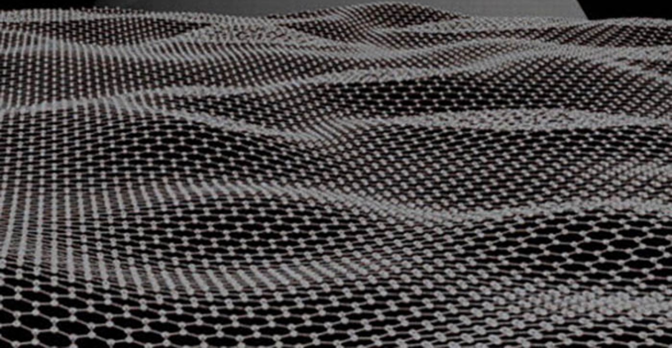
BROWN LeMAY BURSTEN MURPHY WOODWARD

TWELFTH EDITION

CHEMISTRY

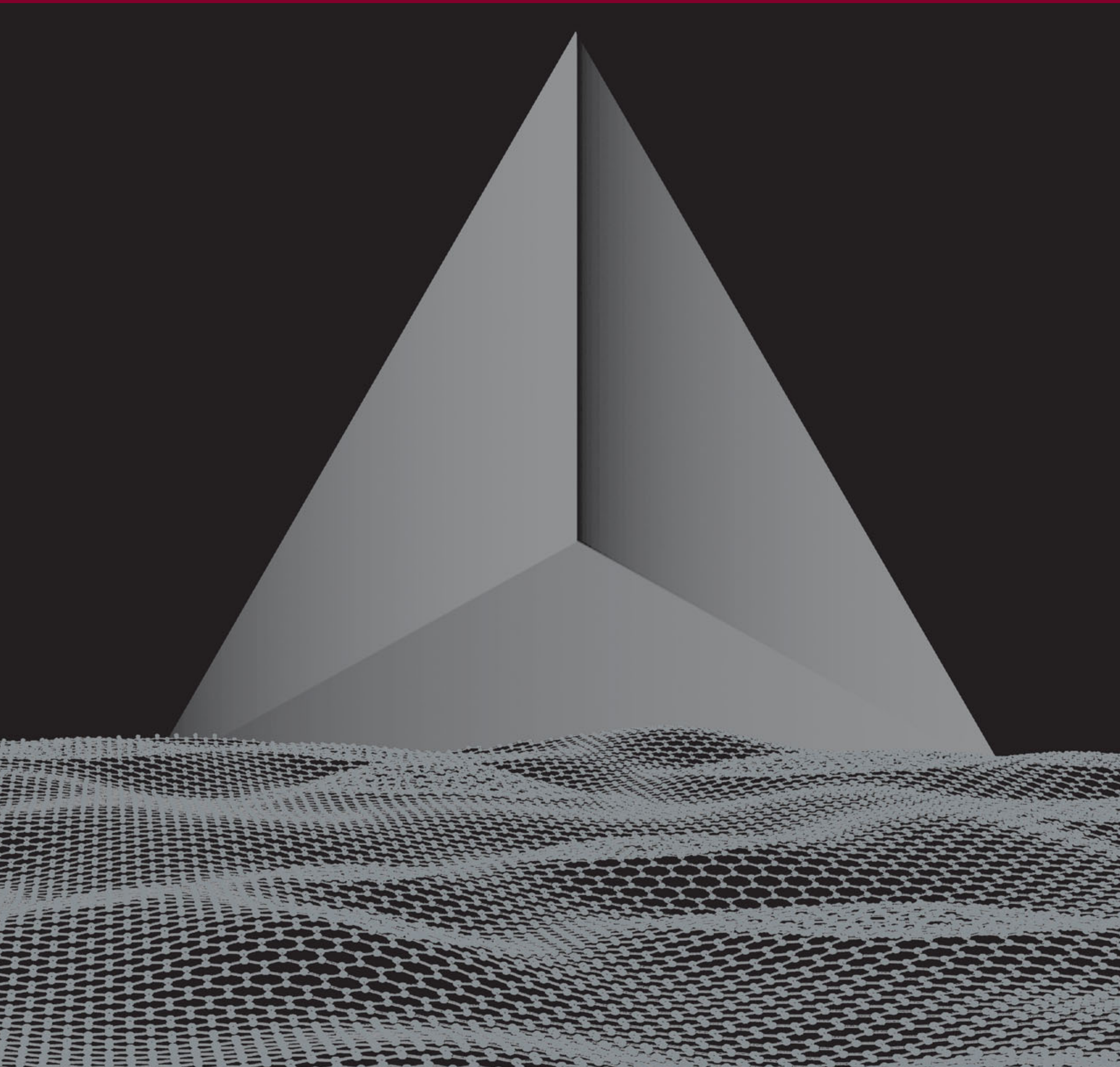
THE CENTRAL SCIENCE



TWELFTH EDITION

CHEMISTRY

THE CENTRAL SCIENCE



TWELFTH EDITION

CHEMISTRY

THE CENTRAL SCIENCE

THEODORE L. BROWN
University of Illinois at Urbana-Champaign

H. EUGENE LEMAY, JR.
University of Nevada, Reno

BRUCE E. BURSTEN
University of Tennessee, Knoxville

CATHERINE J. MURPHY
University of Illinois at Urbana-Champaign

PATRICK M. WOODWARD
The Ohio State University

Prentice Hall
Boston Columbus Indianapolis New York San Francisco Upper Saddle River
Amsterdam Cape Town Dubai London Madrid Milan Munich Paris Montréal Toronto
Delhi Mexico City São Paulo Sydney Hong Kong Seoul Singapore Taipei Tokyo

Editor in Chief, Chemistry: Adam Jaworski
Acquisitions Editor: Terry Haugen
Marketing Manager: Erin Gardner
Project Editor: Jennifer Hart
Editorial Assistant: Catherine Martinez
Marketing Assistant: Nicola Houston
VP/Executive Director, Development: Carol Trueheart
Development Editor, Text: Irene Nunes
Development Editor, Art: Greg Gambino
Managing Editor, Chemistry and Geosciences: Gina M. Cheselka
Project Manager: Shari Toron
Full-Service Project Management/Composition: Rebecca Dunn/Preparé, Inc.
Senior Manufacturing and Operations Manager: Nick Sklitsis
Operations Specialist: Maura Zaldivar
Art Director: Mark Ong
Senior Technical Art Specialist: Connie Long
Art Studio: Precision Graphics
Photo Research Manager: Elaine Soares
Photo Researcher: Eric Schrader
Senior Media Producer: Angela Bernhardt
Associate Media Producer: Kristin Mayo
Media Supervisor: Liz Winer
Production Coordinator, Media: Shannon Kong
Electrostatic Potential Maps: Richard Johnson, Chemistry Department, University of New Hampshire
Cover Credit: Graphene by Dr. Jannik C. Meyer of the University of Ulm, Germany

Library of Congress Cataloging-in-Publication Data

Chemistry: the central science / Theodore L. Brown ... [et al.]—12th ed.
p. cm.
Includes bibliographical references and index.
ISBN 978-0-321-69672-4 (alk. paper)
1. Chemistry—Textbooks. I. Brown, Theodore L. (Theodore Lawrence), 1928-

QD31.3.C43145 2012
540—dc22

2010043754

Printed in the United States of America
10 9 8 7 6 5 4 3 2 1

Prentice Hall
is an imprint of
PEARSON

ISBN-10: 0-321-69672-7/ISBN-13: 978-0-321-69672-4 (Student Edition)
ISBN-10: 0-321-76754-3/ISBN-13: 978-0-321-76754-7 (Exam Copy)

www.pearsonhighered.com

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

BRIEF CONTENTS

CONTENTS


Virgin


ONE OR TWO TA
OUTH EVERY 4 HOU
EEDED
DIAZEPAM 5MG
DSUP:

11 LIQUIDS AND INTERMOLECULAR FORCES 424

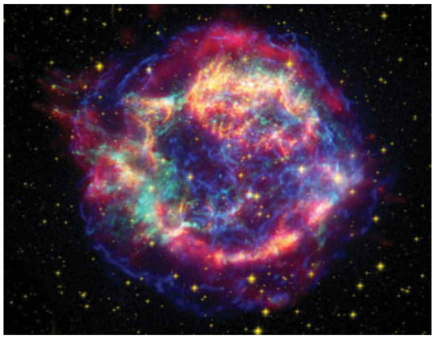
12 SOLIDS AND MODERN MATERIALS 462

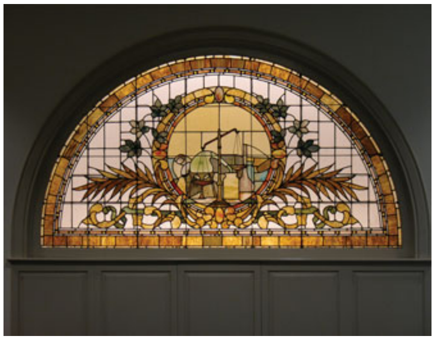
14 CHEMICAL KINETICS 556

15 CHEMICAL EQUILIBRIUM 610

17 ADDITIONAL ASPECTS OF AQUEOUS EQUILIBRIA 702

18 CHEMISTRY OF THE ENVIRONMENT 748





23 TRANSITION METALS AND COORDINATION CHEMISTRY 962

24 THE CHEMISTRY OF LIFE: ORGANIC AND BIOLOGICAL CHEMISTRY 1004

Appendices

CHEMICAL APPLICATIONS AND ESSAYS

CHEMISTRY PUT TO WORK

A CLOSER LOOK

CHEMISTRY AND LIFE

STRATEGIES IN CHEMISTRY

PREFACE

TO THE INSTRUCTOR

Philosophy

The cover of this new edition of *Chemistry: The Central Science* features a striking illustration of the structure of graphene, a recently discovered form of carbon. As we began preparing the previous edition in 2006, single-layer graphene was virtually unknown. The extraordinary properties of graphene, and its promise for future applications, has already resulted in a Nobel Prize. An understanding of the structure and many of the properties of graphene is well within the reach of an undergraduate student of general chemistry. Through such examples, it is possible to demonstrate in a general chemistry course that chemistry is a dynamic science in continuous development. New research leads to new applications of chemistry in other fields of science and in technology. In addition, environmental and economic concerns bring about changes in the place of chemistry in society. Our textbook reflects this dynamic, changing character. We hope that it also conveys the excitement that scientists experience in making new discoveries that contribute to our understanding of the physical world.

New ideas about how to teach chemistry are constantly being developed, and many of them are reflected in how our textbook is organized and in the ways in which topics are presented. This edition incorporates a number of new methodologies to assist students, including use of the Internet, computer-based classroom tools, Web-based tools, particularly MasteringChemistry®, and more effective means of testing.

As authors, we want this text to be a central, indispensable learning tool for students. It can be carried everywhere and used at any time. It is the one place students can go to obtain the information needed for learning, skill development, reference, and test preparation. At the same time, the text provides the 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 teacher, 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. Together we have logged many years of teaching experience. We hope this is evident in our pacing, choice of examples, and the kinds of study aids and motivational tools we have employed. Because we believe that students are more enthusiastic about learning chemistry when they see its importance to their own goals and interests, we have highlighted many important applications of chemistry in everyday life. We hope you make use of this material.

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. But the text and all the supplementary materials provided to support its use must work in concert with you, the instructor. There is a great deal for the students to use here, 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 Internet resources available. Emphasize conceptual understanding and place less emphasis on simple manipulative, algorithmic problem solving.

What's New in This Edition?

A great many changes have been made in producing this twelfth edition. The entire art program for the text has been reworked, and new features connected with the art have been introduced.

- Nearly every figure in the book has undergone some modification, and hundreds of figures have been entirely redone.
- A systematic effort has been made to move information that was contained in figure captions directly into the figures.
- Explanatory labels have been employed extensively in figures to guide the student in understanding the art.
- In several important places, art has been modified to convey the notion of progression in time, as in a reaction. See, for instance, Figures 4.4 and 14.27.
- New designs have been employed to more closely integrate photographic materials into figures that convey chemical principles, as in Figure 2.21.
- A new feature called **Go Figure** has been added to about 40% of the figures. This feature asks the student a question that can be answered by examining the figure. It tests whether the student has in fact examined the figure and understands its primary message. Answers to the **Go Figure** questions are provided in the back of the text.
- New end-of-chapter exercises have been added, and many of those carried over from the eleventh edition have been significantly revised. Results from analysis of student responses to MasteringChemistry, the online homework program connected with the text, have been used to eliminate questions that did not appear to be functioning well and to assess the degree to which instructors have used the end-of-chapter materials. On the basis of these analyses, many exercises have been revised or eliminated.
- Chapter introductions have been redesigned to enhance the student's exposure to the aims of the chapter and its contents.
- The presentation of hybrid orbitals in Chapter 9 and elsewhere has been rewritten to limit the treatment to *s* and *p* orbitals, based on theoretical work indicating that *d* orbital participation in hybridization is not significant.
- The treatment of condensed phases, liquids and solids, has been reorganized into two chapters that contain much new material. Chapter 11 deals with liquids and intermolecular forces, while Chapter 12 deals with solids, starting from the basics of crystal structures and covering a broad range of materials (including metals, semiconductors, polymers, and nanomaterials) in a cohesive manner.
- Chapter 18 on the Chemistry of the Environment has been substantially revised to focus on how human activities affect Earth's atmosphere and water, and to enlarge the coverage of the green chemistry initiative.
- The treatment of metals, Chapter 23 of the eleventh edition, has been reorganized and augmented. Structure and bonding in metals and alloys are now covered in Chapter 12 (Solids and Modern Materials), and other parts of Chapter 23 have been combined with material from Chapter 24 of the eleventh edition to form a new chapter, Transition Metals and Coordination Chemistry. Material covering occurrences and production of metals that was not widely used by instructors has been eliminated.

Throughout the text, the writing has been improved by enhancing the clarity and flow of ideas while achieving an economy of words. Thus, despite the addition of new features, the length of the text has not changed significantly.

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 deal with 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.

The focus of the text then changes (Chapters 10–13) 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, much as in earlier editions. Chapter 12, however, is now devoted to solids, presenting an enlarged and more contemporary view of the solid state as well as of modern materials. This change is appropriate, given the ever-increasing importance of solid-state materials in solar energy, illumination, and electronics. Chapter 12 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 been revised to focus more sharply on the impacts of human activities on Earth's water and atmosphere and on green chemistry.

After a discussion of nuclear chemistry (Chapter 21), the book ends with three survey chapters. Chapter 22, on nonmetals, has been consolidated slightly from the eleventh edition. Chapter 23 now deals with the chemistry of transition metals, including coordination compounds, and the last chapter deals with the chemistry of organic compounds and elementary biochemical themes. These final four chapters are developed in a parallel fashion and can be treated in any order.

Our chapter sequence provides a fairly standard organization, but we recognize that not everyone teaches all the topics in just 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's New in This Edition** on page xxvii details changes made throughout the new edition. Beyond a mere listing, however, it is worth dwelling on the general goals we set in formulating the twelfth 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 major systemic change in the new edition involves the art program. It is widely recognized that contemporary students rely more on visual learning materials than in the past, yet for the most part textbook art has not evolved greatly in response other than a greater use of molecular art. In this edition, with the help of a strong editorial development team, we have redone a large portion of the figures with the aim of increasing their power as teaching tools. What can we do to encourage students to study a figure, and how can we help them learn from it? The first step has been to incorporate elements that direct attention to the figure's major features. The flow from one important aspect to the next, particularly involving processes occurring over time, has been emphasized through new layouts and through the use of both visual and textual cues, as in Figures 2.15, 4.3, 4.9, and 14.17. Our aim is to draw the student into a more careful and thoughtful viewing through extensive use of explanatory labels and other devices. A new feature called **Go Figure**, analogous to the **Give It Some Thought** exercises we pioneered in the tenth edition, directs attention to the art and provides an opportunity for students to judge whether they have really absorbed the content of the figure. We have also found new and more effective ways to show trends and relationships in figures involving presentations of data, as in Figures 7.6, 8.8, and 8.15.

We have continued to use the **What's Ahead** overview at the opening of each chapter, introduced in the ninth edition. *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. The **Give It Some Thought** exercises that we introduced in the tenth edition have proved to be very popular, and we have continued to refine their use. These informal, sharply focused questions give students opportunities to test whether they are "getting it" as they read along.

We have continued to emphasize conceptual exercises in the end-of-chapter exercise materials. The **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. The **Integrative Exercises**, which give students the opportunity to solve problems that integrate concepts from the present chapter with those of previous chapters, have been continued. The importance of integrative problem solving is highlighted by the **Sample Integrative Exercise** that 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. The results from student use of MasteringChemistry have enabled us to more reliably evaluate the effectiveness of our end-of-chapter exercises and make changes accordingly.

New essays in our well-received ***Chemistry Put to Work*** and ***Chemistry and Life*** series emphasize world events, scientific discoveries, and medical breakthroughs that have occurred since publication of the eleventh edition. 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.

TO THE STUDENT

***Chemistry: The Central Science*, Twelfth 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. The **Key Skills** 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.

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.

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.

Twelfth Edition Reviewers

Rebecca Barlag	Ohio University
Hafed, Bascal	University of Findlay
Donald Bellew	University of New Mexico
Elzbieta Cook	Louisiana State University
Robert Dunn	University of Kansas
Michael Hay	Pennsylvania State University
Carl Hoeger	University of California at San Diego
Kathryn Rowberg	Purdue University at Calumet
Lewis Silverman	University of Missouri at Columbia
Clyde Webster	University of California at Riverside
Troy Wood	University of Buffalo

Twelfth Edition Accuracy Reviewers

Rebecca Barlag	Ohio University
Kelly Beefus	Anoka-Ramsey Community College
Louis J. Kirschenbaum	University of Rhode Island
Barbara Mowery	York College
Maria Vogt	Bloomfield College

Twelth Edition Focus Group Participants

Robert Carter	University of Massachusetts at Boston Harbor
Tom Clayton	Knox College
Elzbieta Cook	Louisiana State University
Debra Feakes	Texas State University at San Marcos
Robert Gellert	Glendale Community College
John Gorden	Auburn University
Thomas J. Greenbowe	Iowa State University
Kingston Jesudoss	Iowa State University
Daniela Kohen	Carleton University
Sergiy Kryatov	Tufts University
Jeff McVey	Texas State University at San Marcos
Michael Seymour	Hope College
Matthew Stoltzfus	The Ohio State University

MasteringChemistry® Summit Participants

Phil Bennett	Santa Fe Community College
Jo Blackburn	Richland College
John Bookstaver	St. Charles Community College
David Carter	Angelo State University
Doug Cody	Nassau Community College
Tom Dowd	Harper College
Palmer Graves	Florida International University
Margie Haak	Oregon State University
Brad Herrick	Colorado School of Mines
Jeff Jenson	University of Findlay
Jeff McVey	Texas State University at San Marcos
Gary Michels	Creighton University
Bob Pribush	Butler University
Al Rives	Wake Forest University
Joel Russell	Oakland University
Greg Szulczewski	University of Alabama, Tuscaloosa
Matt Tarr	University of New Orleans
Dennis Taylor	Clemson University
Harold Trimm	Broome Community College
Emanuel Waddell	University of Alabama, Huntsville
Kurt Winklemann	Florida Institute of Technology
Klaus Woelk	University of Missouri, Rolla
Steve Wood	Brigham Young University

Reviewers of Previous Editions of *Chemistry: The Central Science*

S.K. Airee	University of Tennessee
John J. Alexander	University of Cincinnati
Robert Allendoerfer	SUNY Buffalo
Patricia Amateis	Virginia Polytechnic Institute and State University
Sandra Anderson	University of Wisconsin
John Arnold	University of California
Socorro Arteaga	El Paso Community College
Margaret Asirvatham	University of Colorado
Todd L. Austell	University of North Carolina, Chapel Hill
Melita Balch	University of Illinois at Chicago
Rosemary Bartoszek-Loza	The Ohio State University
Boyd Beck	Snow College
Amy Beilstein	Centre College
Victor Berner	New Mexico Junior College
Narayan Bhat	University of Texas, Pan American
Merrill Blackman	United States Military Academy
Salah M. Blaih	Kent State University
James A. Boiani	SUNY Geneseo
Leon Borowski	Diablo Valley College
Simon Bott	University of Houston
Kevin L. Bray	Washington State University
Daeg Scott Brenner	Clark University
Gregory Alan Brewer	Catholic University of America
Karen Brewer	Virginia Polytechnic Institute and State University
Edward Brown	Lee University
Gary Buckley	Cameron University
Carmela Byrnes	Texas A&M University
B. Edward Cain	Rochester Institute of Technology

Kim Calvo	University of Akron
Donald L. Campbell	University of Wisconsin
Gene O. Carlisle	Texas A&M University
Elaine Carter	Los Angeles City College
Robert Carter	University of Massachusetts
Ann Cartwright	San Jacinto Central College
David L. Cedeño	Illinois State University
Dana Chatellier	University of Delaware
Stanton Ching	Connecticut College
Paul Chirik	Cornell University
William Cleaver	University of Vermont
Beverly Clement	Blinn College
Robert D. Cloney	Fordham University
John Collins	Broward Community College
Edward Werner Cook	Tunxis Community Technical College
Elzbieta Cook	Louisiana State University
Enriqueta Cortez	South Texas College
Thomas Edgar Crumm	Indiana University of Pennsylvania
Dwaine Davis	Forsyth Tech Community College
Ramón López de la Vega	Florida International University
Nancy De Luca	University of Massachusetts, Lowell North Campus
Angel de Dios	Georgetown University
John M. DeKorte	Glendale Community College
Daniel Domin	Tennessee State University
James Donaldson	University of Toronto
Bill Donovan	University of Akron
Stephen Drucker	University of Wisconsin-Eau Claire
Ronald Duchovic	Indiana University-Purdue University at Fort Wayne
David Easter	Southwest Texas State University
Joseph Ellison	United States Military Academy
George O. Evans II	East Carolina University
James M. Farrar	University of Rochester
Gregory M. Ferrence	Illinois State University
Clark L. Fields	University of Northern Colorado
Jennifer Firestine	Lindenwood University
Jan M. Fleischner	College of New Jersey
Paul A. Flowers	University of North Carolina at Pembroke
Michelle Fossum	Laney College
Roger Frampton	Tidewater Community College
Joe Franek	University of Minnesota
David Frank	California State University
Cheryl B. Frech	University of Central Oklahoma
Ewa Fredette	Moraine Valley College
Kenneth A. French	Blinn College
Karen Frindell	Santa Rosa Junior College
John I. Gelder	Oklahoma State University
Paul Gilletti	Mesa Community College
Peter Gold	Pennsylvania State University
Eric Goll	Brookdale Community College
James Gordon	Central Methodist College
Thomas J. Greenbowe	Iowa State University
Michael Greenlief	University of Missouri
Eric P. Grimsrud	Montana State University
John Hagadorn	University of Colorado
Randy Hall	Louisiana State University
John M. Halpin	New York University
Marie Hankins	University of Southern Indiana
Robert M. Hanson	St. Olaf College
Daniel Haworth	Marquette University
Inna Hefley	Blinn College
David Henderson	Trinity College
Paul Higgs	Barry University
Carl A. Hoeger	University of California, San Diego
Gary G. Hoffman	Florida International University
Deborah Hokien	Marywood University
Robin Horner	Fayetteville Tech Community College
Roger K. House	Moraine Valley College
Michael O. Hurst	Georgia Southern University
William Jensen	South Dakota State University
Janet Johannessen	County College of Morris
Milton D. Johnston, Jr.	University of South Florida
Andrew Jones	Southern Alberta Institute of Technology
Booker Juma	Fayetteville State University
Ismail Kady	East Tennessee State University
Siam Kahmis	University of Pittsburgh
Steven Keller	University of Missouri
John W. Kenney	Eastern New Mexico University
Neil Kestner	Louisiana State University
Leslie Kinsland	University of Louisiana
Louis J. Kirschenbaum	University of Rhode Island
Donald Kleinfelter	University of Tennessee, Knoxville
David Kort	George Mason University
George P. Kreishman	University of Cincinnati
Paul Kreiss	Anne Arundel Community College
Manickham Krishnamurthy	Howard University
Brian D. Kybett	University of Regina
William R. Lammela	Nazareth College
John T. Landrum	Florida International University
Richard Langley	Stephen F. Austin State University
N. Dale Ledford	University of South Alabama
Ernestine Lee	Utah State University
David Lehmpuhl	University of Southern Colorado
Robley J. Light	Florida State University
Donald E. Linn, Jr.	Indiana University-Purdue University Indianapolis
David Lippmann	Southwest Texas State
Patrick Lloyd	Kingsborough Community College
Encarnacion Lopez	Miami Dade College, Wolfson
Arthur Low	Tarleton State University
Gary L. Lyon	Louisiana State University
Preston J. MacDougall	Middle Tennessee State University
Jeffrey Madura	Duquesne University
Larry Manno	Triton College
Asoka Marasinghe	Moorhead State University
Earl L. Mark	ITT Technical Institute
Pamela Marks	Arizona State University
Albert H. Martin	Moravian College
Przemyslaw Maslak	Pennsylvania State University
Hilary L. Maybaum	ThinkQuest, Inc.
Armin Mayr	El Paso Community College
Marcus T. McEllistrem	University of Wisconsin
Craig McLauchlan	Illinois State University
William A. Meena	Valley College
Joseph Merola	Virginia Polytechnic Institute and State University
Stephen Mezyk	California State University
Eric Miller	San Juan College
Gordon Miller	Iowa State University
Shelley Minteer	Saint Louis University
Massoud (Matt) Miri	Rochester Institute of Technology
Mohammad Moharerrzadeh	Bowie State University
Tracy Morkin	Emory University
Barbara Mowery	Yorktown, VA
Kathleen E. Murphy	Daemen College
Kathy Nabona	Austin Community College
Robert Nelson	Georgia Southern University
Al Nichols	Jacksonville State University

Ross Nord	Eastern Michigan University
Jessica Orvis	Georgia Southern University
Mark Ott	Jackson Community College
Jason Overby	College of Charleston
Robert H. Paine	Rochester Institute of Technology
Robert T. Paine	University of New Mexico
Sandra Patrick	Malaspina University College
Mary Jane Patterson	Brazosport College
Tammi Pavelec	Lindenwood University
Albert Payton	Broward Community College
Christopher J. Peeples	University of Tulsa
Kim Percell	Cape Fear Community College
Gita Perkins	Estrella Mountain Community College
Richard Perkins	University of Louisiana
Nancy Peterson	North Central College
Robert C. Pfaff	Saint Joseph's College
John Pfeffer	Highline Community College
Lou Pignolet	University of Minnesota
Bernard Powell	University of Texas
Jeffrey A. Rahn	Eastern Washington University
Steve Rathbone	Blinn College
Scott Reeve	Arkansas State University
John Reissner	University of North Carolina
Helen Richter	University of Akron
Thomas Ridgway	University of Cincinnati
Mark G. Rockley	Oklahoma State University
Lenore Rodicio	Miami Dade College
Amy L. Rogers	College of Charleston
Jimmy R. Rogers	University of Texas at Arlington
Steven Rowley	Middlesex Community College
James E. Russo	Whitman College
Theodore Sakano	Rockland Community College
Michael J. Sanger	University of Northern Iowa
Jerry L. Sarquis	Miami University
James P. Schneider	Portland Community College
Mark Schraf	West Virginia University
Gray Scrimgeour	University of Toronto
Paula Secondo	Western Connecticut State University
Kathy Thrush Shaginaw	Villanova University
Susan M. Shih	College of DuPage
David Shinn	University of Hawaii at Hilo
Vince Sollimo	Burlington Community College
David Soriano	University of Pittsburgh-Bradford
Eugene Stevens	Binghamton University
James Symes	Cosumnes River College
Iwao Teraoka	Polytechnic University
Kathy Thrush	Villanova University
Domenic J. Tiani	University of North Carolina, Chapel Hill
Edmund Tisko	University of Nebraska at Omaha
Richard S. Treptow	Chicago State University
Michael Tubergen	Kent State University
Claudia Turro	The Ohio State University
James Tyrell	Southern Illinois University
Michael J. Van Stipdonk	Wichita State University
Philip Verhalen	Panola College
Ann Verner	University of Toronto at Scarborough
Edward Vickner	Gloucester County Community College
John Vincent	University of Alabama
Maria Vogt	Bloomfield College
Tony Wallner	Barry University
Lichang Wang	Southern Illinois University
Thomas R. Webb	Auburn University
Karen Weichelman	University of Louisiana-Lafayette
Paul G. Wenthold	Purdue University
Laurence Werbelow	New Mexico Institute of Mining and Technology
Wayne Wesolowski	University Of Arizona
Sarah West	University of Notre Dame
Linda M. Wilkes	University at Southern Colorado
Charles A. Wilkie	Marquette University
Darren L. Williams	West Texas A&M University
Troy Wood	SUNY Buffalo
Thao Yang	University of Wisconsin
David Zax	Cornell University
Dr. Susan M. Zirpoli	Slippery Rock University

We would also like to express our gratitude to our many team members at Pearson Prentice Hall whose hard work, imagination, and commitment have contributed so greatly to the final form of this edition: Nicole Folchetti, our former Editor in Chief, brought energy and imagination not only to this edition but to earlier ones as well; Terry Haugen, our Chemistry Editor, for many fresh ideas and his unflagging enthusiasm, continuous encouragement, and support; Jennifer Hart, our Project Editor, who very effectively coordinated the scheduling and tracked the multidimensional deadlines that come with a project of this magnitude; Erin Gardner, our marketing manager, for her energy, enthusiam, and creative promotion of our text; Irene Nunes, our Development Editor, whose diligence and careful attention to detail were invaluable to this revision, especially in keeping us on task in terms of consistency and student understanding; Donna Mulder, our Copy Editor, for her keen eye; Greg Gambino, our Art Developmental Editor, who managed the complex task of bringing our sketches into final form and who contributed so many great ideas to the new art program; Shari Toron, our Project Manager, who managed the complex responsibilities of bringing the design, photos, artwork, and writing together with efficiency and good cheer. The Pearson Prentice Hall team is a first-class operation.

There are many others who also deserve special recognition, including the following: Eric Schrader, 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. We thank Dr. Jannik C. Meyer of the University of Ulm, Germany, for providing us with a high resolution image of graphene used in the cover design.

Finally, we wish to thank our families and friends for their love, support, encouragement, and patience as we brought this twelfth edition to completion.

Theodore L. Brown
Department of Chemistry
University of Illinois
at Urbana-Champaign
Urbana, IL 61801
tlbrown@illinois.edu
or ***tlbrown1@earthlink.net***

H. Eugene LeMay, Jr.
Department of Chemistry
University of Nevada
Reno, NV 89557
lemay@unr.edu

Bruce E. Bursten
College of Arts and Sciences
University of Tennessee
Knoxville, TN 37996
bbursten@utk.edu

Catherine J. Murphy
Department of Chemistry
University of Illinois
at Urbana-Champaign
Urbana, IL 61801
murphycj@illinois.edu.

Patrick M. Woodward
Department of Chemistry
The Ohio State University
Columbus, OH 43210
woodward@chemistry.ohio-state.edu

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 Mastering Chemistry. 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.

Student's Guide (0-321-70458-4) 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 (0-321-70548-3) 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 (0-321-70501-7) 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 (0-321-70502-5) Prepared by John H. Nelson and Kenneth C. Kemp, both of the University of Nevada, with contributions by Matthew Stoltzfus of The Ohio State University. This manual contains 43 finely tuned experiments chosen to introduce students to basic lab techniques and to illustrate core chemical principles. This new edition has been revised to correlate more tightly with the text and now includes GIST questions and section references to 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 (0-321-70500-9) 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.

Instructor's Resource Center on CD-DVD (0-321-70503-3) This resource provides an integrated collection of resources to help instructors make efficient and effective use of their time. This DVD features all artwork from the text, including figures and tables in PDF format for high-resolution printing, as well as four 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 two presentations contain worked "in-chapter" sample exercises and questions to be used with Classroom Response Systems. This DVD also contains movies, animations, and electronic files of the Instructor's Resource Manual, as well as the Test Item File.

Printed Testbank (0-321-70497-5) Prepared by Joseph P. Laurino of the University of Tampa. The Test Item File now provides a selection of more than 4000 test questions with 300 new questions in the twelfth edition and 200 additional algorithmic questions.

Instructor's Resource Manual (0-321-70499-1) 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.

Transparencies (0-321-70498-3) Approximately 275 full-color transparencies put principles into visual perspective and save you time when preparing lectures.

Annotated Instructor's Edition to Laboratory Experiments (0-321-71197-1) Prepared by John H. Nelson and Kenneth C. Kemp, both of the University of Nevada, 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)
978-0-321-70506-8 / 0-321-70506-8

Blackboard Test Item File (IRC download only)
978-0-321-70507-5 / 0-321-70507-6

ABOUT THE AUTHORS

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. 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.

A GUIDE TO USING THIS TEXT

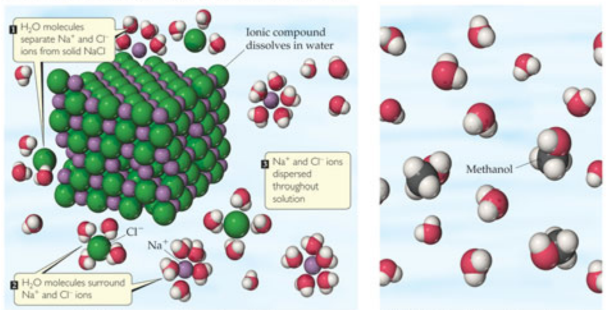
■ *Chemistry: The Central Science* has been the leader in general chemistry for decades. Now, its unrivaled problems, scientific accuracy, and clarity have been upheld and are woven seamlessly with each new feature. The **Twelfth Edition** is this text's most ambitious revision to date; every word and piece of art has been scrutinized for effectiveness by all five authors, and many revisions are based on student performance data gathered through MasteringChemistry.®

Visualizing concepts makes chemistry accessible

Chemistry is by nature an abstract subject. First, it relies on a symbolic language based on chemical formulas and equations. Second, it is based on the behavior of atoms and molecules—particles far too small to see. By presenting chemistry visually, the authors help you to "see" the chemistry you need to learn and increase your success in the course.

GO FIGURE

Which solution, NaCl(*aq*) or CH_3OH(*aq*), conducts electricity?



(a) Ionic compounds like sodium chloride, NaCl, form ions when they dissolve

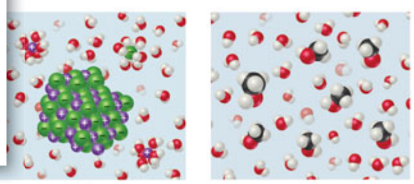
(b) Molecular substances like methanol, CH_3OH, dissolve without forming ions

▲ FIGURE 4.3 **Dissolution in water.** (a) When an ionic compound, such as sodium chloride, NaCl, dissolves in water, H_2O molecules separate, surround, and uniformly disperse the ions into the liquid. (b) Molecular substances that dissolve in water, such as methanol, CH_3OH, usually do so without forming ions. We can think of this as a simple mixing of two molecular species. In both (a) and (b) the water molecules have been moved apart so that the solute particles can be seen clearly.

Twelfth Edition

Molecular Illustrations

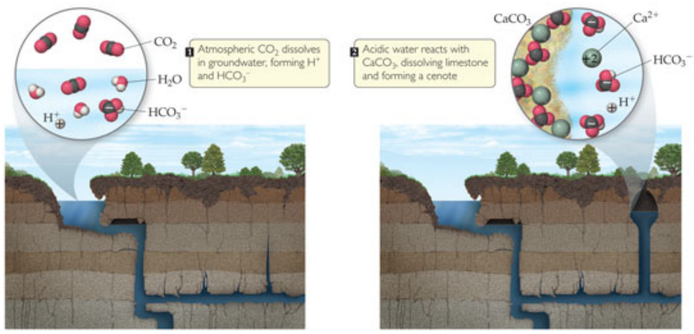
Molecular Illustrations are computer-generated renditions of molecules and materials that represent matter visually at the atomic level. These drawings help you visualize molecules in three dimensions, and enhance your understanding of molecular architecture.



(a) (b)

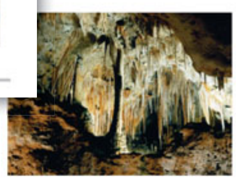
▲ Figure 4.3 **Dissolution in water.** (a) When an ionic compound dissolves in water, H_2O molecules separate, surround, and disperse the ions into the liquid. (b) Methanol, CH_3OH, a molecular compound, dissolves without forming ions. The methanol molecules contain black spheres, which represent carbon atoms. In both parts (a) and (b) the water molecules have been moved apart so that the solute particles can be seen more clearly.

Eleventh Edition



▲ FIGURE 4.1 Cenote formation.

Twelfth Edition

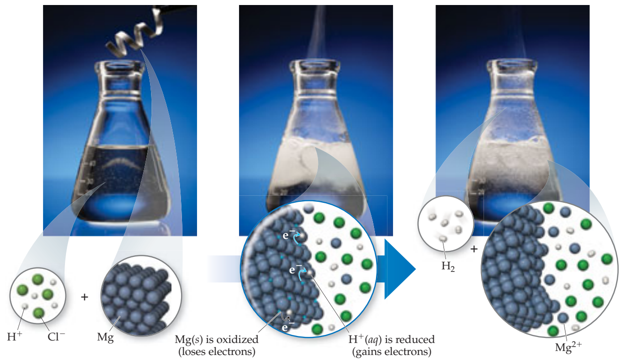


▲ Figure 4.1 **Limestone cave.** When CO_2 dissolves in water, the resulting solution is slightly acidic. Limestone caves are formed by the dissolving action of this acidic solution acting on $CaCO_3$ in the limestone.

Eleventh Edition

Multi-Focus Graphics

To help you develop a more complete understanding of the topic presented, **Multi-Focus Graphics** provide macroscopic, microscopic, and symbolic perspectives to portray various chemical concepts. The Twelfth Edition adds to these graphics an intermediate process that shows you where chemistry is occurring in problem solving.



Reactants $\quad$ *Products*

$$2\,HCl(aq) + Mg(s) \longrightarrow H_2(g) + MgCl_2(aq)$$

Oxidation number $\quad +1\ -1 \quad 0 \qquad\qquad 0 \quad +2\ -1$

▲ **FIGURE 4.13** **Reaction of magnesium metal with hydrochloric acid.** The metal is readily oxidized by the acid, producing hydrogen gas, $H_2(g)$, and $MgCl_2(aq)$.

Macro to Micro Art

These illustrations offer three parts: a macroscopic image (what you can see with your eyes); a molecular image (what the molecules are doing); and a symbolic representation (how chemists represent the process with symbols and equations).

A new intermediate step has been added, showing where chemistry occurs in the problem-solving process.

A focus on relevance makes chemistry meaningful

Chemistry occurs all around us, throughout every day. Recognizing the importance of chemistry in your daily life can improve your understanding of chemical concepts.

CHEMISTRY PUT TO WORK

Antacids

Your stomach secretes acids to help digest foods. These acids, which include hydrochloric acid, contain about 0.1 mol of H^+ per liter of solution. The stomach and digestive tract are normally protected from the corrosive effects of stomach acid by a mucosal lining. Holes can develop in this lining, however, allowing the acid to attack the underlying tissue, causing painful damage. These holes, known as ulcers, can be caused by the secretion of excess acids or by a weakness in the digestive lining. Studies indicate, however, that many ulcers are caused by bacterial infection. Between 10 and 20% of Americans suffer from ulcers at some point in their lives. Many others experience occasional indigestion or heartburn due to digestive acids entering the esophagus.

We can address the problem of excess stomach acid in two ways: (1) removing the excess acid or (2) decreasing the production of acid. Substances that remove excess acid are called *antacids*, whereas those that decrease acid production are called *acid inhibitors*. ◀ FIGURE 4.10 shows several common over-the-counter antacids, which usually contain hydroxide, carbonate, or bicarbonate ions (▼ TABLE 4.4). Antiulcer drugs, such as Tagamet® and Zantac®, are acid inhibitors. They act on acid-producing cells in the lining of the stomach. Formulations that control acid in this way are now available as over-the-counter drugs.

RELATED EXERCISE: 4.95

▲ **FIGURE 4.10** **Antacids.** These products all serve as acid-neutralizing agents in the stomach.

TABLE 4.4 • Some Common Antacids

Commercial Name	Acid-Neutralizing Agents
Alka-Seltzer®	$NaHCO_3$
Amphojel®	$Al(OH)_3$
Di-Gel®	$Mg(OH)_2$ and $CaCO_3$
Milk of Magnesia	$Mg(OH)_2$
Maalox®	$Mg(OH)_2$ and $Al(OH)_3$
Mylanta®	$Mg(OH)_2$ and $Al(OH)_3$
Rolaids®	$NaAl(OH)_2CO_3$
Tums®	$CaCO_3$

Chemistry Put to Work and Chemistry and Life

Chemistry's connection to world events, scientific discoveries, and medical breakthroughs are showcased in **Chemistry and Life** and **Chemistry Put to Work** features throughout the text.

CHEMISTRY AND LIFE

DRINKING TOO MUCH WATER CAN KILL YOU

For a long time dehydration was considered a potential danger for people engaged in extended vigorous activity. Thus, athletes were encouraged to drink lots of water while engaged in active sport. The trend toward extensive hydration has spread throughout society, so that today many people carry water bottles everywhere and dutifully keep well hydrated.

In some circumstances, however, drinking too much water is a greater danger than not drinking enough. Excess water consumption can lead to *hyponatremia*, a condition in which the concentration of sodium ion in the blood is too low. In the past decade at least four marathon runners have died from hyponatremia-related trauma, and dozens more have become seriously ill. For example, a first-time marathoner named Hillary Bellamy, running in the Marine Corps marathon in 2003, collapsed near mile 22 and died the next day. One physician who treated her said that she died from hyponatremia-induced brain swelling, the result of drinking too much water before and during the race.

The normal blood sodium level is 135 to 145 m*M* (*millimolar*). When that level drops to 125 m*M*, dizziness and confusion set in. A concentration below 120 m*M* can be critical. Dangerously low levels can occur in any active athlete who is sweating out salt (NaCl) at the same time that excessive amounts of NaCl-free water are being drunk to compensate for water loss. The condition affects women more than men because of differences in body composition and patterns of metabolism. Drinking a sport drink that contains some electrolytes helps to prevent hyponatremia.

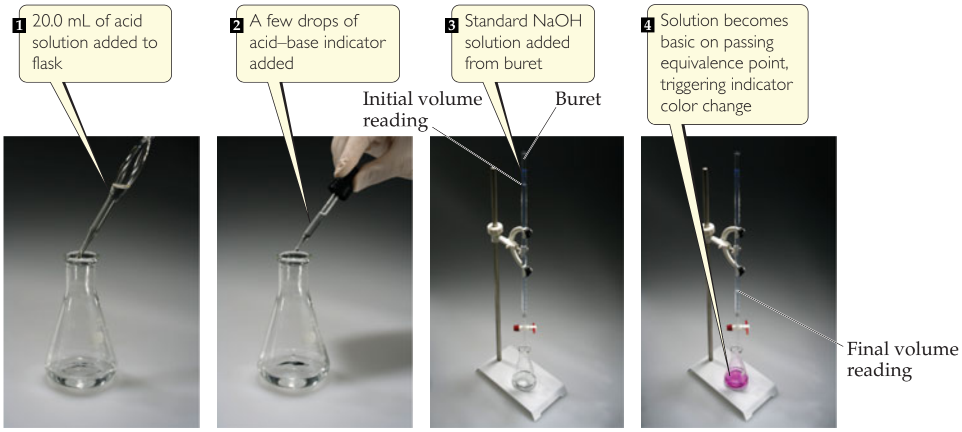
RELATED EXERCISES: 4.63, 4.64

CONCEPTUAL UNDERSTANDING BRINGS CHEMISTRY TO LIFE

The authors help you achieve a deeper understanding of concepts through a variety of learning aids, including **Give it Some Thought** and NEW! **Go Figure** questions.

GO FIGURE

How would the volume of standard solution added change if that solution were $Ba(OH)_2(aq)$ instead of $NaOH(aq)$?



▲ **FIGURE 4.19 Procedure for titrating an acid against a standard solution of NaOH.** The acid–base indicator, phenolphthalein, is colorless in acidic solution but takes on a pink color in basic solution.

NEW! Go Figure questions

Go Figure questions encourage you to stop and analyze the artwork in the text, for conceptual understanding. "Voice Balloons" in selected figures help you break down and understand the components of the image. These questions are also available in MasteringChemistry.

GIVE IT SOME THOUGHT

What is the principal reason we must consider the uncertainty principle when discussing electrons and other subatomic particles but not when discussing our macroscopic world?

Give It Some Thought (GIST) questions

These informal, sharply focused exercises give you opportunities to test whether you are "getting it" as you read along. We've increased the number of GIST questions in the Twelfth Edition.

PROBLEM-SOLVING SKILLS HELP YOU SUCCEED IN YOUR COURSE

A consistent problem-solving process is incorporated throughout, so you'll always know where to go when solving problems.

SAMPLE EXERCISE 5.6 **Measuring ΔH Using a Coffee-Cup Calorimeter**

When a student mixes 50 mL of 1.0 M HCl and 50 mL of 1.0 M NaOH in a coffee-cup calorimeter, the temperature of the resultant solution increases from 21.0 °C to 27.5 °C. Calculate the enthalpy change for the reaction in kJ/mol HCl, assuming that the calorimeter loses only a negligible quantity of heat, that the total volume of the solution is 100 mL, that its density is 1.0 g/mL, and that its specific heat is 4.18 J/g-K.

SOLUTION

Analyze Mixing solutions of HCl and NaOH results in an acid–base reaction:

$$HCl(aq) + NaOH(aq) \longrightarrow H_2O(l) + NaCl(aq)$$

We need to calculate the heat produced per mole of HCl, given the temperature increase of the solution, the number of moles of HCl and NaOH involved, and the density and specific heat of the solution.

Plan The total heat produced can be calculated using Equation 5.23. The number of moles of HCl consumed in the reaction must be calculated from the volume and molarity of this substance, and this amount is then used to determine the heat produced per mol HCl.

Solve

Because the total volume of the solution is 100 mL, its mass is	$(100\ mL)(1.0\ g/mL) = 100\ g$
The temperature change is	$\Delta T = 27.5\ °C - 21.0\ °C = 6.5\ °C = 6.5\ K$
Using Equation 5.23, we have	$q_{rxn} = -C_s \times m \times \Delta T$ $= -(4.18\ J/g\text{-}K)(100\ g)(6.5\ K) = -2.7 \times 10^3\ J = -2.7\ kJ$
Because the process occurs at constant pressure,	$\Delta H = q_P = -2.7\ kJ$
To express the enthalpy change on a molar basis, we use the fact that the number of moles of HCl is given by the product of the volume (50 mL = 0.050 L) and concentration (1.0 M = 1.0 mol/L) of the HCl solution:	$(0.050\ L)(1.0\ mol/L) = 0.050\ mol$
Thus, the enthalpy change per mole of HCl is	$\Delta H = -2.7\ kJ/0.050\ mol = -54\ kJ/mol$

Check ΔH is negative (exothermic), which is expected for the reaction of an acid with a base and evidenced by the fact that the reaction causes the temperature of the solution to increase. The magnitude of the molar enthalpy change seems reasonable.

PRACTICE EXERCISE

When 50.0 mL of 0.100 M $AgNO_3$ and 50.0 mL of 0.100 M HCl are mixed in a constant-pressure calorimeter, the temperature of the mixture increases from 22.30 °C to 23.11 °C. The temperature increase is caused by the following reaction:

$$AgNO_3(aq) + HCl(aq) \longrightarrow AgCl(s) + HNO_3(aq)$$

Calculate ΔH for this reaction in kJ/mol $AgNO_3$, assuming that the combined solution has a mass of 100.0 g and a specific heat of 4.18 J/g °C.

Answer: −68,000 J/mol = −68 kJ/mol

Analyze/Plan/Solve/Check

This four-step problem-solving method helps you understand what you are being asked to solve, to plan how you will solve each problem, to work your way through the solution, and to check your answers. This method is introduced in Chapter 3 and reinforced throughout the book.

Dual-Column Problem-Solving Strategies

Found in Selected Sample Exercises, these strategies explain the thought process involved in each step of a mathematical calculation using a unique layout for clarity. They help you develop a conceptual understanding of those calculations.

STRATEGIES IN CHEMISTRY

PROBLEM SOLVING

Practice is the key to success in solving problems. As you practice, you can improve your skills by following these steps:

Step 1: Analyze the problem. Read the problem carefully. What does it say? Draw a picture or diagram that will help you to visualize the problem. Write down both the data you are given and the quantity you need to obtain (the unknown).

Step 2: Develop a plan for solving the problem. Consider a possible path between the given information and the unknown. What principles or equations relate the known data to the unknown? Recognize that some data may not be given explicitly in the problem; you may be expected to know certain quantities (such as Avogadro's number) or look them up in tables (such as atomic weights). Recognize also that your plan may involve either a single step or a series of steps with intermediate answers.

Step 3: Solve the problem. Use the known information and suitable equations or relationships to solve for the unknown. Dimensional analysis (Section 1.6) is a useful tool for solving a great number of problems. Be careful with significant figures, signs, and units.

Step 4: Check the solution. Read the problem again to make sure you have found all the solutions asked for in the problem. Does your answer make sense? That is, is the answer outrageously large or small or is it in the ballpark? Finally, are the units and significant figures correct?

Strategies in Chemistry

Strategies in Chemistry teach ways to analyze information and organize thoughts, helping to improve your problem-solving and critical-thinking abilities.

UPDATED END-OF-CHAPTER MATERIALS BOOST YOUR COMPREHENSION

Unique to the Twelfth Edition, the end-of-chapter materials have been updated and streamlined based on student performance data gathered through MasteringChemistry. Only content that has proven to increase student comprehension of fundamental concepts has been retained.

CHAPTER SUMMARY AND KEY TERMS

INTRODUCTION AND SECTION 3.1 The study of the quantitative relationships between chemical formulas and chemical equations is known as **stoichiometry**. One of the important concepts of stoichiometry is the law of conservation of mass, which states that the total mass of the products of a chemical reaction is the same as the total mass of the reactants. The same numbers of atoms of each type are present before and after a chemical reaction. A balanced **chemical equation** shows equal numbers of atoms of each element on each side of the equation. Equations are balanced by placing coefficients in front of the chemical formulas for the **reactants** and **products** of a reaction, *not* by changing the subscripts in chemical formulas.

SECTION 3.2 Among the reaction types described in this chapter are (1) **combination reactions**, in which two reactants combine to form one product; (2) **decomposition reactions**, in which a single reactant forms two or more products; and (3) **combustion reactions** in oxygen, in which a hydrocarbon or related compound reacts with O_2 to form CO_2 and H_2O.

SECTION 3.3 Much quantitative information can be determined from chemical formulas and balanced chemical equations by using atomic weights. The **formula weight** of a compound equals the sum of the atomic weights of the atoms in its formula. If the formula is a molecular formula, the formula weight is also called the **molecular weight**. Atomic weights and formula weights can be used to determine the elemental composition of a compound.

SECTION 3.4 A mole of any substance is **Avogadro's number** (6.02×10^{23}) of formula units of that substance. The mass of a **mole** of atoms, molecules, or ions (the **molar mass**) equals the formula weight of that material expressed in grams. The mass of one molecule of H_2O, for example, is 18 amu, so the mass of 1 mol of H_2O is 18 g. That is, the molar mass of H_2O is 18 g/mol.

SECTION 3.5 The empirical formula of any substance can be determined from its percent composition by calculating the relative number of moles of each atom in 100 g of the substance. If the substance is molecular in nature, its molecular formula can be determined from the empirical formula if the molecular weight is also known.

SECTIONS 3.6 AND 3.7 The mole concept can be used to calculate the relative quantities of reactants and products in chemical reactions. The coefficients in a balanced equation give the relative numbers of moles of the reactants and products. To calculate the number of grams of a product from the number of grams of a reactant, first convert grams of reactant to moles of reactant. Then use the coefficients in the balanced equation to convert the number of moles of reactant to moles of product. Finally, convert moles of product to grams of product.

A **limiting reactant** is completely consumed in a reaction. When it is used up, the reaction stops, thus limiting the quantities of products formed. The **theoretical yield** of a reaction is the quantity of product calculated to form when all of the limiting reactant reacts. The actual yield of a reaction is always less than the theoretical yield. The **percent yield** compares the actual and theoretical yields.

Summary with Key Terms

These list all of the chapter's boldfaced items, organized by section in order of appearance, with page references. Definitions are found in the Glossary.

KEY EQUATIONS

• $E_{el} = \dfrac{\kappa Q_1 Q_2}{d}$	[8.4]	The potential energy of two interacting charges
• $\mu = Qr$	[8.11]	The dipole moment of two charges of equal magnitude but opposite sign, separated by a distance r
• $\Delta H_{rxn} = \Sigma$(bond enthalpies of bonds broken) − Σ(bond enthalpies of bonds formed)	[8.12]	The enthalpy change as a function of bond enthalpies for reactions involving gas-phase molecules

Key Equations

The **Key Equations** section lists each of the key equations and important quantitative relationships from the chapter.

KEY SKILLS

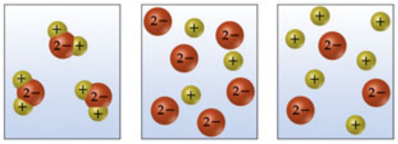
- Write Lewis symbols for atoms and ions. (Section 8.1)
- Understand lattice energy and be able to arrange compounds in order of increasing lattice energy based on the charges and sizes of the ions involved. (Section 8.2)
- Use atomic electron configurations and the octet rule to write Lewis structures for molecules to determine their electron distribution. (Section 8.3)
- Use electronegativity differences to identify nonpolar covalent, polar covalent, and ionic bonds. (Section 8.4)
- Calculate charge separation in diatomic molecules based on the experimentally measured dipole moment and bond distance. (Section 8.4)
- Calculate formal charges from Lewis structures and use those formal charges to identify the dominant Lewis structure for a molecule or ion. (Section 8.5)
- Recognize molecules where resonance structures are needed to describe the bonding. (Section 8.6)
- Recognize exceptions to the octet rule and draw accurate Lewis structures even when the octet rule is not obeyed. (Section 8.7)
- Understand the relationship between bond type (single, double, and triple), bond strength (or enthalpy), and bond length. (Section 8.8)
- Use bond enthalpies to estimate enthalpy changes for reactions involving gas-phase reactants and products. (Section 8.8)

Key Skills

The **Key Skills** section in each chapter lists the fundamental concepts you should comprehend.

VISUALIZING CONCEPTS

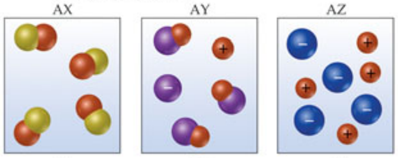
4.1 Which of the following schematic drawings best describes a solution of Li_2SO_4 in water (water molecules not shown for simplicity)? [Section 4.1]



(a) (b) (c)

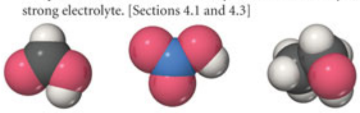
4.2 Aqueous solutions of three different substances, AX, AY, and AZ, are represented by the three accompanying diagrams. Identify each substance as a strong electrolyte, weak electrolyte, or nonelectrolyte. [Section 4.1]

AX AY AZ



(a) (b) (c)

4.3 Use the molecular representations shown here to classify each compound as either a nonelectrolyte, a weak electrolyte, or a strong electrolyte. [Sections 4.1 and 4.3]

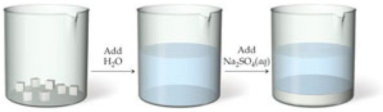


(a) (b) (c)

See inside back cover for element color scheme.

4.4 A 0.1 *M* solution of acetic acid, CH_3COOH, causes the lightbulb in the apparatus of Figure 4.2 to glow about as brightly as a 0.001 *M* solution of HBr. How do you account for this fact? [Section 4.1]

4.5 You are presented with a white solid and told that due to careless labeling it is not clear if the substance is barium chloride, lead chloride, or zinc chloride. When you transfer the solid to a beaker and add water, the solid dissolves to give a clear solution. Next a $Na_2SO_4(aq)$ solution is added and a white precipitate forms. What is the identity of the unknown white solid? [Section 4.2]



4.6 We have seen that ions in aqueous solution are stabilized by the attractions between the ions and the water molecules. Why then do some pairs of ions in solution form precipitates? [Section 4.2]

4.7 Which of the following ions will *always* be a spectator ion in a precipitation reaction? **(a)** Cl^-, **(b)** NO_3^-, **(c)** NH_4^+, **(d)** S^{2-}, **(e)** SO_4^{2-}. Explain briefly. [Section 4.2]

4.8 The labels have fallen off three bottles containing powdered samples of metals; one contains zinc, one lead, and the other platinum. You have three solutions at your disposal: 1 *M* sodium nitrate, 1 *M* nitric acid, and 1 *M* nickel nitrate. How could you use these solutions to determine the identities of each metal powder? [Section 4.4]

4.9 Explain how a redox reaction involves electrons in the same way that a neutralization reaction involves protons. [Sections 4.3 and 4.4]

4.10 If you want to double the concentration of a solution, how could you do it? [Section 4.5]

Visualizing Concepts

Visualizing Concepts exercises begin the end-of-chapter exercises and ask you to consider concepts through the use of models, graphs, and other visual materials. These help you develop a conceptual understanding of the key ideas in the chapter. Additional conceptual exercises are found among the end-of-chapter exercises.

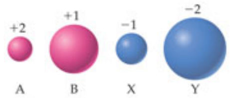
EXERCISES

VISUALIZING CONCEPTS

8.1 For each of these Lewis symbols, indicate the group in the periodic table in which the element X belongs: [Section 8.1]

(a) $\cdot\ddot{X}\cdot$ (b) $\cdot X \cdot$ (c) $:\ddot{X}\cdot$

8.2 Illustrated are four ions—A, B, X, and Y— showing their relative ionic radii. The ions shown in red carry positive charges: a



Exercises

End-of-Chapter Exercises are grouped by topic and presented in matched pairs based on data gathered from MasteringChemistry, giving you multiple opportunities to test each concept.

INTEGRATIVE EXERCISES

6.97 Microwave ovens use microwave radiation to heat food. The energy of the microwaves is absorbed by water molecules in food and then transferred to other components of the food. **(a)** Suppose that the microwave radiation has a wavelength of 11.2 cm. How many photons are required to heat 200 mL of coffee from 23 °C to 60 °C? **(b)** Suppose the microwave's power is 900 W (1 Watt = 1 joule-second). How long would you have to heat the coffee in part (a)?

6.98 The stratospheric ozone (O_3) layer helps to protect us from harmful ultraviolet radiation. It does so by absorbing ultraviolet light and falling apart into an O_2 molecule and an oxygen atom, a process known as photodissociation.

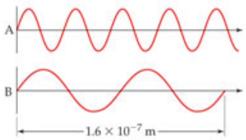
$$O_3(g) \longrightarrow O_2(g) + O(g)$$

Use the data in Appendix C to calculate the enthalpy change for this reaction. What is the maximum wavelength a photon can have if it is to possess sufficient energy to cause this dissociation? In what portion of the spectrum does this wavelength occur?

ADDITIONAL EXERCISES

6.75 Consider the two waves shown here, which we will consider to represent two electromagnetic radiations:

(a) What is the wavelength of wave A? Of wave B?
(b) What is the frequency of wave A? Of wave B?
(c) Identify the regions of the electromagnetic spectrum to which waves A and B belong.



[4.114] The newest US standard for arsenate in drinking water, mandated by the Safe Drinking Water Act, required that by January 2006, public water supplies must contain no greater than 10 parts per billion (ppb) arsenic. If this arsenic is present as arsenate, AsO_4^{3-}, what mass of sodium arsenate would be present in a 1.00-L sample of drinking water that just meets the standard? Parts per billion is defined on a mass basis as

$$\text{ppb} = \frac{\text{g solute}}{\text{g solution}} \times 10^9.$$

Integrative Exercises

Included among the exercises at the end of Chapters 3-24, **Integrative Exercises** connect concepts for the current chapter with those from previous chapters. These help you gain a deeper understanding of how chemistry fits together and serve as an overall review of key concepts.

Additional Exercises

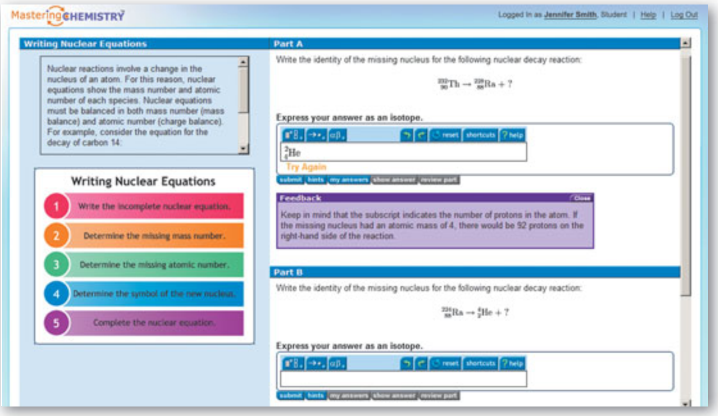
Additional Exercises follow the paired exercises and are not categorized, because many of these exercises draw on multiple concepts from within the chapter.

Bracketed Challenge Problems

The Bracketed Challenge Problems have been revised for the Twelfth Edition, based on student performance data gathered through MasteringChemistry reflecting the difficulty of the problem.

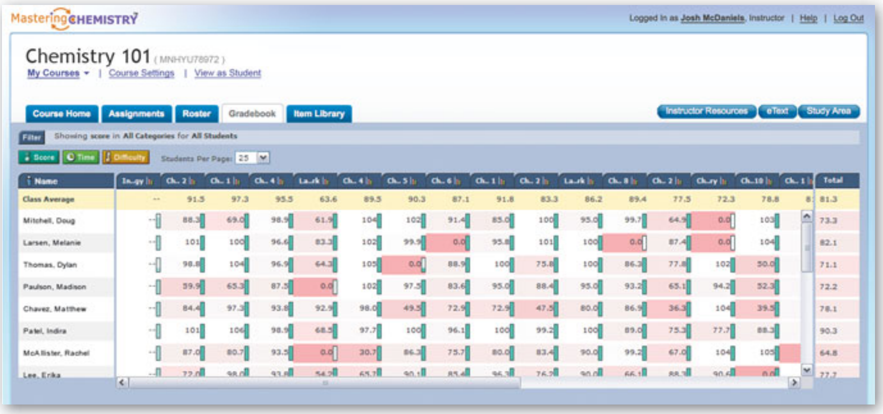
PERSONALIZED COACHING AND FEEDBACK AT YOUR FINGERTIPS

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. To learn more, visit **www.masteringchemistry.com**



Student Tutorials

MasteringChemistry is the only system to provide instantaneous feedback specific to the most-common wrong answers. Students can submit an answer and receive immediate, error-specific feedback. Simpler sub-problems—"hints"—are provided upon request.



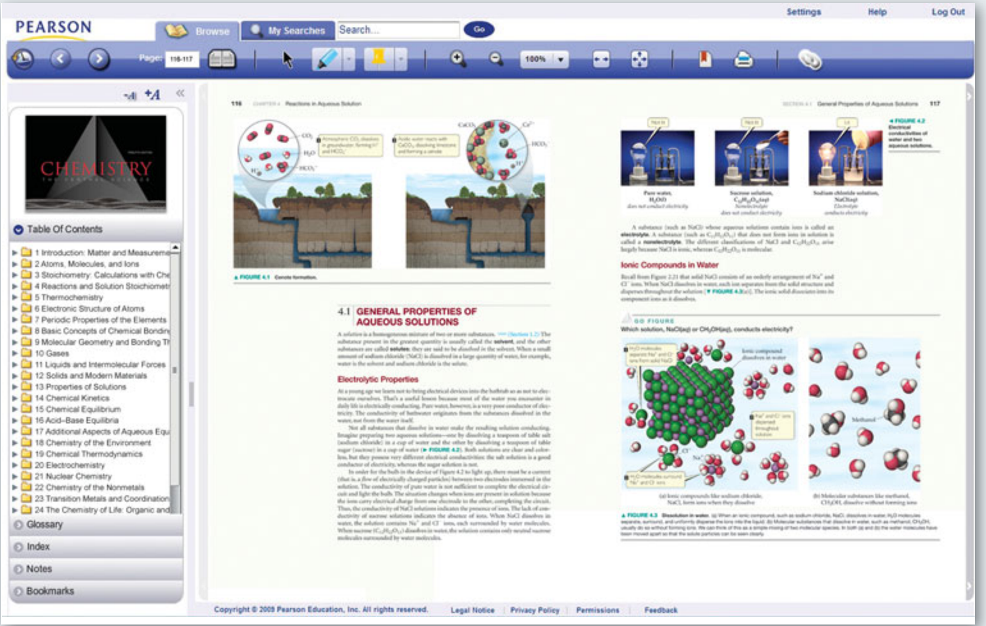
Gradebook

MasteringChemistry is the only system to capture the step-by-step work of each student in class, including wrong answers submitted, hints requested, and time taken on every step. This data powers an unprecedented gradebook.

Student Performance Snapshot

This screen provides your favorite weekly diagnostics. With a single click, charts summarize the most difficult problems, vulnerable students, grade distribution, and even score improvement over the course.

EXTEND LEARNING BEYOND THE CLASSROOM



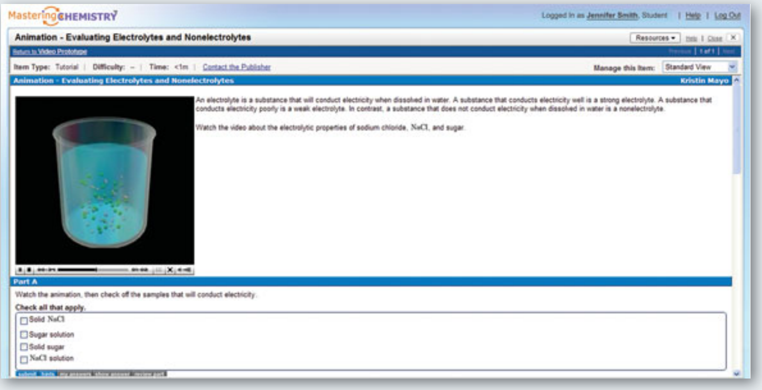
Pearson eText

The eText gives students access to the text whenever and wherever they can access the Internet. The eText pages look exactly like the printed text, and include powerful interactive and customization features.

Students can:

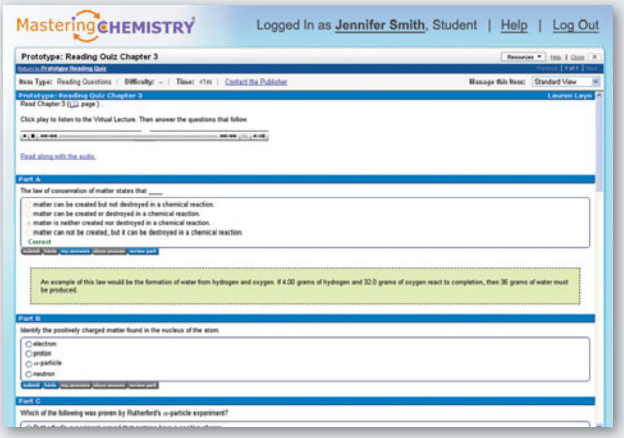
- Create notes, highlight text in different colors, create book marks, zoom, click hyperlinked words and phrases to view definitions, and view in single-page or two-page format.
- Link directly to associated media files, enabling them to view an animation as they read the text.
- Perform a full-text search and save or export notes.

Instructors can share their notes and highlights with students, and can also hide chapters that they do not want students to read.



NEW! Visualizations

These new tutorials enable you to make connections between real-life phenomena and the underlying chemistry that explains such phenomena. The tutorials increase your understanding of chemistry and clearly illustrate cause-and-effect relationships.



NEW! Reading Quizzes

Chapter-specific quizzes and activities focus on important, hard-to-grasp chemistry concepts.

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.

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*.

HUBBLE SPACE TELESCOPE IMAGE of the Omega Nebula, a 15-light-year-wide expanding remnant of a star's supernova explosion. The orange filaments are the tattered remains of the star and consist mostly of hydrogen, the simplest and most plentiful element in the universe. Hydrogen occurs as molecules in cool regions of the nebula, as atoms in hotter regions, and as ions in the hottest regions. The processes that occur within stars are responsible for creating other chemical elements from hydrogen.

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.

INTRODUCTION: MATTER AND MEASUREMENT

HAVE YOU EVER WONDERED why the stars shine? Or why leaves change color in the fall or how a battery generates electricity? Have you ever wondered why keeping foods cold slows their spoilage and how our bodies use food to maintain life? Chemistry answers these questions as well as countless others.

Chemistry is the study of matter and the changes that matter undergoes. One of the joys of learning chemistry is seeing how chemical principles operate in all aspects of our lives, from everyday activities like cooking dinner to more complex processes like the development of drugs to cure cancer. Chemical principles also operate in the far reaches of our galaxy (chapter-opening photograph) as well as within and around us.

This first chapter provides an overview of what chemistry is about and what chemists do. The preceding "What's Ahead" list gives an overview of the chapter organization and of some of the ideas we will consider. As you study, keep in mind that the chemical facts and concepts you are asked to learn are not ends in themselves; they are tools to help you better understand the world around you.

1.1 THE STUDY OF CHEMISTRY

Before traveling to an unfamiliar city, you might look at a map to get some sense of where you are heading. Because chemistry may be unfamiliar to you, it's useful to get a general idea of what lies ahead before you embark on your journey. In fact, you might even ask why you are taking the trip.

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. Countless experiments have shown that the tremendous variety of matter in our world is due to combinations of only about 100 substances called **elements**. As we proceed through this text, we will seek to relate the properties of matter to its composition, that is, to the particular elements it contains.

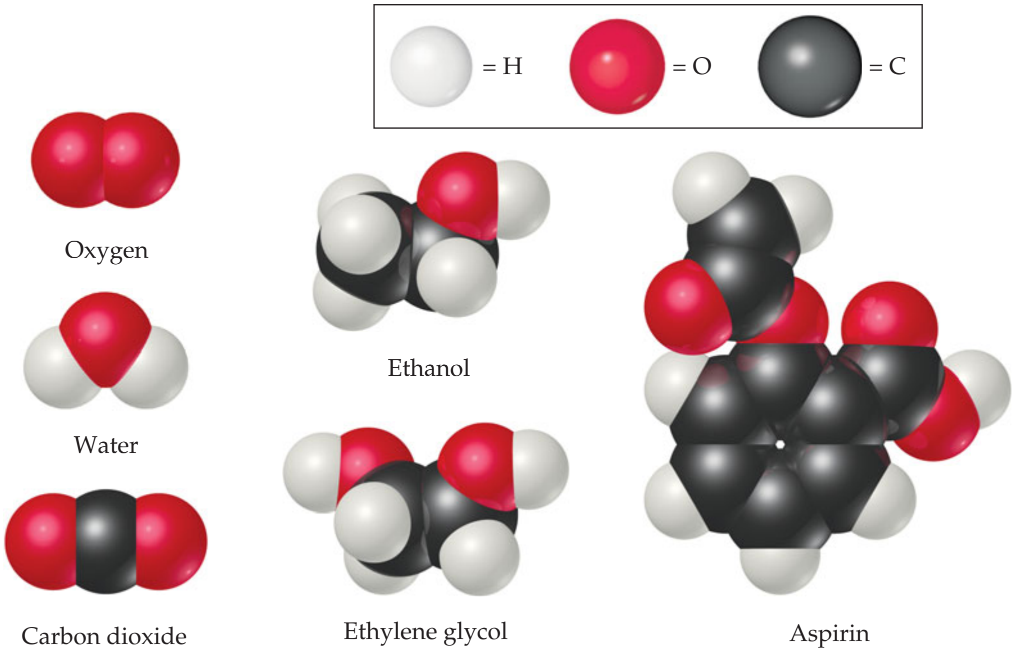
Chemistry also provides a background for understanding the properties of matter in terms of **atoms**, the almost infinitesimally small building blocks of matter. Each element is composed of a unique kind of atom. We will see that the properties of matter relate to both the kinds of atoms the matter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

In **molecules**, two or more atoms are joined together 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. Ethanol, for example, is the alcohol in

GO FIGURE

How many carbon atoms are in one aspirin molecule?



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

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.

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 in order 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.

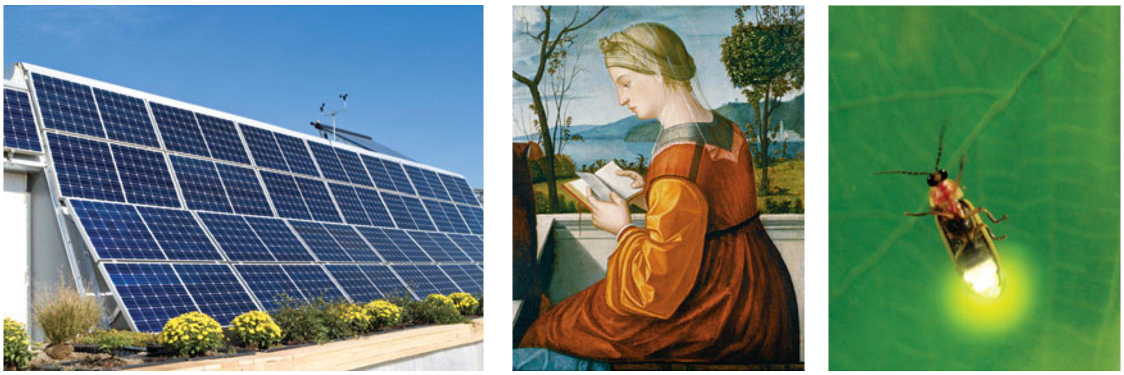
GIVE IT SOME THOUGHT

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

Why Study Chemistry?

Chemistry greatly impacts our daily lives. Indeed, chemistry lies near the heart of many matters of public concern: improvement of health care, conservation of natural resources, protection of the environment, and provision of our daily needs for food, clothing, and shelter. Using chemistry, we have discovered pharmaceutical chemicals that enhance health and prolong lives. We have increased food production through the use of fertilizers and pesticides, and we have developed plastics and other materials used in almost every facet of our lives, from electronics to sporting equipment to building construction. Unfortunately, some chemicals can harm our health or the environment. As educated citizens and consumers, it is in our best interest to understand the profound effects, both positive and negative, that chemicals have on our lives and to strike an informed balance about their uses.

Most of you are studying chemistry, however, not merely to satisfy your curiosity or to become more informed consumers or citizens but also because it is an essential part of your curriculum. Your major might be chemistry, but it could be biology, engineering, pharmacy, agriculture, geology, or some other field. Why do so many subjects share an essential tie to chemistry? The answer is that chemistry is the *central science,* central to a fundamental understanding of other sciences and technologies. For example, our interactions with the material world raise basic questions about the materials around us. What are their compositions and properties? How do they interact with us and with our environment? How, why, and when do materials undergo change? These questions are important whether the material is part of a solar cell, a pigment used by a Renaissance painter, or a living creature (▼ **FIGURE 1.2**).



(a) (b) (c)

◀ **FIGURE 1.2** **Chemistry helps us understand the world around us.**
(a) Solar cells are made of silicon. (b) A Renaissance painting, *Young Girl Reading,* by Vittore Carpaccio (1472–1526), uses pigments that keep their color for years.
(c) The light from this firefly is the result of a chemical reaction within the animal.

By studying chemistry, you will learn to use the powerful language and ideas that have evolved to describe and enhance our understanding of matter. Furthermore, an understanding of chemistry provides powerful insights into other areas of modern science, technology, and engineering.

CHEMISTRY PUT TO WORK

Chemistry and the Chemical Industry

Chemistry is all around us. Many people are familiar with household chemicals such as those shown in ▶ FIGURE 1.3, but few realize the size and importance of the chemical industry. Worldwide sales of chemicals and related products manufactured in the United States total approximately \$550 billion annually. The chemical industry employs more than 10% of all scientists and engineers and is a major contributor to the US economy.

Vast amounts of chemicals are produced each year and serve as raw materials for a variety of uses, including the manufacture and processing of metals, plastics, fertilizers, pharmaceuticals, fuels, paints, adhesives, pesticides, synthetic fibers, and microprocessor chips. ▼ TABLE 1.1 lists the top eight chemicals produced in the United States.

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, work with 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 spend years working 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, or run computer simulations to understand how molecules move and react on very fast time scales. The collective chemical enterprise is a rich mix of all of these activities.

▶ **FIGURE 1.3 Common household chemicals.**

TABLE 1.1 • The Top Eight Chemicals Produced by the US Chemical Industry in 2008[a]

Rank	Chemical	Formula	2008 Production (Billions of Pounds)	Principal End Uses
1	Sulfuric acid	H_2SO_4	71	Fertilizers, chemical manufacturing
2	Ethylene	C_2H_4	50	Plastics, antifreeze
3	Lime	CaO	44	Paper, cement, steel
4	Propylene	C_3H_6	33	Plastics
5	Ammonia	NH_3	21	Fertilizers
6	Chlorine	Cl_2	21	Bleaches, plastics, water purification
7	Phosphoric acid	H_3PO_4	20	Fertilizers
8	Sodium hydroxide	$NaOH$	16	Aluminum production, soap

[a]Most data from *Chemical and Engineering News,* July 6, 2009, pp. 53, 56. Data on lime from U.S. Geological Survey.

1.2 CLASSIFICATIONS OF MATTER

Let's begin our study of chemistry by examining some fundamental ways in which matter is classified. Two principal ways of classifying matter are according to physical state (gas, liquid, or solid) and according to composition (element, compound, or mixture).

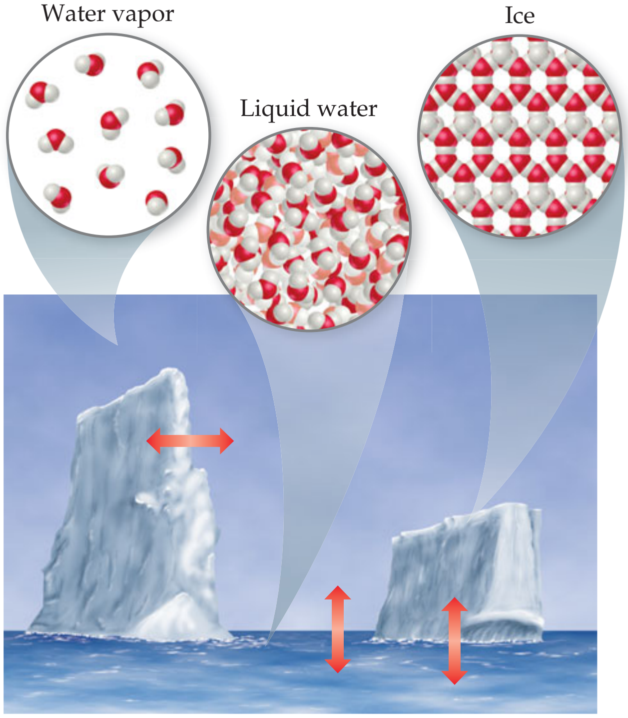
States of Matter

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 conforms to the volume and shape of 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 but has no specific shape. It 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. When we look at steam or clouds, we see tiny droplets of liquid water dispersed in the atmosphere. 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), the primary components of seawater, 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. For example, 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,