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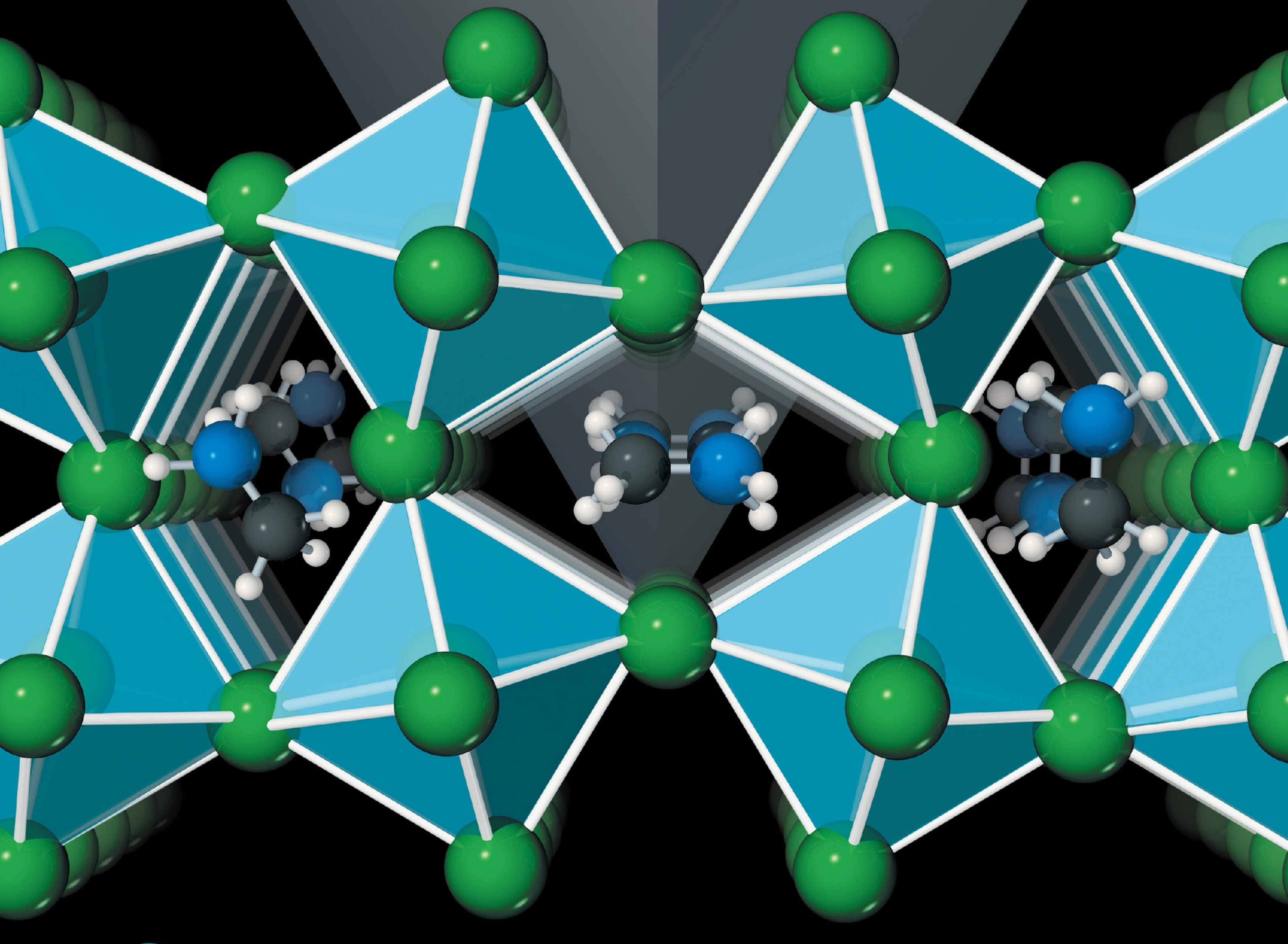
CHEMISTRY

THE CENTRAL SCIENCE

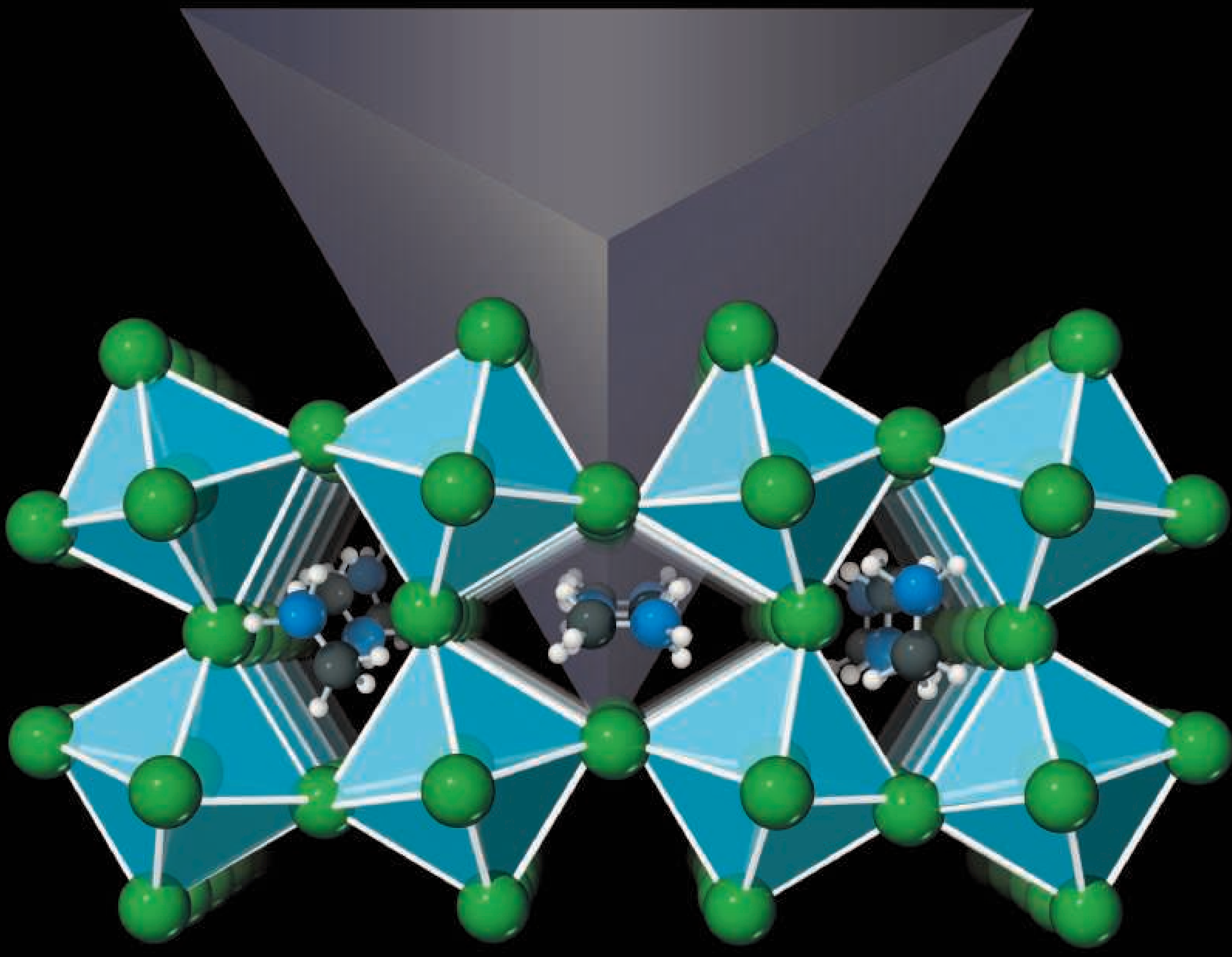


Pearson

14TH EDITION

CHEMISTRY

THE CENTRAL SCIENCE 14TH EDITION



The halide perovskites, exemplified by methylammonium lead iodide ($CH_3NH_3PbI_3$), whose structure is shown on the front cover, have emerged in recent years as alternatives to conventional semiconductors like silicon, gallium arsenide, and cadmium selenide. These materials show tremendous potential for use in devices such as light-emitting diodes and radiation detectors, but no application has generated more excitement than their performance in solar cells. Scientists have been able to prepare halide perovskite-based solar cells that convert sunlight to electricity with 20% efficiency, a figure comparable to the best silicon solar cells on the market. While the high efficiencies are impressive, the truly revolutionary breakthrough is that halide perovskite solar cells can be made from solution using inexpensive, readily available laboratory equipment, whereas fabrication of solar cells from conventional semiconductors requires expensive, sophisticated facilities. Chemists are actively researching alternative perovskite materials that do not contain lead and are less prone to degradation upon exposure to moist air.

CHEMISTRY

THE CENTRAL SCIENCE 14TH 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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BRIEF CONTENTS

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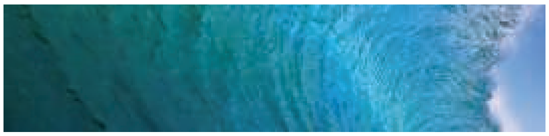

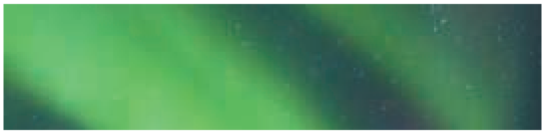

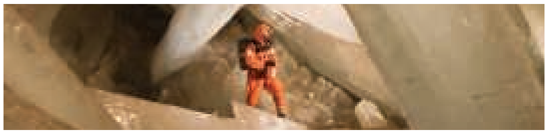

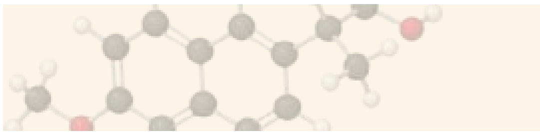

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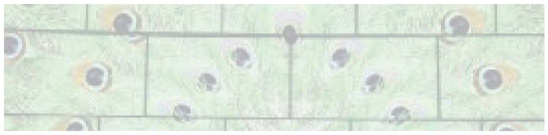

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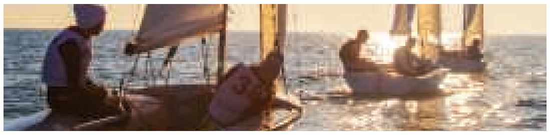

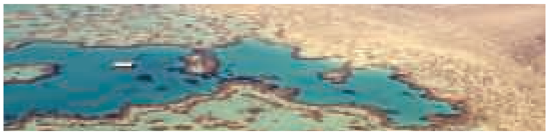

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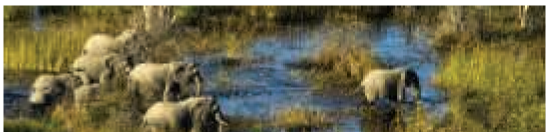

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CHEMICAL APPLICATIONS AND ESSAYS

A Closer Look

Chemistry Put to Work

Chemistry and Life

Strategies for Success

INTERACTIVE MEDIA

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Smart Figures

Interactive Sample Exercises

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. Collectively we have taught general chemistry to multiple generations of students. So we understand the challenges and opportunities of teaching a class that so many students take. We have also been active researchers who appreciate both the learning and the discovery aspects of the chemical sciences. 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 fourteenth 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? How can we help your students not only learn the principles of chemistry, but also become critical thinkers who can think more like chemists? The answers lie 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. This edition incorporates a number of those new methodologies, including use of 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. MasteringChemistry™ not only provides feedback on a question by question basis, but using Knewton-enhanced adaptive follow-up assignments and Dynamic Study Modules, it now 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 best 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 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 student in a one-year course. 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. Also consider emphasizing conceptual understanding (placing less emphasis on simple manipulative, algorithmic problem solving) and urging students to use the rich on-line resources available.

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. By incorporating bond enthalpies in the Thermochemistry chapter we aim to emphasize the connection between the macroscopic properties of substances and the submicroscopic world of atoms and bonds. 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. For more advanced students, *A 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, while Chapter 12 is devoted to solids, presenting a contemporary view of the solid state as well as of modern materials accessible to general chemistry students. 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 the materials (semiconductors, polymers, nanomaterials, and so forth) that are most relevant to your students and your own interests. This section of the book concludes with Chapter 13 which covers the formation and properties of solutions.

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 an independent, modular 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.

New in This Edition

As with every new edition of *Chemistry: The Central Science* the book has undergone a great many changes as we strive to keep the content current, and to improve the clarity and effectiveness of the text, the art, and the exercises. Among the myriad changes there are certain points of emphasis that we use to organize and guide the revision process. In creating the fourteenth edition our revision was organized around the following points:

- Our treatment of energy and thermochemistry has been significantly revised. The concept of energy is now introduced in Chapter 1, whereas previously it did not appear until Chapter 5. This change allows instructors greater freedom in the order in which they cover the material. For example, this change would facilitate coverage of Chapters 6 and 7 immediately following Chapter 2, a sequence that is in line with an atoms-first approach to teaching general chemistry. More importantly, bond enthalpies are now integrated into Chapter 5 to emphasize the connection between macroscopic quantities, like reaction enthalpies, and the submicroscopic world of atoms and bonds. We feel this change leads to a better integration of thermochemical concepts with the surrounding chapters. Bond enthalpies are revisited in Chapter 8 after students have developed a more sophisticated view of chemical bonding.
- Considerable effort was made to provide students with a clear discussion, superior problem sets, and better real-

time feedback on their understanding of the material. The author team used an interactive e-book platform to view passages that students highlighted in their reading along with the related notes and questions that detailed what they did not understand. In response, numerous passages were revised for greater clarity.

- Extensive effort has gone into creating enhanced content for the eText version of the book. These features make the eText so much more than just an electronic copy of the physical textbook. New Smart Figures take key figures from the text and bring them to life through animation and narration. Likewise, new Smart Sample Exercises animate key sample exercises from the text, offering students a more in depth and detailed discussion than can be provided in the printed text. These interactive features will also include follow-up questions, which can be assigned in MasteringChemistry™.
- We used metadata from MasteringChemistry™ to inform our revisions. In the thirteenth edition a second *Practice Exercise* was added to accompany each *Sample Exercise*. Nearly all of the additional practice exercises were multiple choice questions with wrong answer distractors written to identify student misconceptions and common mistakes. As implemented in MasteringChemistry™, feedback was provided with each wrong answer to help students recognize their misconceptions. In this new edition we have carefully scrutinized the metadata from MasteringChemistry™ to identify practice exercises that either were not challenging the students or were not being used. Those exercises have either been modified or changed entirely. A similar effort was made to revise *Give It Some Thought* and *Go Figure* questions to make them more effective and amenable to use in MasteringChemistry™. Finally, the number of end-of-chapter exercises that have wrong answer feedback in MasteringChemistry™ has been dramatically expanded. We have also replaced outdated or little-used end-of-chapter exercises (~10 per chapter).
- Finally, subtle but important changes have been made to allow students to quickly reference important concepts and assess their knowledge of the material. Key points are now set in italic with line spaces above and below for greater emphasis. New skills-based *How To . . .* features offer step-by-step guidance for solving specific types of problems such as Drawing Lewis Structures, Balancing Redox Equations, and Naming Acids. These features, with numbered steps encased by a thin rule, are integrated into the main discussion and are easy to find. Finally, each Learning Objective is now correlated to specific end-of-chapter exercises. This allows students to test their mastery of each learning objective when preparing for quizzes and exams.

Changes in This Edition

The **New in This Edition** section details changes made throughout this 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 the fourteenth edition continues the trajectory set in the previous two editions: to make greater and more effective use of the figures as learning tools, by drawing the reader more directly into the figure. The style of the art has been revised throughout for enhanced clarity and a cleaner more modern look. This includes: new white-background annotation boxes with crisp, thin leaders; richer and more saturated colors in the art, and expanded use of 3D renderings. An editorial review of every figure in the text resulted in numerous minor revisions to the art and its labels in order to increase clarity. The *Go Figure* questions have been carefully scrutinized. Using statistics from MasteringChemistry™, many have been modified or changed entirely to engage and challenge students to think critically about the concept(s) that underlie each figure. The *Give it Some Thought* feature has been revised in a similar vein to stimulate more thoughtful reading of the text and foster 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," have been renamed *Strategies for Success* to better convey their usefulness to the student.

We have continued to emphasize conceptual exercises in the end-of-chapter problems. In each chapter we begin the exercises with the well-received *Visualizing Concepts* category. These exercises are designed to facilitate conceptual understanding through use of models, graphs, photographs, 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 relevant to 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:

Chapter 1, and every chapter that follows, begins with a new chapter opening photo and backstory to provide a real world context for the material that follows. A new section on the nature of energy (Section 1.4) has been added to Chapter 1. The inclusion of energy in the opening chapter provides much greater flexibility for the order in which subsequent chapters can be covered. 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.

In Chapter 2 the figures depicting the key experiments that led to the discovery of the structure of the atom—Millikan's Oil Drop experiment and Rutherford's Gold Foil experiment—have been enhanced. This is also the first occurrence of the periodic table which has been updated throughout the text to reflect the acceptance and naming of elements 113 (Nihonium), 115 (Muscovium), 117 (Tennessine), and 118 (Oganesson).

Chapter 5 has undergone the most extensive revision in the book. Early parts of the chapter have been modified to reflect the fact that basic concepts of energy are now introduced in Chapter 1. Two new figures have been added. Figure 5.3 qualitatively relates electrostatic potential energy to changes in the bonding of an ionic solid, while Figure 5.16 provides a real-world analogy to help students understand the relationship between spontaneity and reaction enthalpy. The figure illustrating exothermic and endothermic reactions (Figure 5.8) has been modified to show before and after images of the reaction. Finally, to stress the atomistic origins of reaction enthalpies, a new section (Section 5.8) on bond enthalpies has been added, as discussed earlier.

A new Sample Exercise has been added to Chapter 6 that shows how the radii of orbits in the Bohr model of the hydrogen atom depend on the principal quantum number and how the electron behavior changes when a photon is emitted or absorbed.

Chapter 8 has seen some of its content on bond enthalpies moved to Chapter 5. The concepts there are now reinforced here.

In Chapter 11, attention has been paid to the text regarding various intermolecular forces to make clear that chemists usually think about them in units of energy, not units of force. A new checklist art piece replaces old Figure 11.14 in order to make it clear that intermolecular interaction energies are additive.

Chapter 12 has a new *A Closer Look* box entitled *Modern Materials in the Automobile* which discusses the wide range of materials used in a hybrid automobile, including semiconductors, ionic solids, alloys, polymers, and more. A new *Chemistry Put To Work* entitled *Microporous and Mesoporous Materials* examines materials with different pore sizes and their application in ion exchange and catalytic converters.

In Chapter 15 a new *A Closer Look* box on *Temperature Changes and Le Châtelier's Principle* explains the theoretical underpinnings of the empirical rules that successfully predict how temperature changes influence the equilibrium constants of exothermic and endothermic reactions.

In Chapter 16 a new *A Closer Look* box on *Polyprotic Acids* explicitly shows the speciation of ions as a function of pH.

In Chapter 17 a new *A Closer Look* box entitled *Lead Contamination in Drinking Water* explores the chemistry behind the water quality crisis in Flint, Michigan.

Chapter 18 has been revised to reflect the most up-to-date data on atmospheric CO_2 levels and the ozone hole. Figure 18.4, showing the UV absorption spectrum of ozone, has been added so students can understand its role in filtering out harmful UV radiation from the sun. A new Sample Exercise (18.3) walks students through the steps needed to calculate the amount of CO_2 produced from combustion of a hydrocarbon.

In Chapter 19 we have substantially rewritten the early sections to help students better understand the concepts of spontaneous, nonspontaneous, reversible, and irreversible processes and their relationships. These improvements have led to a clearer definition of entropy.

To the Student

Chemistry: The Central Science, Fourteenth 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 we may 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 may 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 generally not be enough for successful learning of chapter concepts and problem-solving skills. You will often 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.* These 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 will also 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 *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 features in this new 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. For 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.

Fourteenth Edition Reviewers

Carribeth Bliem, *University of North Carolina, Chapel Hill*
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William Butler, *Rochester Institute of Technology*
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We would also like to express our gratitude to our many team members at Pearson whose hard work, imagination, and commitment have contributed so greatly to the final form of this edition: Chris Hess, our chemistry editor, for many fresh ideas and his unflagging enthusiasm, continuous encouragement, and support; Jennifer Hart, Director of Development, who has brought her experience and insight to oversight of the entire project; Matt Walker, our development editor, whose depth of experience, good judgment, and careful attention to detail were invaluable to this revision, especially in keeping us on task in terms of consistency and student understanding. The Pearson team is a first-class operation.

There are many others who also deserve special recognition, including the following: Mary Tindle, our production editor, who skillfully kept the process moving and us authors on track; 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 fourteenth edition to completion.

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ABOUT THE AUTHORS

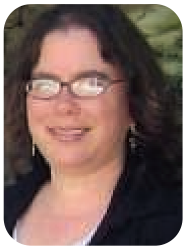
The Brown/Lemay/Bursten/Murphy/Woodward/Stoltzfus Author Team values collaboration as an integral component to overall success. While each author brings unique talent, research interests, and teaching experiences, the team works together to review and develop the entire text. It is this collaboration 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 fourteenth edition and accompanying MasteringChemistry™ course are highlighted on the upcoming 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.

H. Eugene Lemay, Jr., received his B.S. degree in Chemistry from Pacific Lutheran University (Washington) and his Ph.D. in Chemistry in 1966 from the University of Illinois, Urbana-Champaign. He then joined the faculty of the University of Nevada, Reno, where he is currently Professor of Chemistry, Emeritus. He has enjoyed Visiting Professorships at the University of North Carolina at Chapel Hill, at the University College of Wales in Great Britain, and at the University of California, Los Angeles. Professor LeMay is a popular and effective teacher, who has taught thousands of students during more than 40 years of university teaching. Known for the clarity of his lectures and his sense of humor, he has received several teaching awards, including the University Distinguished Teacher of the Year Award (1991) and the first Regents' Teaching Award given by the State of Nevada Board of Regents (1997).

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. In 2015, he moved to Worcester Polytechnic Institute as Provost and Professor of Chemistry and Biochemistry. 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 received the University Distinguished Teaching Award in

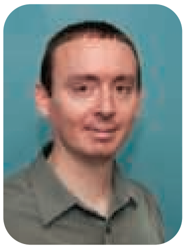
1982 and 1996, the Arts and Sciences Student Council Outstanding Teaching Award in 1984, and the University Distinguished Scholar Award in 1990. He received the Spiers Memorial Prize and Medal of the Royal Society of Chemistry in 2003, and the Morley Medal of the Cleveland Section of the American Chemical Society in 2005. He was President of the American Chemical Society for 2008 and Chair of the Section on Chemistry of the American Association for the Advancement of Science in 2015. 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. From 2006–2011, Professor Murphy served as a Senior Editor for the *Journal of Physical Chemistry*; in 2011 she became the Deputy Editor for the *Journal of Physical Chemistry C*. She is an elected Fellow of the American Association for the Advancement of Science (2008), the American Chemical Society (2011), the Royal Society of Chemistry (2014), and the U.S. National Academy of Sciences (2015). Professor Murphy's research program focuses on the synthesis, optical properties, surface chemistry, biological applications, and environmental implications of colloidal inorganic nanomaterials.

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 has served as Vice Chair for Undergraduate Studies in the Department of Chemistry and Biochemistry at Ohio State University, and director of the Ohio REEL program. He is currently the Vice President of the Neutron Scattering Society of America. Professor Woodward's research program focuses on understanding the links between bonding, structure, and properties of solid-state inorganic materials.

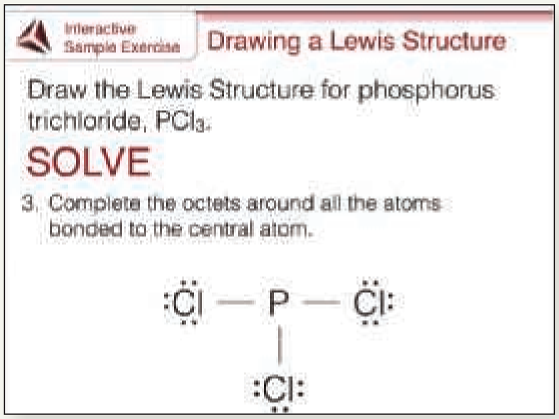
Matthew W. Stoltzfus received his B.S. degree in Chemistry from Millersville University in 2002 and his Ph. D. in Chemistry in 2007 from The Ohio State University. He spent two years as a teaching postdoctoral assistant for the Ohio REEL program, an NSF-funded center that works to bring authentic research 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 served as a Faculty Fellow 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 200,000 students from all over the world. The iTunes U course, along with the videos at www.drfus.com, are designed to supplement the text and can be used by any general chemistry student. 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.

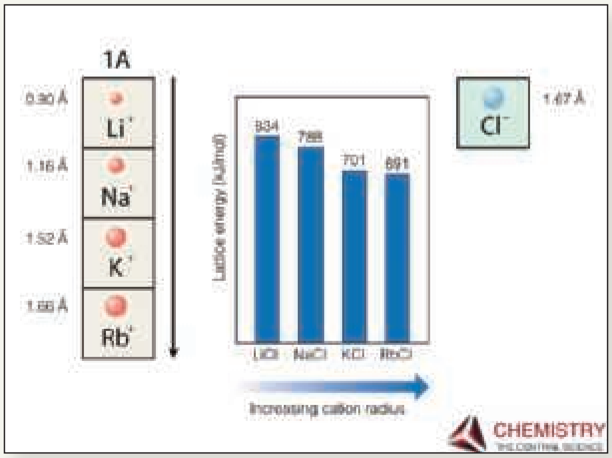


Michael W. Lufaso received his B.S. degree in Chemistry from Youngstown State University in 1998 and his Ph.D. in Chemistry from the Ohio State University in 2002. He was a National Research Council Postdoctoral Fellow at the National Institute for Standards and Technology and a postdoctoral fellow at the University of South Carolina. In 2006 he joined the University of North Florida where he currently holds the rank of Associate Professor in the Department of Chemistry. He was a Brian Andreen Cottrell College Science Award winner from Research Corporation. He was named a Munoz Presidential Professor in 2011 and received an Outstanding Faculty Scholarship award in 2014. He has authored laboratory manuals and taught ten different undergraduate courses primarily in the areas of general, inorganic, and solid state chemistry. His undergraduate research program focuses on structure prediction, synthesis, and characterization of the structure and properties of solid state materials.

New Levels of Student Interaction for Improved Conceptual Understanding

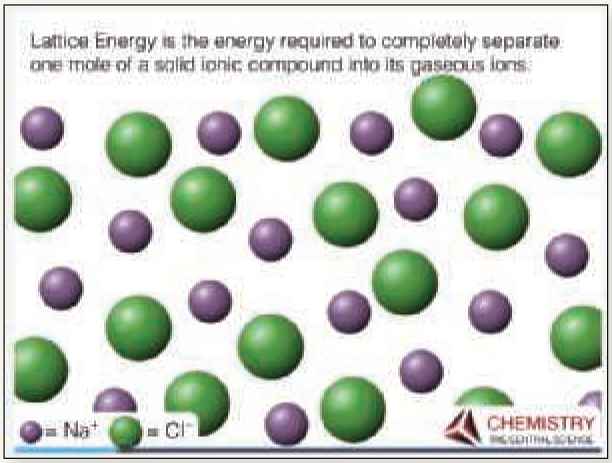
Embedded in eText 2.0, as well as assignable in MasteringChemistry™, new features engage students through interactivity to enhance the reading experience and help them learn challenging chemistry concepts.





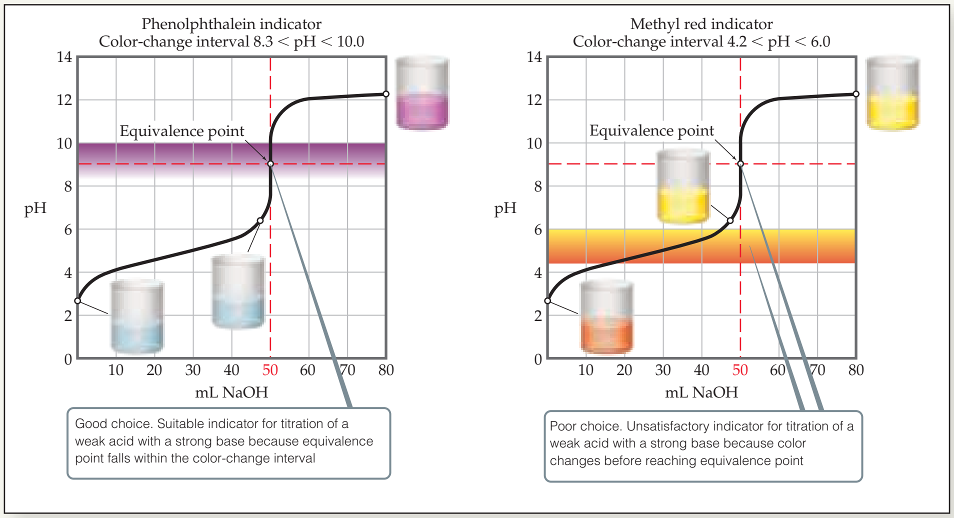
NEW! 50 Interactive Sample Exercises bring key *Sample Exercises* in the text to life through animation and narration. Author Matt Stoltzfus uses the text's *Analyze/Plan/Solve/Check* technique to guide students through the problem-solving process. Play icons within the text identify each Interactive Sample Exercise. Clicking the icon in the eText launches a visual and conceptual presentation which goes beyond the static page. The *Practice Exercises* within each *Sample Exercise* can also be assigned in MasteringChemistry™ where students will receive answer-specific feedback.

NEW! 27 Smart Figures walk students through complex visual representations, dispelling common misconceptions before they take root. Each *Smart Figure* converts a static in-text figure into a dynamic process narrated by author Matt Stoltzfus. Play icons within the text identify each *Smart Figure*. Clicking the icon in the eText launches the animation. Smart Figures are assignable in MasteringChemistry™ where they are accompanied by a multiple-choice question with answer-specific video feedback. Selecting the correct answer launches a brief wrap-up video that highlights the key concepts behind the answer.



Visually Revised to Better Help Students Build General Chemistry

The visual program has been revised for enhanced clarity and to create a clean, modern look. Style changes include: expanded use of 3D renderings, new white annotation boxes with crisp leader lines, and a more saturated art palette.



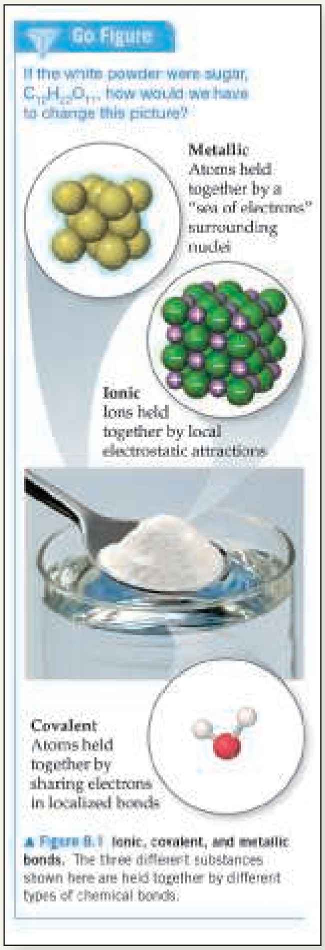
REVISED! Annotations offer expanded explanations; additional new leaders emphasize key relationships and key points in figures.

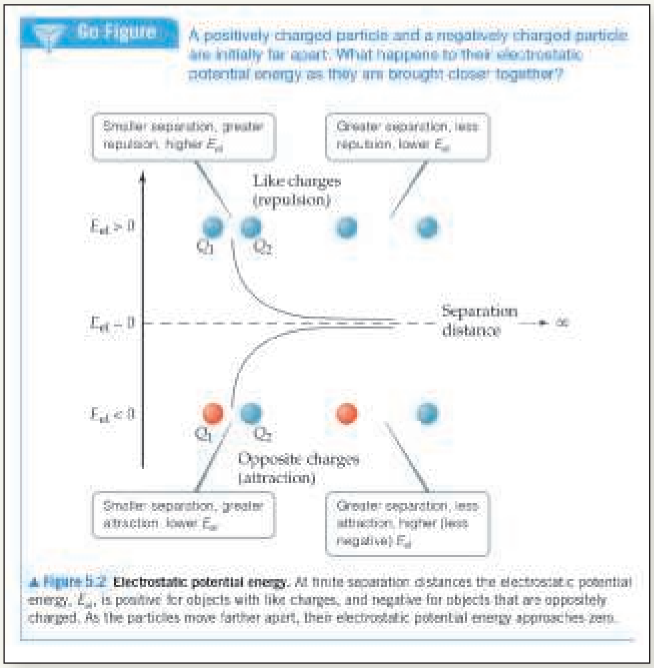
NEW! Before and after photos clearly show characteristics of endothermic and exothermic reactions. Added reaction equations connect the chemistry to what's happening in the photos.

◀ Figure 5.8 **Endothermic and exothermic reactions.** In both instances, the system is defined as the reactants and products, while surroundings are the containers and everything else in the universe.

Knowledge and Understanding

The authors used the wealth of student data in MasteringChemistry™ to identify the areas where students struggle most, revising discussions, figures, and exercises throughout the text to address misconceptions and encourage thinking about the real-world use of chemistry.





NEW! The author team utilized Mastering metadata to edit and clarify in-chapter *Go Figure* and *Give It Some Thought* questions, as well as end-of-chapter problems. User data helped them to identify problematic questions and then modify, replace, or delete—resulting in a more diverse and polished set of problems.

UPDATED! *A Closer Look* features have been updated to reflect recent news and discoveries in the field of chemistry, providing relevance and applications for students. End-of-chapter questions give students the chance to test whether they understood the concept or not.

Continuous Learning
Before, During, and After Class

NEW! eText 2.0

- **Full eReader functionality** includes page navigation, search, glossary, highlighting, note taking, annotations, and more.
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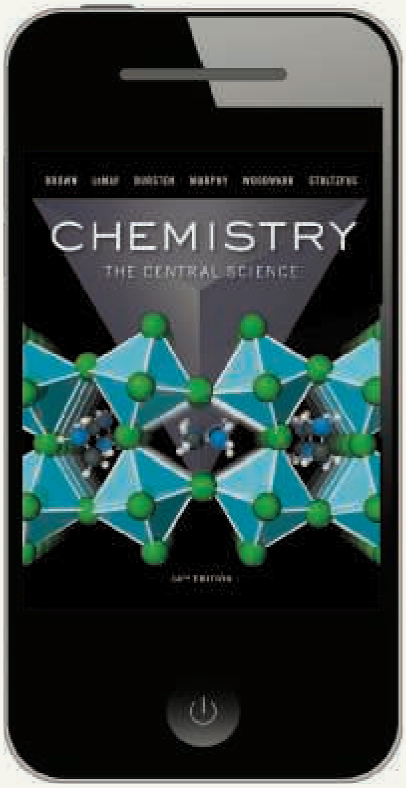

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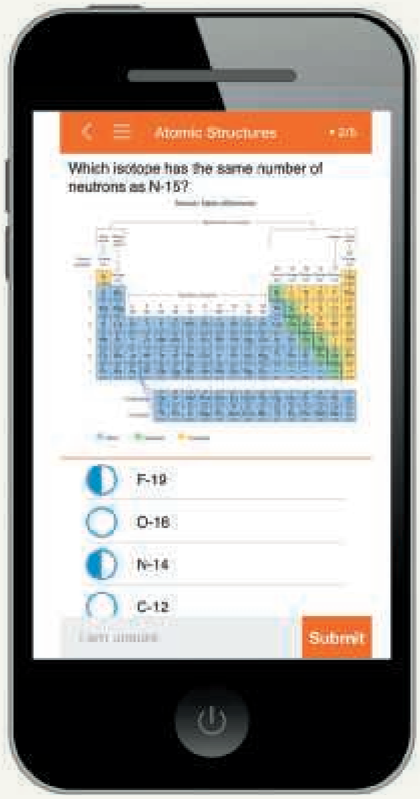

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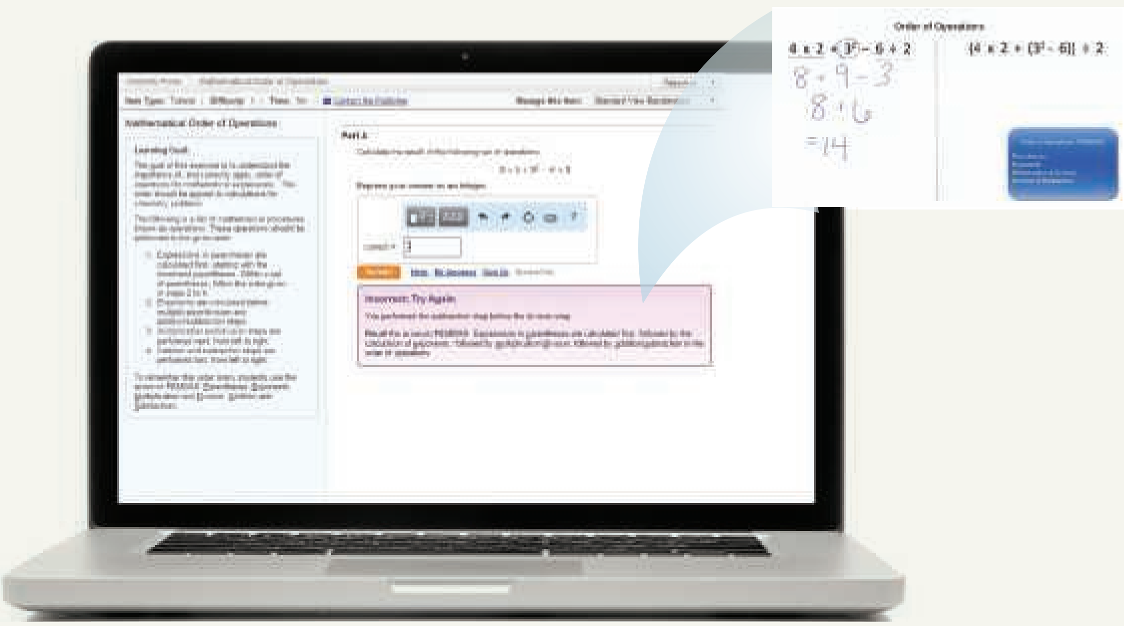

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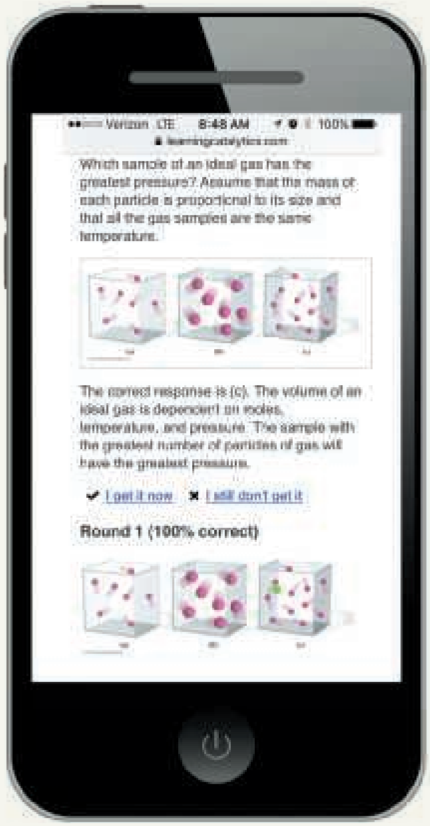

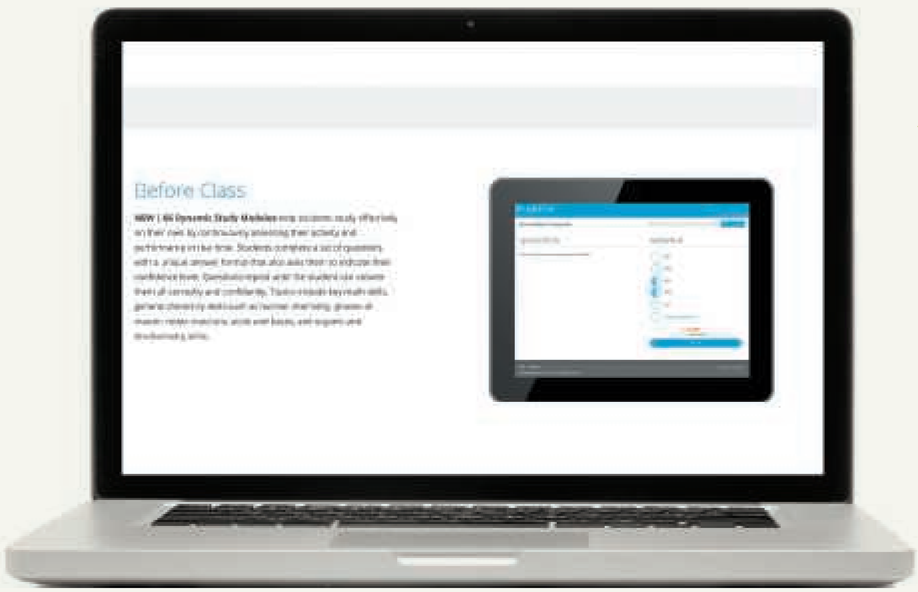

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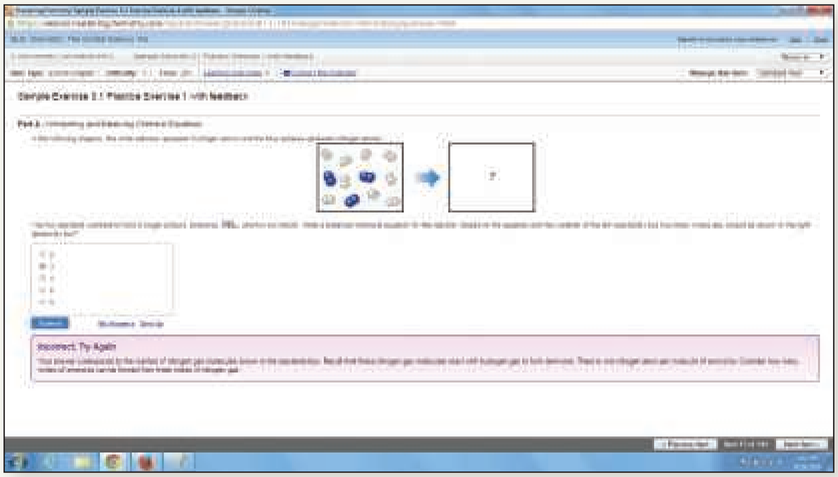

Design An Experiment feature provides a departure from the usual kinds of end-of-chapter exercises with an inquiry-based, open-ended approach that tries to stimulate the student to "think like a scientist." Designed to foster critical thinking, each exercise presents the student with a scenario in which various unknowns require investigation. The student is called upon to ponder how experiments might be set up to provide answers to particular questions about observations.

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Instructor Manual 0134554604		√	Instructor	Organized by chapter, this useful guide includes objectives, lecture outlines, references to figures and solved problems, as well as teaching tips.
Instructor Resource Materials 0134557220		√	Instructor	The material available for download includes: • All illustrations, tables, and photos from the text in JPEG format • Pre-built PowerPoint™ Presentations (lecture, worked examples, images) • TestGen computerized software with the TestGen version of the Testbank • Word.doc files of the Test Item File
Student Guide 0134554078	√		Student	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 student guide also features MCAT practice questions.
Solutions Manual 0134552245	√		Instructor/ Student	Full solutions to all of the exercises (both red and black) in the text are provided.
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Solutions Manual to Black Exercises 0134580095	√		Student	Full solutions to all of the black-numbered exercises in the text are provided.
Laboratory Experiments 0134566203	√		Student	This manual contains 43 finely-tuned experiments chosen to introduce students to basic lab techniques and to illustrate core chemical principles.
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CHEMISTRY

THE CENTRAL SCIENCE 14TH EDITION


1

INTRODUCTION: MATTER, ENERGY, AND MEASUREMENT

The title of this book—*Chemistry: The Central Science*—reflects the fact that much of what goes on in the world around us involves chemistry. Everyday chemical processes include the changes that produce brilliant fall colors in leaves, the ways our bodies process the food we eat, and the electrical energy that powers our cell phones.

Chemistry is the study of matter, its properties, 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 will also learn how the properties of substances can be tailored for specific applications by controlling their composition and structure. For example, the synthetic pigments chemists developed in the nineteenth century were used extensively by impressionist artists like van Gogh and Monet.

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 MANUFACTURE OF SYNTHETIC PIGMENTS** is one of the oldest examples of industrial chemistry. The impressionist artists made extensive use of the bold colors of the newly available pigments, as exemplified in van Gogh's painting Road with Cyprus and Star.

WHAT'S AHEAD

1.1 ▶ The Study of Chemistry Learn what chemistry is, what chemists do, and why it is useful to study chemistry.

1.2 ▶ Classifications of Matter Examine fundamental ways to classify matter; distinguish between *pure substances* and *mixtures* and between *elements* and *compounds*.

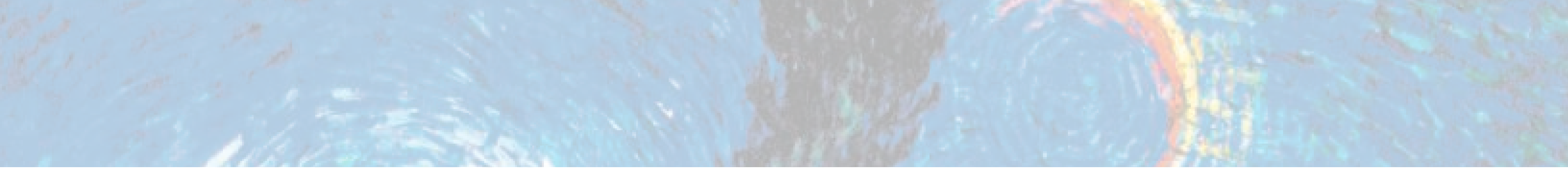
1.3 ▶ Properties of Matter Use *properties* to characterize, identify, and separate substances; distinguish between chemical and physical properties.

1.4 ▶ The Nature of Energy Explore the nature of energy and the forms it takes, notably kinetic energy and potential energy.

1.5 ▶ Units of Measurement Learn how numbers and units of the metric system are used in science to describe properties.

1.6 ▶ Uncertainty in Measurement Use significant figures to express the inherent uncertainty in measured quantities and in calculations.

1.7 ▶ Dimensional Analysis Learn to carry numbers and units through calculations; use units to check if a calculation is correct.



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 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.

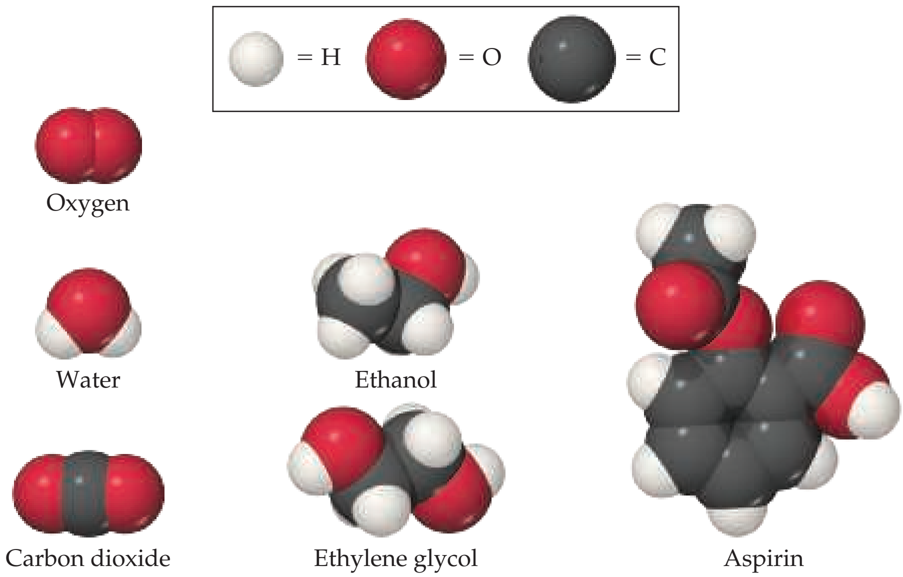
The Atomic and Molecular Perspective of Chemistry

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

Go Figure Which molecule has the most carbon atoms? How many carbon atoms does it contain?



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

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. 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.

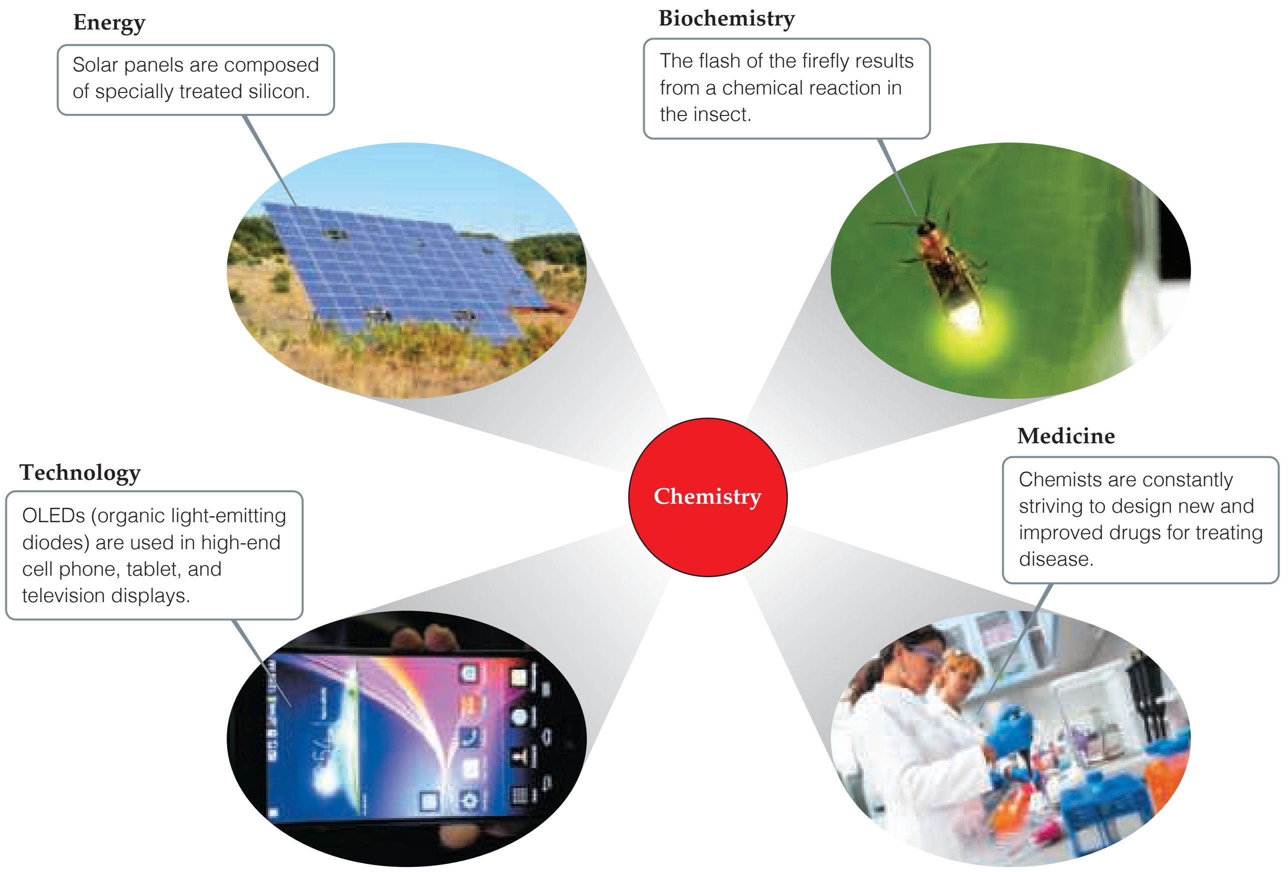
Give It Some Thought

(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, light-emitting diodes (LEDs), and building materials. We have also discovered that some chemicals are 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, in order 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. We are all familiar with household chemicals, particularly those used for cleaning as shown in **Figure 1.3**. However, few realize the size and importance of the chemical industry. The chemical industry in the United States is estimated to be an $800 billion enterprise that employs over 800,000 people and accounts for 14% of all U.S. exports.

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: They (1) make new types of matter: materials, substances, or combinations of substances with desired proerties; (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 used for household cleaning.**

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*).

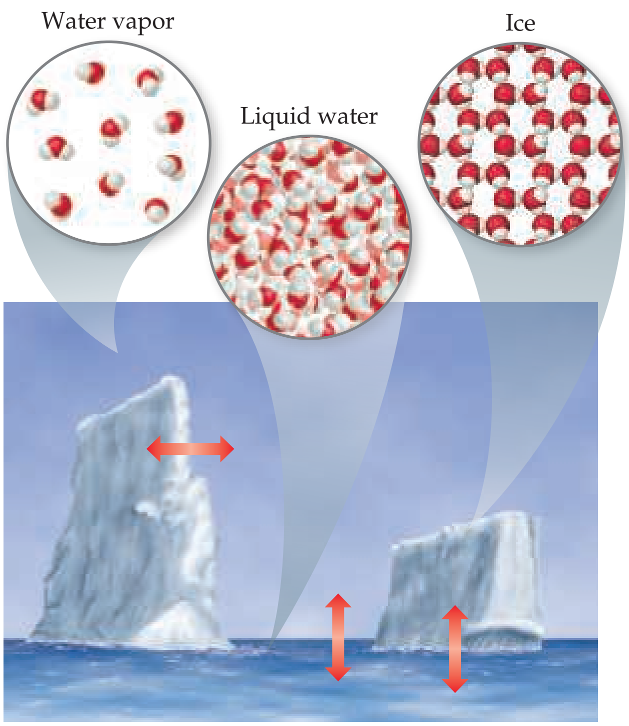
States of Matter

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, assumes the shape of the portion of the container it occupies, and is not compressible to any appreciable extent.
- A **solid** has both a definite shape and a definite volume and is not compressible 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 while the molecules are for the most part locked in place in a solid, they retain considerable freedom of motion in a liquid. 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

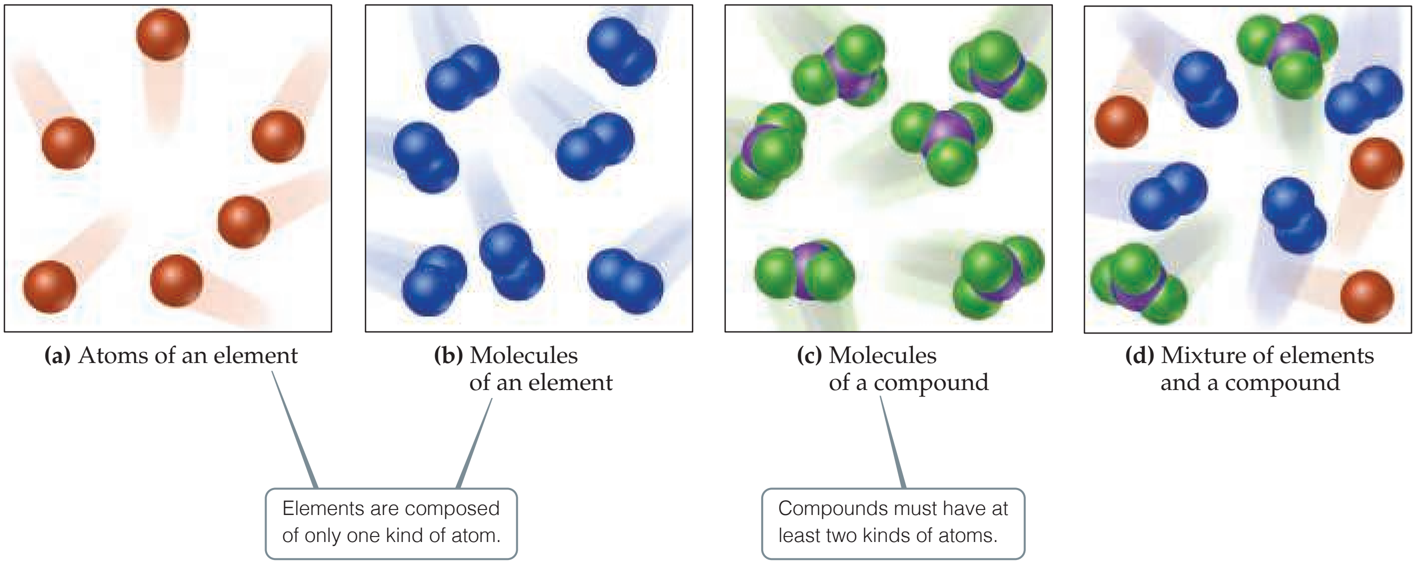
Most forms of matter we encounter—the air we breathe (a gas), the gasoline we burn in our cars (a liquid), and the sidewalk we walk on (a solid)—are not chemically pure. We can, however, separate these forms of matter into pure substances. A **pure substance** (usually referred to simply as a *substance*) 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.

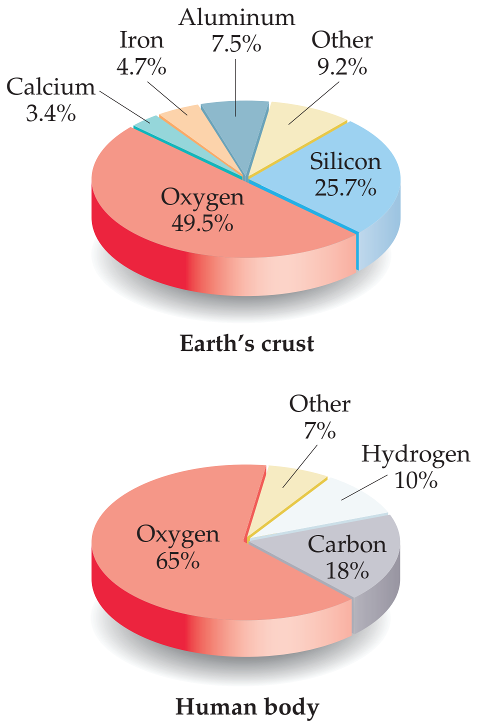
Figure 1.5(**d**) shows a mixture of substances. **Mixtures** are combinations of two or more substances in which each substance retains its chemical identity.

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 If the lower pie chart was drawn as the percentage in terms of number of atoms rather than the percentage in terms of mass, would the hydrogen slice of the pie get larger or smaller?



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

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).

Table 1.1 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 1.1). 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

TABLE 1.1 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.

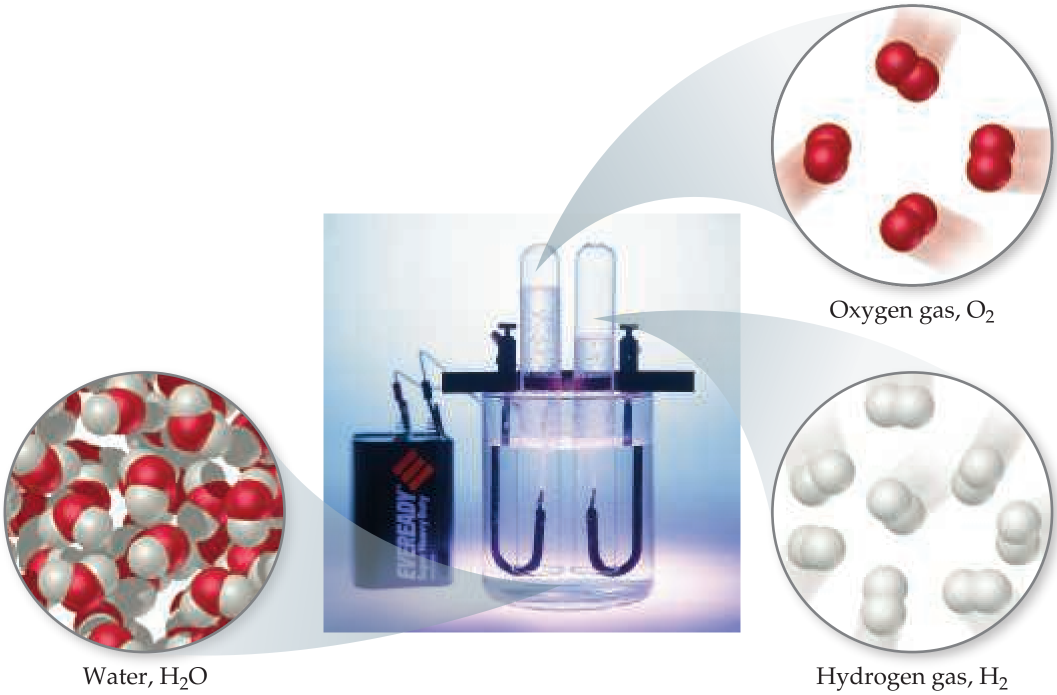
Section 2.5 and consider the periodically repeating properties of the elements in Chapter 7.

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**).

Go Figure

Is the volume of H_2 produced larger than the volume of O_2 produced because (a) hydrogen atoms are lighter than oxygen atoms, (**b**) hydrogen atoms are larger than oxygen atoms, or (**c**) each water molecule contains one oxygen atom and two hydrogen atoms?



▲ **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.

Decomposing pure water into its constituent elements shows that it contains 11% hydrogen and 89% oxygen by mass, regardless of its source. This ratio is constant because every water molecule has the same number of hydrogen and oxygen atoms. While the mass percentages make it seem that water is mostly oxygen, there are actually two hydrogen atoms and only one oxygen atom per molecule. The explanation for this apparent discrepancy comes from the fact that hydrogen atoms are much lighter than oxygen atoms. This macroscopic composition corresponds to the molecular composition, which consists of two hydrogen atoms combined with one oxygen atom: