your book, take advantage of the unique tools it provides to get the most out of your time in chemistry.

The bottom line is to work hard, study effectively, and use the tools available to you, including this textbook. We want to help you learn more about the world of chemistry and why chemistry is the central science. If you really learn chemistry, you can be the life of the party, impress your friends and parents, and … well, also pass the course with a good grade.

Acknowledgments

The production of a textbook is a team effort requiring the involvement of many people besides the authors who contributed hard work and talent to bring this edition to life. Although their names don't appear on the cover of the book, their creativity, time, and support have been instrumental in all stages of its development and production.

Each of us has benefited greatly from discussions with colleagues and from correspondence with instructors and students both here and abroad. Colleagues have also helped immensely by reviewing our materials, sharing their insights, and providing suggestions for improvements. On this edition, we were particularly blessed with an exceptional group of accuracy checkers who read through our materials looking for both technical inaccuracies and typographical errors.

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There are many others who also deserve special recognition, including the following: Greg Johnson, our production editor, who skillfully kept the process moving and us authors on track; Kerri Wilson, our photo researcher, who was so effective in finding photos to bring chemistry to life for students; and Roxy Wilson (University of Illinois), who so ably coordinated the difficult job of working out solutions to the end-of-chapter exercises. Finally, we wish to thank our families and friends for their love, support, encouragement, and patience as we brought this thirteenth edition to completion.

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List of Resources

For Students

MasteringChemistry®
(http://www.masteringchemistry.com)

MasteringChemistry® is the most effective, widely used online tutorial, homework and assessment system for chemistry. It helps instructors maximize class time with customizable, easy-to-assign, and automatically graded assessments that motivate students to learn outside of class and arrive prepared for lecture. These assessments can easily be customized and personalized by instructors to suit their individual teaching style. The powerful gradebook provides unique insight into student and class performance even before the first test. As a result, instructors can spend class time where students need it most.

Pearson eText The integration of Pearson eText within MasteringChemistry® gives students with eTexts easy access to the electronic text when they are logged into MasteringChemistry®. Pearson eText pages look exactly like the printed text, offering powerful new functionality for students and instructors. Users can create notes, highlight text in different colors, create bookmarks, zoom, view in single-page or two-page view, and more.

Students Guide (0-321-94928-5) Prepared by James C. Hill of California State University. This book assists students through the text material with chapter overviews, learning objectives, a review of key terms, as well as self-tests with answers and explanations. This edition also features MCAT practice questions.

Solutions to Red Exercises (0-321-94926-9) Prepared by Roxy Wilson of the University of Illinois, Urbana-Champaign. Full solutions to all the red-numbered exercises in the text are provided. (Short answers to red exercises are found in the appendix of the text.)

Solutions to Black Exercises (0-321-94927-7) Prepared by Roxy Wilson of the University of Illinois, Urbana-Champaign. Full solutions to all the black-numbered exercises in the text are provided.

Laboratory Experiments (0-321-94991-9) Prepared by John H. Nelson of the University of Nevada, and Michael Lufaso of the University of North Florida with contributions by Matthew Stoltzfus of The Ohio State University. This manual contains 40 finely tuned experiments chosen to introduce students to basic lab techniques and to illustrate core chemical principles. This new edition has been revised with the addition of four brand new experiments to correlate more tightly with the text. You can also customize these labs through Catalyst, our custom database program. For more information, visit *http://www.pearsoncustom.com/custom-library/*

For Instructors

Solutions to Exercises (0-321-94925-0) Prepared by Roxy Wilson of the University of Illinois, Urbana-Champaign. This manual contains all end-of-chapter exercises in the text. With an instructor's permission, this manual may be made available to students.

Online Instructor Resource Center (0-321-94923-4) This resource provides an integrated collection of resources to help instructors make efficient and effective use of their time. It features all artwork from the text, including figures and tables in PDF format for high-resolution printing, as well as five prebuilt PowerPoint™ presentations. The first presentation contains the images embedded within PowerPoint slides. The second includes a complete lecture outline that is modifiable by the user. The final three presentations contain worked "in-chapter" sample exercises and questions to be used with Classroom Response Systems. The Instructor Resource Center also contains movies, animations, and electronic files of the Instructor Resource Manual, as well as the Test Item File.

TestGen Testbank (0-321-94924-2) Prepared by Andrea Leonard of the University of Louisiana. The Test Item File now provides a selection of more than 4,000 test questions with 200 new questions in the thirteenth edition and 200 additional algorithmic questions.

Online Instructor Resource Manual (0-321-94929-3) Prepared by Linda Brunauer of Santa Clara University and Elzbieta Cook of Louisiana State University. Organized by chapter, this manual offers detailed lecture outlines and complete descriptions of all available lecture demonstrations, interactive media assets, common student misconceptions, and more.

Annotated Instructor's Edition to Laboratory Experiments (0-321-98608-3) Prepared by John H. Nelson of the University of Nevada, and Michael Lufaso of the University of North Florida with contributions by Matthew Stoltzfus of the Ohio State University. This AIE combines the full student lab manual with appendices covering the proper disposal of chemical waste, safety instructions for the lab, descriptions of standard lab equipment, answers to questions, and more.

WebCT Test Item File (IRC download only)
0-321-94931-5

Blackboard Test Item File (IRC download only)
0-321-94930-7

About the Authors

THE BROWN/LEMAY/BURSTEN/MURPHY/WOODWARD/STOLTZFUS AUTHOR TEAM values collaboration as an integral component to overall success. While each author brings unique talent, research interests, and teaching experiences, the team works together to review and develop the entire text. It is this collaboration that keeps the content ahead of educational trends and contributes to continuous innovations in teaching and learning throughout the text and technology. Some of the new key features in the thirteenth edition and accompanying MasteringChemistry® course are highlighted on the following pages.

THEODORE L. BROWN received his Ph.D. from Michigan State University in 1956. Since then, he has been a member of the faculty of the University of Illinois, Urbana-Champaign, where he is now Professor of Chemistry, Emeritus. He served as Vice Chancellor for Research, and Dean of The Graduate College, from 1980 to 1986, and as Founding Director of the Arnold and Mabel Beckman Institute for Advanced Science and Technology from 1987 to 1993. Professor Brown has been an Alfred P. Sloan Foundation Research Fellow and has been awarded a Guggenheim Fellowship. In 1972 he was awarded the American Chemical Society Award for Research in Inorganic Chemistry and received the American Chemical Society Award for Distinguished Service in the Advancement of Inorganic Chemistry in 1993. He has been elected a Fellow of the American Association for the Advancement of Science, the American Academy of Arts and Sciences, and the American Chemical Society.

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BRUCE E. BURSTEN received his Ph.D. in Chemistry from the University of Wisconsin in 1978. After two years as a National Science Foundation Postdoctoral Fellow at Texas A&M University, he joined the faculty of The Ohio State University, where he rose to the rank of Distinguished University Professor. In 2005, he moved to the University of Tennessee, Knoxville, as Distinguished Professor of Chemistry and Dean of the College of Arts and Sciences. Professor Bursten has been a Camille and Henry Dreyfus Foundation Teacher-Scholar and an Alfred P. Sloan Foundation Research Fellow, and he is a Fellow of both the American Association for the Advancement of Science and the American Chemical Society. At Ohio State he has received the University Distinguished Teaching Award in 1982 and 1996, the Arts and Sciences Student Council Outstanding Teaching Award in 1984, and the University Distinguished Scholar Award in 1990. He received the Spiers Memorial Prize and Medal of the Royal Society of Chemistry in 2003, and the Morley Medal of the Cleveland Section of the American Chemical Society in 2005. He was President of the American Chemical Society for 2008. In addition to his teaching and service activities, Professor Bursten's research program focuses on compounds of the transition-metal and actinide elements.

CATHERINE J. MURPHY received two B.S. degrees, one in Chemistry and one in Biochemistry, from the University of Illinois, Urbana-Champaign, in 1986. She received her Ph.D. in Chemistry from the University of Wisconsin in 1990. She was a National Science Foundation and National Institutes of Health Postdoctoral Fellow at the California Institute of Technology from 1990 to 1993. In 1993, she joined the faculty of the University of South Carolina, Columbia, becoming the Guy F. Lipscomb Professor of Chemistry in 2003. In 2009 she moved to the University of Illinois, Urbana-Champaign, as the Peter C. and Gretchen Miller Markunas Professor of Chemistry. Professor Murphy has been honored for both research and teaching as a Camille Dreyfus Teacher-Scholar, an Alfred P. Sloan Foundation Research Fellow, a Cottrell Scholar of the Research Corporation, a National Science Foundation CAREER Award winner, and a subsequent NSF Award for Special Creativity. She has also received a USC Mortar Board Excellence in Teaching Award, the USC Golden Key Faculty Award for Creative Integration of Research and Undergraduate Teaching, the USC Michael J. Mungo Undergraduate Teaching Award, and the USC Outstanding Undergraduate Research Mentor Award. Since 2006, Professor Murphy has served as a Senior Editor for the Journal of Physical Chemistry. In 2008 she was elected a Fellow of the American Association for the Advancement of Science. Professor Murphy's research program focuses on the synthesis and optical properties of inorganic nanomaterials, and on the local structure and dynamics of the DNA double helix.

PATRICK M. WOODWARD received B.S. degrees in both Chemistry and Engineering from Idaho State University in 1991. He received a M.S. degree in Materials Science and a Ph.D. in Chemistry from Oregon State University in 1996. He spent two years as a postdoctoral researcher in the Department of Physics at Brookhaven National Laboratory. In 1998, he joined the faculty of the Chemistry Department at The Ohio State University where he currently holds the rank of Professor. He has enjoyed visiting professorships at the University of Bordeaux in France and the University of Sydney in Australia. Professor Woodward has been an Alfred P. Sloan Foundation Research Fellow and a National Science Foundation CAREER Award winner. He currently serves as an Associate Editor to the Journal of Solid State Chemistry and as the director of the Ohio REEL program, an NSF-funded center that works to bring authentic research experiments into the laboratories of first- and second-year chemistry classes in 15 colleges and universities across the state of Ohio. Professor Woodward's research program focuses on understanding the links between bonding, structure, and properties of solid-state inorganic functional materials.

MATTHEW W. STOLTZFUS received his B.S. degree in Chemistry from Millersville University in 2002 and his Ph. D. in Chemistry in 2007 from The Ohio State University. He spent two years as a teaching postdoctoral assistant for the Ohio REEL program, an NSF-funded center that works to bring authentic research experiments into the general chemistry lab curriculum in 15 colleges and universities across the state of Ohio. In 2009, he joined the faculty of Ohio State where he currently holds the position of Chemistry Lecturer. In addition to lecturing general chemistry, Stoltzfus accepted the Faculty Fellow position for the Digital First Initiative, inspiring instructors to offer engaging digital learning content to students through emerging technology. Through this initiative, he developed an iTunes U general chemistry course, which has attracted over 120,000 students from all over the world. Stoltzfus has received several teaching awards, including the inaugural Ohio State University 2013 Provost's Award for Distinguished Teaching by a Lecturer and he is recognized as an Apple Distinguished Educator.

Data-Driven Analytics

A New Direction in Chemical Education

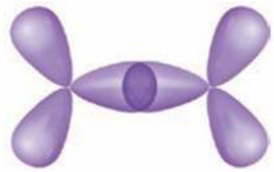
Authors traditionally revise roughly 25% of the end of chapter questions when producing a new edition. These changes typically involve modifying numerical variables/identities of chemical formulas to make them "new" to the next batch of students. While these changes are appropriate for the printed version of the text, one of the strengths of MasteringChemistry® is its ability to randomize variables so that every student receives a "different" problem. Hence, the effort which authors have historically put into changing variables can now be used to improve questions.

In order to make informed decisions, the author team consulted the massive reservoir of data available through MasteringChemistry® to revise their question bank. In particular, they analyzed which problems were frequently assigned and why; they paid careful attention to the amount of time it took students to work through a problem (flagging those that took longer than expected) and they observed the wrong answer submissions and hints used (a measure used to calculate the difficulty of problems). This "metadata" served as a starting point for the discussion of which end of chapter questions should be changed.

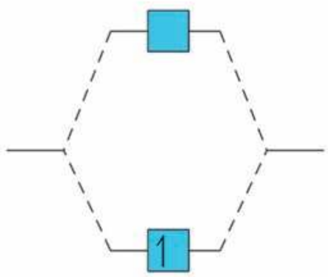
For example, the breadth of ideas presented in Chapter 9 challenges students to understand three-dimensional visualization while simultaneously introducing several new concepts (particularly VSEPR, hybrids, and Molecular Orbital theory) that challenge their critical thinking skills. In revising the exercises for the chapter, the authors drew on the metadata as well as their own experience in assigning Chapter 9 problems in Mastering Chemistry. From these analyses, we were able to articulate two general revision guidelines.

1. **Improve coverage of topic areas that were underutilized:** In Chapter 9, the authors noticed that there was a particularly low usage rate for questions concerning Molecular Orbital Theory. Based on the metadata and their own teaching experience with Mastering, they recognized an opportunity to expand the coverage of MO theory. Two brand new exercises that emphasize the basics of MO theory were the result of this analysis including the example below. This strategy was replicated throughout the entire book.

9.8 The drawing below shows the overlap of two hybrid orbitals to form a bond in a hydrocarbon. (**a**) Which of the following types of bonds is being formed: (i) C—C σ, (ii) C—C π, or (iii) C—H σ? (**b**) Which of the following could be the identity of the hydrocarbon: (i) CH_4, (ii) C_2H_6, (iii) C_2H_4, or (iv) C_2H_2? [Section 9.6]



9.10 The following is part of a molecular orbital energy-level diagram for MOs constructed from 1*s* atomic orbitals.



(**a**) What labels do we use for the two MOs shown? (**b**) For which of the following molecules or ions could this be the energy-level diagram:

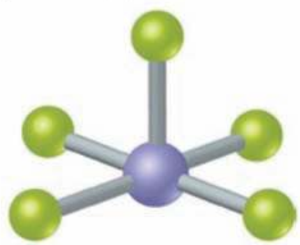
H_2, He_2, H_2^+, He_2^+, or H_2^-?

(**c**) What is the bond order of the molecule or ion? (**d**) If an electron is added to the system, into which of the MOs will it be added? [Section 9.7]

2. **Revise the least assigned existing problems.** Much of the appeal of MasteringChemistry® for students is the immediate feedback they get when they hit submit, which also provides an opportunity to confront any misconceptions right away. For instructors, the appeal is that these problems are automatically graded. Essay questions fail to provide these advantages since they must be graded by an instructor before a student may receive feedback. Wherever possible, we revised current essay questions to include automatically graded material.

Bottom Line: The revision of the end of chapter questions in this edition is informed by robust data-driven analytics providing a new level of pedagogically-sound assessments for your students, all while making the time they spend working these problems even more valuable.

9.93 An AB_5 molecule adopts the geometry shown here. (**a**) What is the name of this geometry? (**b**) Do you think there are any nonbonding electron pairs on atom A? (**c**) Suppose the atoms B are halogen atoms. Of which group in the periodic table is atom A a member: (i) Group 5A, (ii) Group 6A, (iii) Group 7A, (iv) Group 8A, or (v) More information is needed?



9.4 The molecule shown here is *difluoromethane* (CH_2F_2), which is used as a refrigerant called R-32. (**a**) Based on the structure, how many electron domains surround the C atom in this molecule? (**b**) Would the molecule have a nonzero dipole moment? (**c**) If the molecule is polar, which of the following describes the direction of the overall dipole moment vector in the molecule: (i) from the carbon atom toward a fluorine atom, (ii) from the carbon atom to a point midway between the fluorine atoms, (iii) from the carbon atom to a point midway between the hydrogen atoms, or (iv) From the carbon atom toward a hydrogen atom? [Sections 9.2 and 9.3]

Helping Students Think Like Scientists

Design an Experiment

Starting with Chapter 3, every chapter will feature a *Design an Experiment* exercise. The goal of these exercises is to challenge students to think like a scientist, imagining what kind of data needs to be collected and what sort of experimental procedures will provide them the data needed to answer the question. These exercises tend to be integrative, forcing students to draw on many of the skills they have learned in the current and previous chapters.

Strategies in Chemistry

Design an Experiment

One of the most important skills you can learn in school is how to think like a scientist. Questions such as: "What experiment might test this hypothesis?", "How do I interpret these data?", and "Do these data support the hypothesis?" are asked every day by chemists and other scientists as they go about their work.

We want you to become a good critical thinker as well as an active, logical, and curious learner. For this purpose, starting in Chapter 3, we include at the end of each chapter a special exercise called "Design an Experiment." Here is an example:

of the pan? If so, you could weigh it, and calculate the percentage of solids in milk, which would offer good evidence that milk is a mixture. If there is no residue after boiling, then you still cannot distinguish between the two possibilities.

What other experiments might you do to demonstrate that milk is a mixture? You could put a sample of milk in a centrifuge, which you might have used in a biology lab, spin your sample and observe if any solids collect at the bottom of the centrifuge tube; large molecules can be separated in this way from a mixture. Measurement of the mass of the solid at the bottom of the tube is a way to obtain a value for the % solids in milk, and also tells you that milk is indeed a mixture.

Design an Experiment topics include:

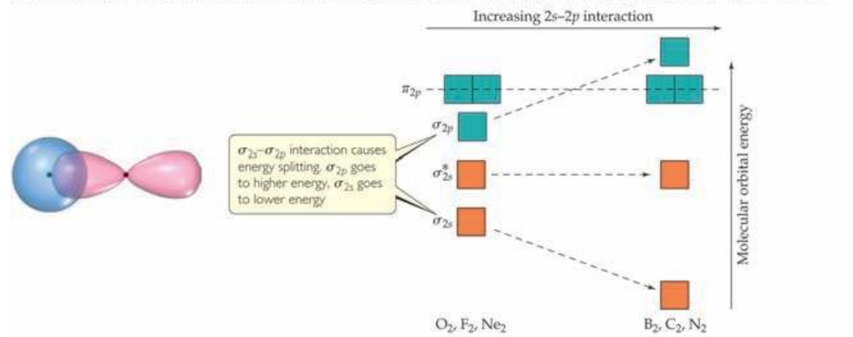
Ch 3: Formation of Sulfur Oxides
Ch 4: Identification of Mysterious White Powders
Ch 5: Joule Experiment
Ch 6: Photoelectric Effect and Electron Configurations
Ch 7: Chemistry of Potassium Superoxide
Ch 8: Benzene Resonance
Ch 9: Colors of Organic Dyes
Ch 10: Identification of an Unknown Noble Gas
Ch 11: Hydraulic Fluids
Ch 12: Polymers
Ch 13: Volatile Solvent Molecules
Ch 14: Reaction Kinetics via Spectrophotometry
Ch 15: Beer's Law and Visible-Light Spectroscopy
Ch 16: Acidity/Basicity of an Unknown Liquid
Ch 17: Understanding Differences in pKa
Ch 18: Effects of Fracking on Groundwater
Ch 19: Drug Candidates and the Equilibrium Constant
Ch 20: Voltaic Cells
Ch 21: Discovery and Properties of Radium
Ch 22: Identification of Unknowns
Ch 23: Synthesis and Characterization of a Coordination Compound
Ch 24: Quaternary Structure in Proteins

Go Figure

Go Figure questions encourage students to stop and analyze the artwork in the text, for conceptual understanding. "Voice Balloons" in selected figures help students break down and understand the components of the image. These questions are also available in MasteringChemistry®. The number of Go Figure questions in the thirteenth edition has increased by 25%.

GO FIGURE

Which molecular orbitals have switched relative energy in the group on the right as compared with the group on the left?



▲ **Figure 9.42** The effect of interactions between 2*s* and 2*p* atomic orbitals.

Practice Exercises

A major new feature of this edition is the addition of a second Practice Exercise to accompany each Sample Exercise within the chapters. The new Practice Exercises are multiple-choice with correct answers provided for the students in an appendix. Specific wrong answer feedback, written by the authors, will be available in MasteringChemistry® The primary goal of the new Practice Exercise feature is to provide students with an additional problem to test mastery of the concepts in the text and to address the most common conceptual misunderstandings. To ensure the questions touched on the most common student misconceptions, the authors consulted the ACS Chemistry Concept inventory before writing their questions.

SAMPLE EXERCISE 2.6 Relating Empirical and Molecular Formulas

Write the empirical formulas for **(a)** glucose, a substance also known as either blood sugar or dextrose—molecular formula $C_6H_{12}O_6$; **(b)** nitrous oxide, a substance used as an anesthetic and commonly called laughing gas—molecular formula N_2O.

SOLUTION

(a) The subscripts of an empirical formula are the smallest whole-number ratios. The smallest ratios are obtained by dividing each subscript by the largest common factor, in this case 6. The resultant empirical formula for glucose is CH_2O.

(b) Because the subscripts in N_2O are already the lowest integral numbers, the empirical formula for nitrous oxide is the same as its molecular formula, N_2O.

Practice Exercise 1

Tetracarbon dioxide is an unstable oxide of carbon with the following molecular structure:

What are the molecular and empirical formulas of this substance? **(a)** C_2O_2, CO_2, **(b)** C_4O, CO, **(c)** CO_2, CO_2, **(d)** C_4O_2, C_2O, **(e)** C_2O, CO_2.

Practice Exercise 2

Give the empirical formula for *decaborane*, whose molecular formula is $B_{10}H_{14}$.

Give It Some Thought (GIST) questions

These informal, sharply-focused exercises allow students the opportunity to gauge whether they are "getting it" as they read the text. The number of GIST questions has increased throughout the text as well as in MasteringChemistry®.

Give It Some Thought

A solution of SO_2 in water contains 0.00023 g of SO_2 per liter of solution. What is the concentration of SO_2 in ppm? In ppb?

Active and Visual

The most effective learning happens when students actively participate and interact with material in order to truly internalize key concepts. The Brown/Lemay/Bursten/Murphy/Woodward/Stoltzfus author team has spent decades refining their text based on educational research to the extent that it has largely defined how the general chemistry course is taught. With the thirteenth edition, these authors have extended this tradition by giving each student a way to personalize their learning experience through MasteringChemistry®. The MasteringChemistry® course for Brown/Lemay/Bursten/Murphy/Woodward/Stoltzfus evolves learning and technology usage far beyond the lecture-homework model. Many of these resources can be used pre-lecture, during class, and for assessment while providing each student with a personalized learning experience which gives them the greatest chance of succeeding.

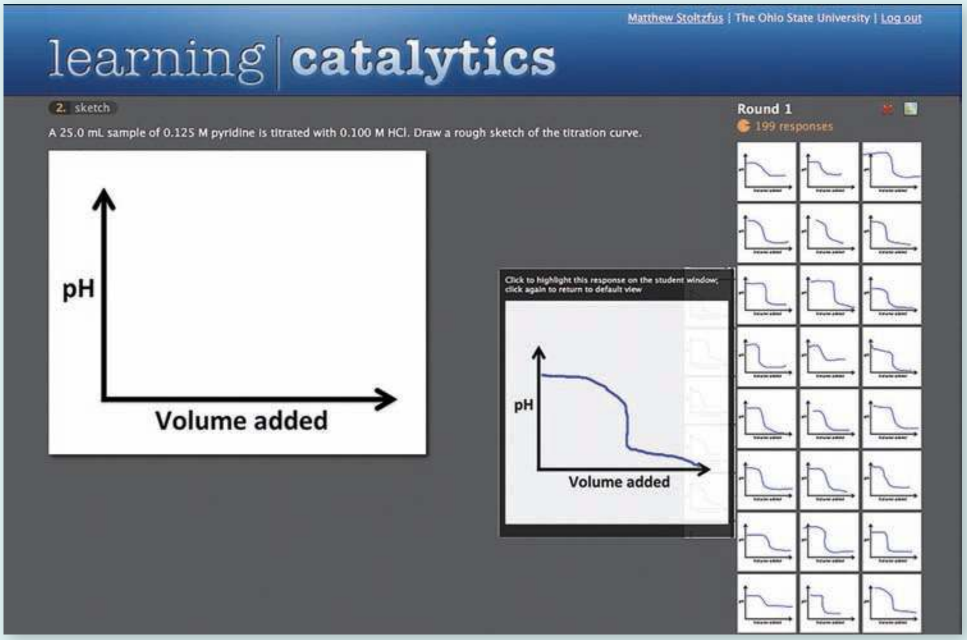
Learning Catalytics

Learning Catalytics™ is a “bring your own device” student engagement, assessment, and classroom intelligence system. With Learning Catalytics™ you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students’ critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics™ fit your course exactly.
- Manage student interactions with intelligent grouping and timing.

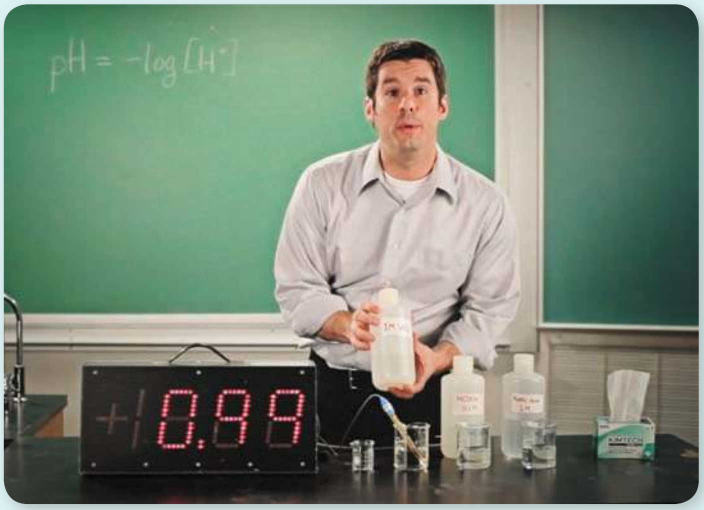
Learning Catalytics™ is a technology that has grown out of twenty years of cutting-edge research, innovation, and implementation of interactive teaching and peer instruction.

Learning Catalytics™ will be included with the purchase of MasteringChemistry® with eText.

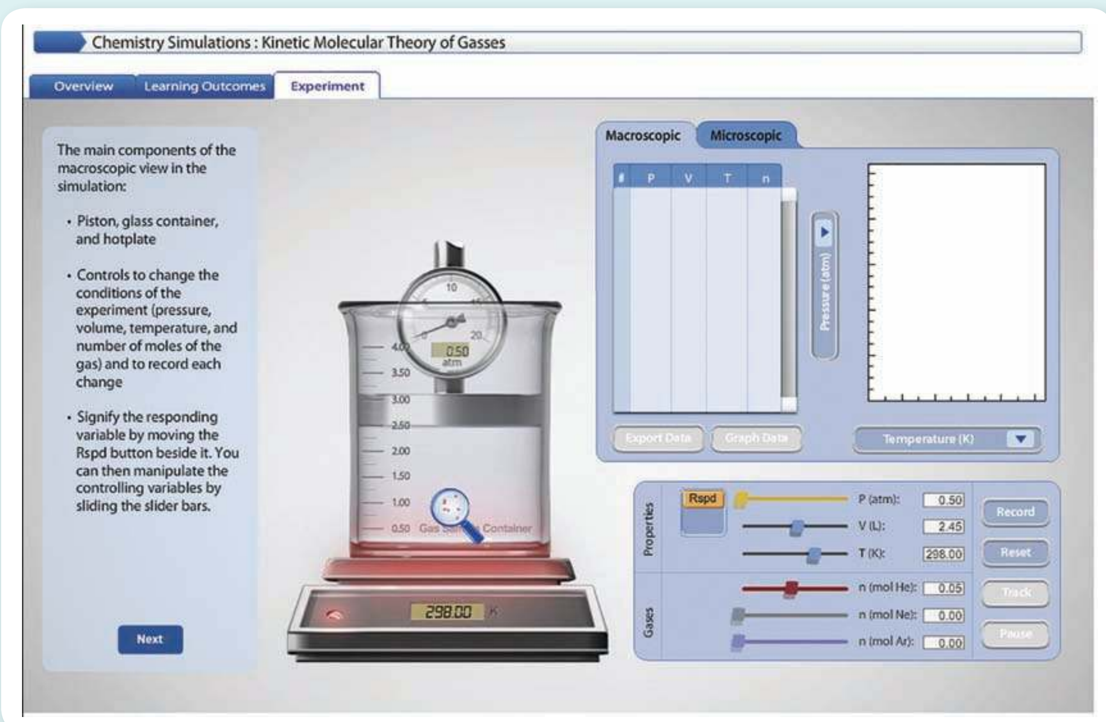


Pause and Predict Videos

Author Dr. Matt Stoltzfus created Pause and Predict Videos. These videos engage students by prompting them to submit a prediction about the outcome of an experiment or demonstration before seeing the final result. A set of assignable tutorials, based on these videos, challenge students to transfer their understanding of the demonstration to related scenarios. These videos are also available in web- and mobile-friendly formats through the study area of MasteringChemistry® and in the Pearson eText.

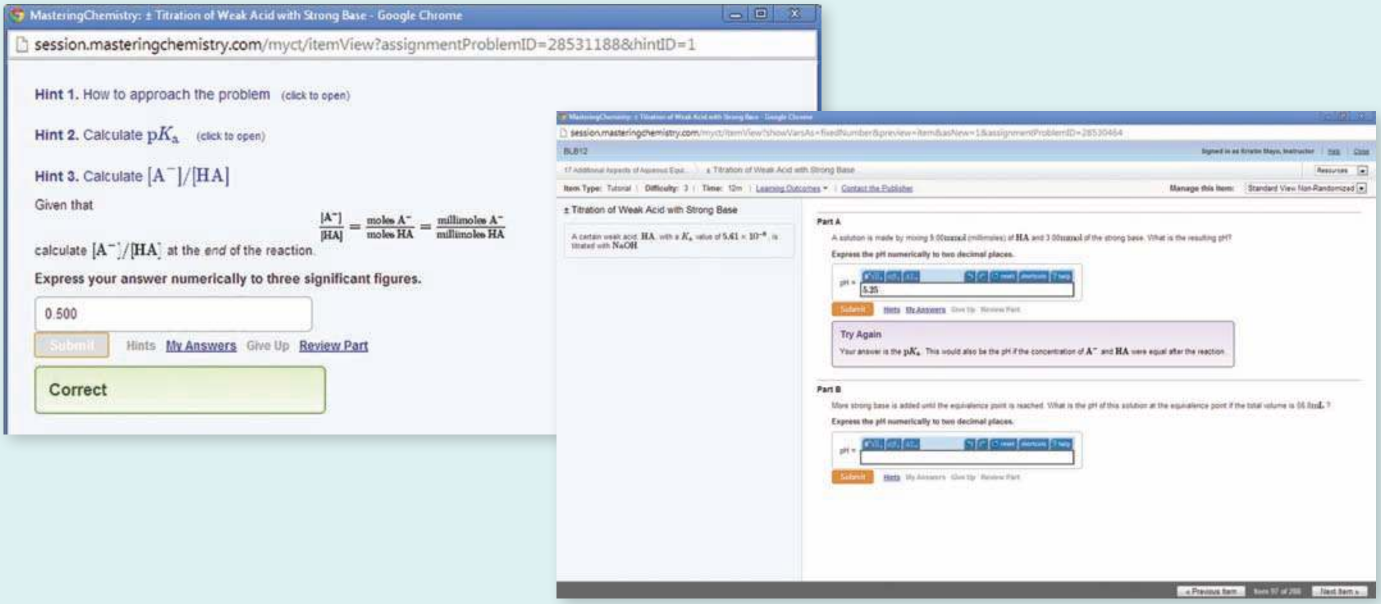


NEW! Simulations, assignable in MasteringChemistry®, include those developed by the PhET Chemistry Group, and the leading authors in simulation development covering some of the most difficult chemistry concepts.



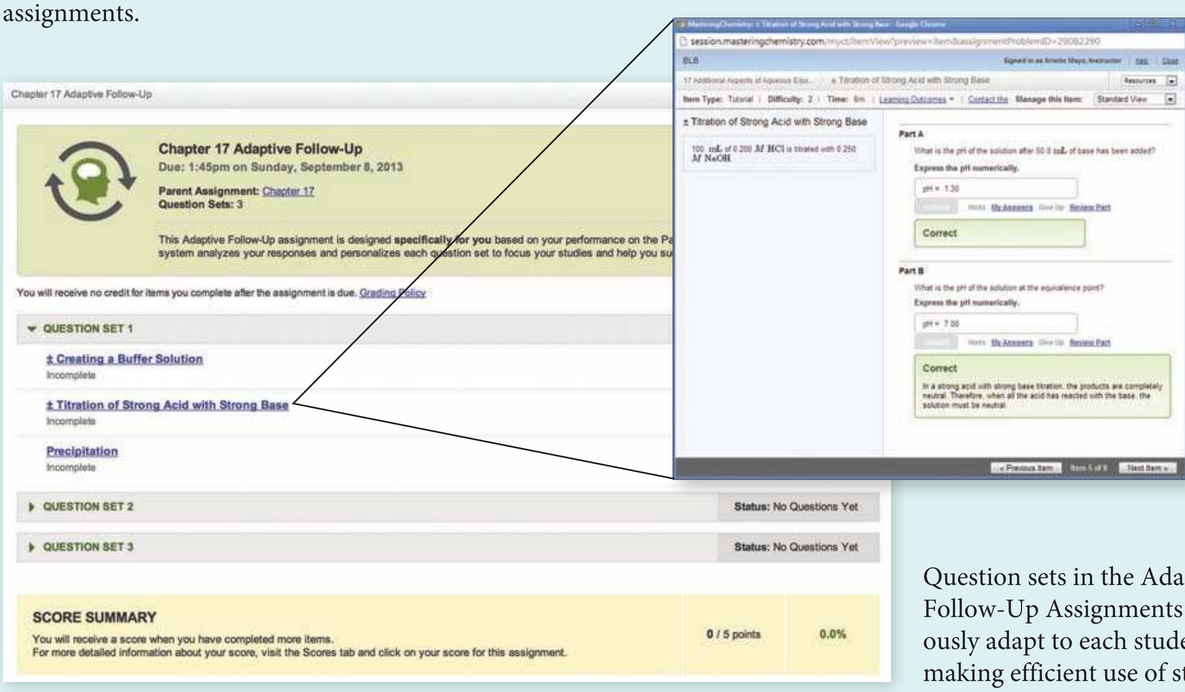
Adaptive

MasteringChemistry® has always been personalized and adaptive on a question level by providing error-specific feedback based on actual student responses; however, Mastering now includes two new adaptive assignment types—Adaptive Follow-Up Assignments and Dynamic Study Modules.



Adaptive Follow-Up Assignments

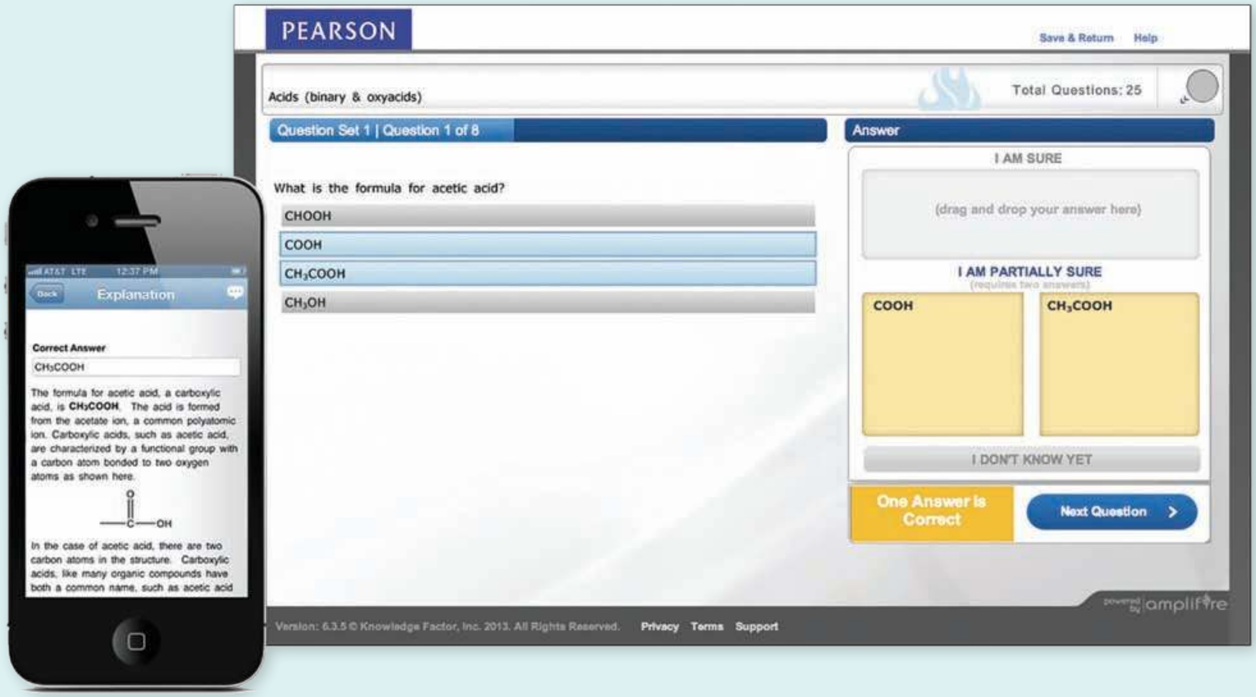
Instructors have the ability to assign adaptive follow-up assignments. Content delivered to students as part of adaptive learning will be automatically personalized for each individual based on strengths and weaknesses identified by his or her performance on Mastering parent assignments.



Question sets in the Adaptive Follow-Up Assignments continuously adapt to each student's needs, making efficient use of study time.

Dynamic Study Modules

NEW! Dynamic Study Modules, designed to enable students to study effectively on their own as well as help students quickly access and learn the nomenclature they need to be successful in chemistry.



These modules can be accessed on smartphones, tablets, and computers and results can be tracked in the MasteringChemistry® Gradebook. Here's how it works:

1. Students receive an initial set of questions and benefit from the metacognition involved with asking them to indicate how confident they are with their answer.
2. After answering each set of questions, students review their answers.
3. Each question has explanation material that reinforces the correct answer response and addresses the misconceptions found in the wrong answer choices.
4. Once students review the explanations, they are presented with a new set of questions. Students cycle through this dynamic process of test-learn-retest until they achieve mastery of the material.

1

Introduction: Matter and Measurement

In the title of this book we refer to chemistry as the *central science.* This title reflects the fact that much of what goes on in the world around us involves chemistry. The changes that produce the brilliant colors of tree leaves in the fall, the electrical energy that powers a cell phone, the spoilage of foods left standing at room temperature, and the many ways in which our bodies use the foods we consume are all everyday examples of chemical processes.

Chemistry is the study of matter and the changes that matter undergoes. As you progress in your study, you will come to see how chemical principles operate in all aspects of our lives, from everyday activities like food preparation to more complex processes such as those that operate in the environment. We use chemical principles to understand a host of phenomena, from the role of salt in our diet to the workings of a lithium ion battery.

This first chapter provides an overview of what chemistry is about and what chemists do. The "What's Ahead" list gives an overview of the chapter organization and of some of the ideas we will consider.

▶ **THE BEAUTIFUL COLORS** that develop in trees in the fall appear when the tree ceases to produce chlorophyll, which imparts the green color to the leaves during the summer. Some of the color we see has been in the leaf all summer, and some develops from the action of sunlight on the leaf as the chlorophyll disappears.

1.1 | The Study of Chemistry

Chemistry is at the heart of many changes we see in the world around us, and it accounts for the myriad of different properties we see in matter. To understand how these changes and properties arise, we need to look far beneath the surfaces of our everyday observations.

WHAT'S AHEAD

1.1 THE STUDY OF CHEMISTRY We begin with a brief description of what chemistry is, what chemists do, and why it is useful to learn chemistry.

1.2 CLASSIFICATIONS OF MATTER Next, we examine some fundamental ways to classify matter, distinguishing between *pure substances* and *mixtures* and between *elements* and *compounds*.

1.3 PROPERTIES OF MATTER We then consider different characteristics, or *properties*, used to characterize, identify, and separate substances, distinguishing between chemical and physical properties.

1.4 UNITS OF MEASUREMENT We observe that many properties rely on quantitative measurements involving numbers and units. The units of measurement used throughout science are those of the *metric system*.

1.5 UNCERTAINTY IN MEASUREMENT We observe that the uncertainty inherent in all measured quantities is expressed by the number of *significant figures* used to report the quantity. Significant figures are also used to express the uncertainty associated with calculations involving measured quantities.

1.6 DIMENSIONAL ANALYSIS We recognize that units as well as numbers are carried through calculations and that obtaining correct units for the result of a calculation is an important way to check whether the calculation is correct.

The Atomic and Molecular Perspective of Chemistry

Chemistry is the study of the properties and behavior of matter. **Matter** is the physical material of the universe; it is anything that has mass and occupies space. A **property** is any characteristic that allows us to recognize a particular type of matter and to distinguish it from other types. This book, your body, the air you are breathing, and the clothes you are wearing are all samples of matter. We observe a tremendous variety of matter in our world, but countless experiments have shown that all matter is comprised of combinations of only about 100 substances called ***elements***. One of our major goals will be to relate the properties of matter to its composition, that is, to the particular elements it contains.

Chemistry also provides a background for understanding the properties of matter in terms of **atoms**, the almost infinitesimally small building blocks of matter. Each element is composed of a unique kind of atom. We will see that the properties of matter relate to both the kinds of atoms the matter contains (*composition*) and the arrangements of these atoms (*structure*).

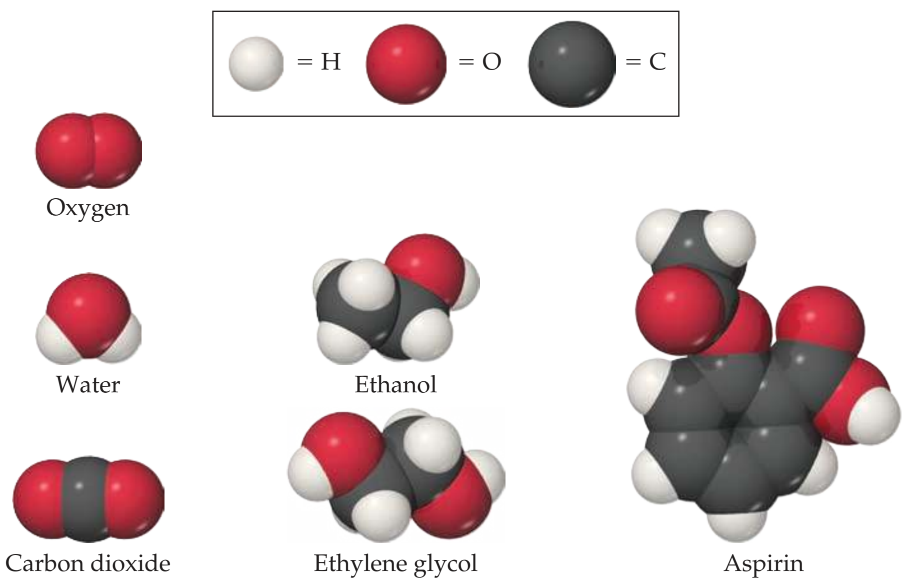
In **molecules**, two or more atoms are joined in specific shapes. Throughout this text you will see molecules represented using colored spheres to show how the atoms are connected (▼ **Figure 1.1**). The color provides a convenient way to distinguish between atoms of different elements. For example, notice that the molecules of ethanol and ethylene glycol in Figure 1.1 have different compositions and structures. Ethanol contains one oxygen atom, depicted by one red sphere. In contrast, ethylene glycol contains two oxygen atoms.

Even apparently minor differences in the composition or structure of molecules can cause profound differences in properties. For example, let's compare ethanol and ethylene glycol, which appear in Figure 1.1 to be quite similar. Ethanol is the alcohol in beverages such as beer and wine, whereas ethylene glycol is a viscous liquid used as automobile antifreeze. The properties of these two substances differ in many ways, as do their biological activities. Ethanol is consumed throughout the world, but you should *never* consume ethylene glycol because it is highly toxic. One of the challenges chemists undertake is to alter the composition or structure of molecules in a controlled way, creating new substances with different properties. For example, the common drug aspirin, shown in Figure 1.1, was first synthesized in 1897 in a successful attempt to improve on a natural product extracted from willow bark that had long been used to alleviate pain.

Every change in the observable world—from boiling water to the changes that occur as our bodies combat invading viruses—has its basis in the world of atoms and molecules.

GO FIGURE

Which of the molecules in the figure has the most carbon atoms? How many are there in that molecule?



▲ **Figure 1.1 Molecular models.** The white, black, and red spheres represent atoms of hydrogen, carbon, and oxygen, respectively.

Thus, as we proceed with our study of chemistry, we will find ourselves thinking in two realms: the *macroscopic* realm of ordinary-sized objects (*macro* = large) and the *submicroscopic* realm of atoms and molecules. We make our observations in the macroscopic world, but to understand that world, we must visualize how atoms and molecules behave at the submicroscopic level. Chemistry is the science that seeks to understand the properties and behavior of matter by studying the properties and behavior of atoms and molecules.

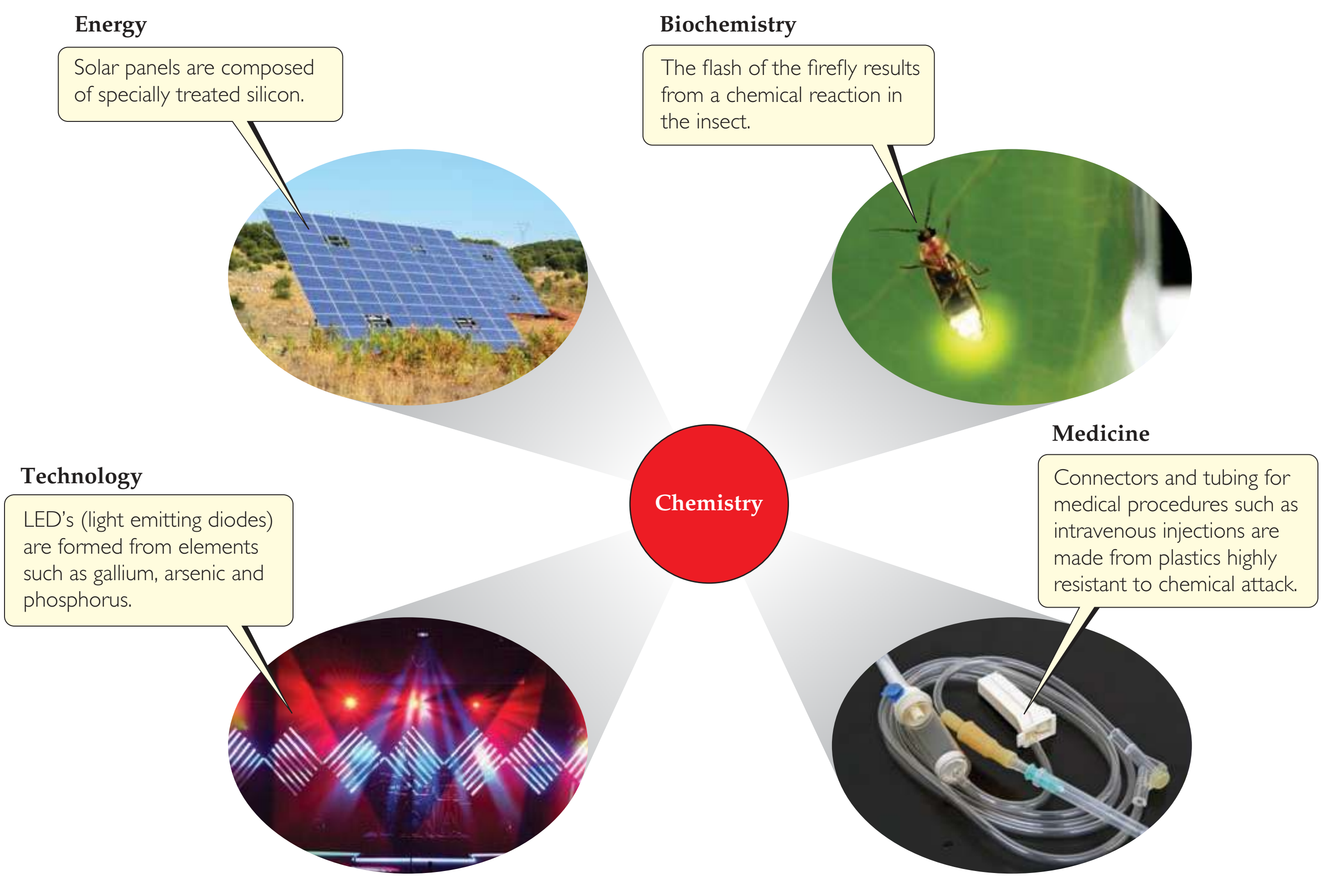
Give It Some Thought

(a) Approximately how many elements are there?
(b) What submicroscopic particles are the building blocks of matter?

Why Study Chemistry?

Chemistry lies near the heart of many matters of public concern, such as improvement of health care, conservation of natural resources, protection of the environment, and the supply of energy needed to keep society running. Using chemistry, we have discovered and continually improved upon pharmaceuticals, fertilizers and pesticides, plastics, solar panels, LEDs, and building materials. We have also discovered that some chemicals are potentially harmful to our health or the environment. This means that we must be sure that the materials with which we come into contact are safe. As a citizen and consumer, it is in your best interest to understand the effects, both positive and negative, that chemicals can have, and to arrive at a balanced outlook regarding their uses.

You may be studying chemistry because it is an essential part of your curriculum. Your major might be chemistry, or it could be biology, engineering, pharmacy, agriculture, geology, or some other field. Chemistry is central to a fundamental understanding of governing principles in many science-related fields. For example, our interactions with the material world raise basic questions about the materials around us. ▼ Figure 1.2 illustrates how chemistry is central to several different realms of modern life.



▲ Figure 1.2 **Chemistry is central to our understanding of the world around us.**

Chemistry Put to Work

Chemistry and the Chemical Industry

Chemistry is all around us. Many people are familiar with household chemicals, particularly kitchen chemicals such as those shown in ▶ Figure 1.3. However, few realize the size and importance of the chemical industry. Worldwide sales of chemicals and related products manufactured in the United States total approximately $585 billion annually. Sales of pharmaceuticals total another $180 billion. The chemical industry employs more than 10% of all scientists and engineers and is a major contributor to the U.S. economy.

Vast amounts of industrial chemicals are produced each year. ▼ Table 1.1 lists several of the chemicals produced in highest volumes in the United States. Notice that they all serve as raw materials for a variety of uses, including the manufacture and processing of metals, plastics, fertilizers, and other goods.

Who are chemists, and what do they do? People who have degrees in chemistry hold a variety of positions in industry, government, and academia. Those in industry work as laboratory chemists, developing new products (research and development); analyzing materials (quality control); or assisting customers in using products (sales and service). Those with more experience or training may work as managers or company directors. Chemists are important members of the scientific workforce in government (the National Institutes of Health, Department of Energy, and Environmental Protection Agency all employ chemists) and at universities. A chemistry degree is also good preparation for careers in teaching, medicine, biomedical research, information science, environmental work, technical sales, government regulatory agencies, and patent law.

Fundamentally, chemists do three things: (1) make new types of matter: materials, substances, or combinations of substances with desired properties; (2) measure the properties of matter; and (3) develop models that explain and/or predict the properties of matter. One chemist, for example, may work in the laboratory to discover new drugs. Another may concentrate on the development of new instrumentation to measure properties of matter at the atomic level. Other chemists may use existing materials and methods to understand how pollutants are transported in the environment or how drugs are processed in the body. Yet another chemist will develop theory, write computer code, and run computer simulations to understand how molecules move and react. The collective chemical enterprise is a rich mix of all of these activities.

▲ Figure 1.3 Common chemicals employed in home food production.

Table 1.1 Several of the Top Chemicals Produced by the U.S. Chemical Industry*

Chemical	Formula	Annual Production (Billions of Pounds)	Principal End Uses
Sulfuric acid	H_2SO_4	70	Fertilizers, chemical manufacturing
Ethylene	C_2H_4	50	Plastics, antifreeze
Lime	CaO	45	Paper, cement, steel
Propylene	C_3H_6	35	Plastics
Ammonia	NH_3	18	Fertilizers
Chlorine	Cl_2	21	Bleaches, plastics, water purification
Phosphoric acid	H_3PO_4	20	Fertilizers
Sodium hydroxide	$NaOH$	16	Aluminum production, soap

1.2 | Classifications of Matter

Let's begin our study of chemistry by examining two fundamental ways in which matter is classified. Matter is typically characterized by (1) its physical state (gas, liquid, or solid) and (2) its composition (whether it is an element, a *compound*, or a *mixture*).

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*Data from Chemical & Engineering News, July 2, 2007, pp. 57, 60, American Chemical Society; data online from U.S. Geological Survey.

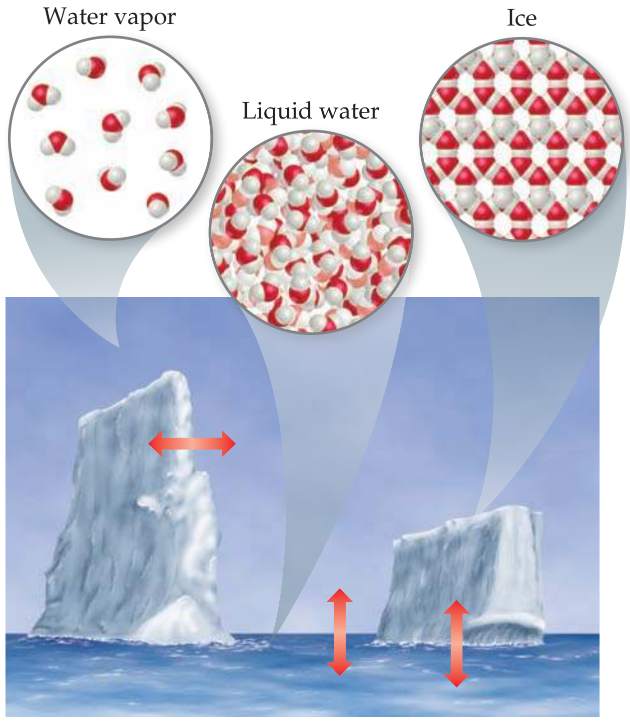
States of Matter

A sample of matter can be a gas, a liquid, or a solid. These three forms, called the **states of matter**, differ in some of their observable properties. A **gas** (also known as *vapor*) has no fixed volume or shape; rather, it uniformly fills its container. A gas can be compressed to occupy a smaller volume, or it can expand to occupy a larger one. A **liquid** has a distinct volume independent of its container, and assumes the shape of the portion of the container it occupies. A **solid** has both a definite shape and a definite volume. Neither liquids nor solids can be compressed to any appreciable extent.

The properties of the states of matter can be understood on the molecular level (▶ Figure 1.4). In a gas the molecules are far apart and moving at high speeds, colliding repeatedly with one another and with the walls of the container. Compressing a gas decreases the amount of space between molecules and increases the frequency of collisions between molecules but does not alter the size or shape of the molecules. In a liquid, the molecules are packed closely together but still move rapidly. The rapid movement allows the molecules to slide over one another; thus, a liquid pours easily. In a solid the molecules are held tightly together, usually in definite arrangements in which the molecules can wiggle only slightly in their otherwise fixed positions. Thus, the distances between molecules are similar in the liquid and solid states, but the two states differ in how free the molecules are to move around. Changes in temperature and/or pressure can lead to conversion from one state of matter to another, illustrated by such familiar processes as ice melting or water vapor condensing.

GO FIGURE

In which form of water are the water molecules farthest apart?



▲ Figure 1.4 **The three physical states of water—water vapor, liquid water, and ice.** We see the liquid and solid states but cannot see the gas (vapor) state. The red arrows show that the three states of matter interconvert.

Pure Substances

Most forms of matter we encounter—the air we breathe (a gas), the gasoline we burn in our cars (a liquid), and the sidewalk we walk on (a solid)—are not chemically pure. We can, however, separate these forms of matter into pure substances. A **pure substance** (usually referred to simply as a *substance*) is matter that has distinct properties and a composition that does not vary from sample to sample. Water and table salt (sodium chloride) are examples of pure substances.

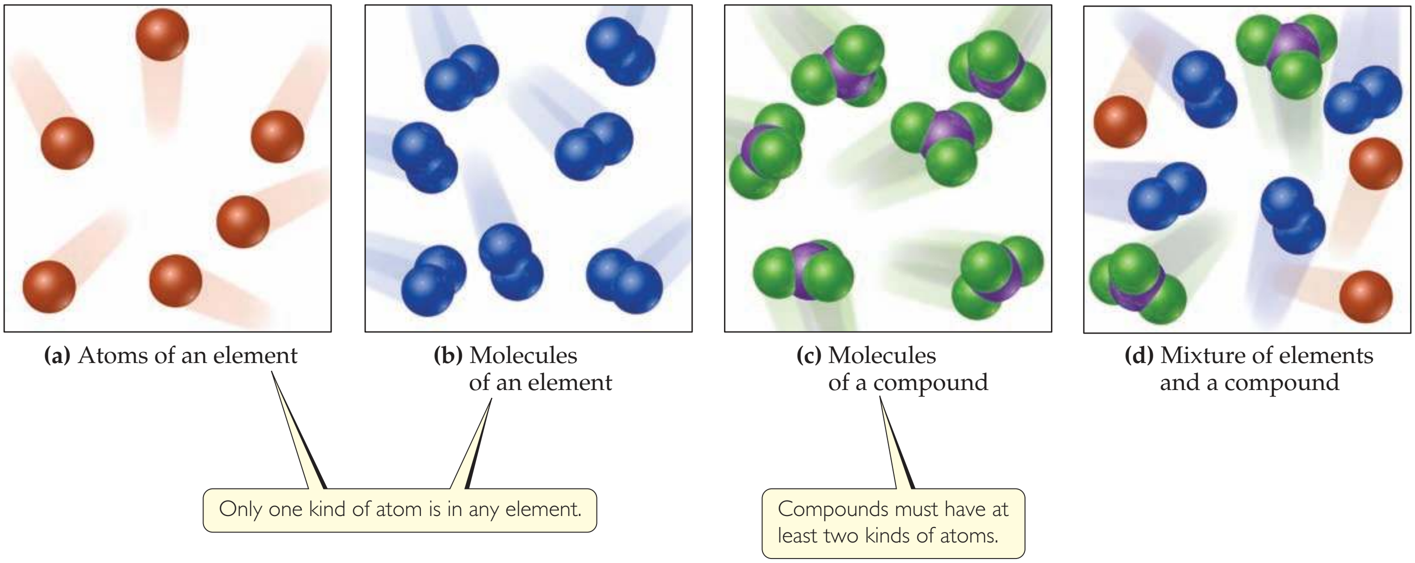
All substances are either elements or compounds. **Elements** are substances that cannot be decomposed into simpler substances. On the molecular level, each element is composed of only one kind of atom [Figure 1.5(**a** and **b**)]. **Compounds** are substances composed of two or more elements; they contain two or more kinds of atoms [Figure 1.5(**c**)]. Water, for example, is a compound composed of two elements: hydrogen and oxygen. Figure 1.5(**d**) shows a mixture of substances. **Mixtures** are combinations of two or more substances in which each substance retains its chemical identity.

Elements

Currently, 118 elements are known, though they vary widely in abundance. Hydrogen constitutes about 74% of the mass in the Milky Way galaxy, and helium constitutes 24%. Closer to home, only five elements—oxygen, silicon, aluminum, iron, and calcium—account for over 90% of Earth's crust (including oceans and atmosphere), and only three—oxygen, carbon, and hydrogen—account for over 90% of the mass of the human body (Figure 1.6).

GO FIGURE

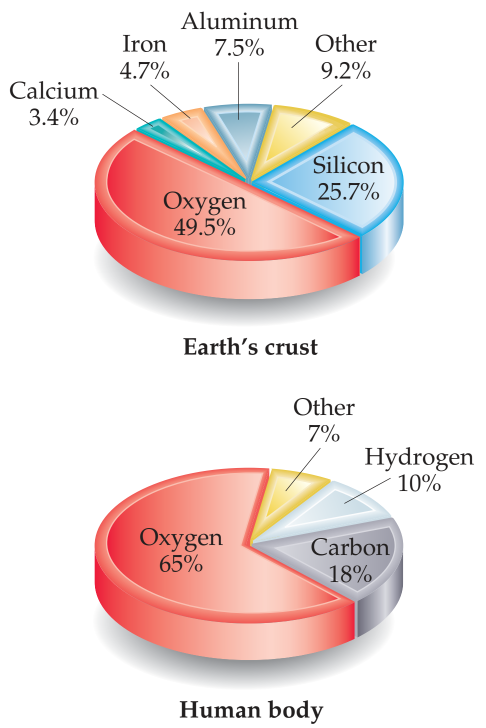
How do the molecules of a compound differ from the molecules of an element?



▲ Figure 1.5 **Molecular comparison of elements, compounds, and mixtures.**

GO FIGURE

Name two significant differences between the elemental composition of Earth's crust and the elemental composition of the human body.



▲ Figure 1.6 **Relative abundances of elements.*** Elements in percent by mass in Earth's crust (including oceans and atmosphere) and the human body.

▼ Table 1.2 lists some common elements, along with the chemical *symbols* used to denote them. The symbol for each element consists of one or two letters, with the first letter capitalized. These symbols are derived mostly from the English names of the elements, but sometimes they are derived from a foreign name instead (last column in Table 1.2). You will need to know these symbols and learn others as we encounter them in the text.

All of the known elements and their symbols are listed on the front inside cover of this text in a table known as the *periodic table*. In the periodic table the elements are arranged in columns so that closely related elements are grouped together. We describe the periodic table in more detail in Section 2.5 and consider the periodically repeating properties of the elements in Chapter 7.

Compounds

Most elements can interact with other elements to form compounds. For example, when hydrogen gas burns in oxygen gas, the elements hydrogen and oxygen combine to form the compound water. Conversely, water can be decomposed into its elements by passing an electrical current through it (▶ Figure 1.7).

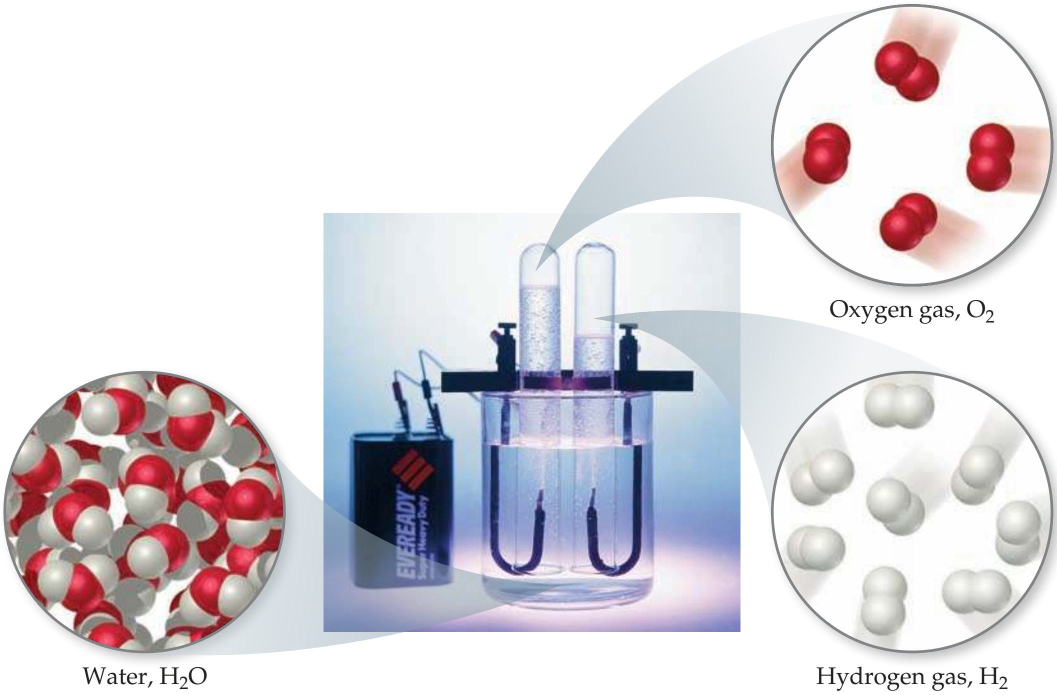
Table 1.2 Some Common Elements and Their Symbols

Carbon	C	Aluminum	Al	Copper	Cu (from *cuprum*)
Fluorine	F	Bromine	Br	Iron	Fe (from *ferrum*)
Hydrogen	H	Calcium	Ca	Lead	Pb (from *plumbum*)
Iodine	I	Chlorine	Cl	Mercury	Hg (from *hydrargyrum*)
Nitrogen	N	Helium	He	Potassium	K (from *kalium*)
Oxygen	O	Lithium	Li	Silver	Ag (from *argentum*)
Phosphorus	P	Magnesium	Mg	Sodium	Na (from *natrium*)
Sulfur	S	Silicon	Si	Tin	Sn (from *stannum*)

**U.S. Geological Survey Circular* 285, U.S Department of the Interior.

GO FIGURE

How are the relative gas volumes collected in the two tubes related to the relative number of gas molecules in the tubes?



▲ **Figure 1.7 Electrolysis of water.** Water decomposes into its component elements, hydrogen and oxygen, when an electrical current is passed through it. The volume of hydrogen, collected in the right test tube, is twice the volume of oxygen.

Pure water, regardless of its source, consists of 11% hydrogen and 89% oxygen by mass. This macroscopic composition corresponds to the molecular composition, which consists of two hydrogen atoms combined with one oxygen atom:

 Hydrogen atom (written H)  Oxygen atom (written O)  Water molecule (written H_2O)

The elements hydrogen and oxygen themselves exist naturally as diatomic (two-atom) molecules:

Oxygen molecule  (written O_2)

Hydrogen molecule  (written H_2)

As seen in ▼ Table 1.3, the properties of water bear no resemblance to the properties of its component elements. Hydrogen, oxygen, and water are each a unique substance, a consequence of the uniqueness of their respective molecules.

Table 1.3 Comparison of Water, Hydrogen, and Oxygen

	Water	Hydrogen	Oxygen
State[a]	Liquid	Gas	Gas
Normal boiling point	100 °C	−253 °C	−183 °C
Density[a]	1000 g/L	0.084 g/L	1.33 g/L
Flammable	No	Yes	No

[a]At room temperature and atmospheric pressure.