CHEMISTRY

fifth edition

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FIFTH EDITION

Chemistry

The Science in Context

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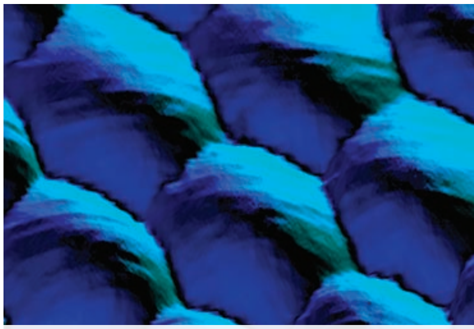

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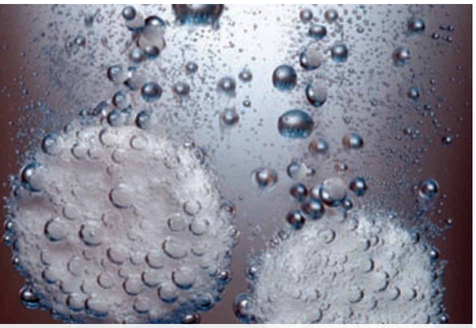

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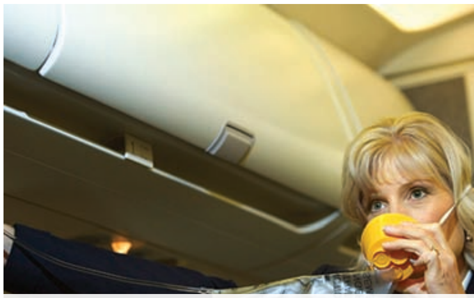

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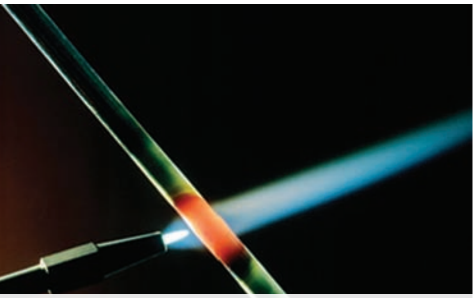

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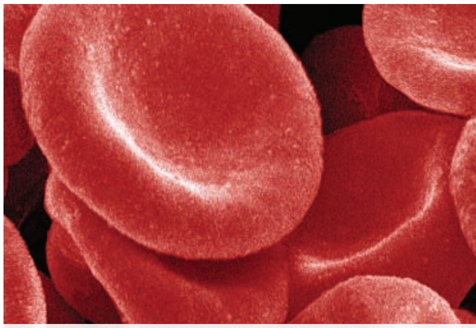

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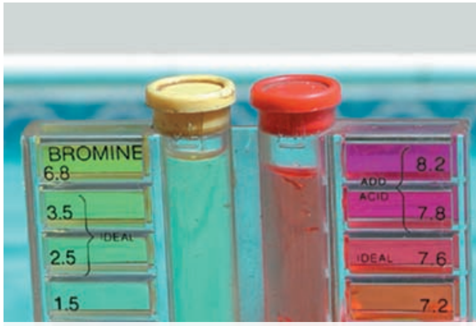

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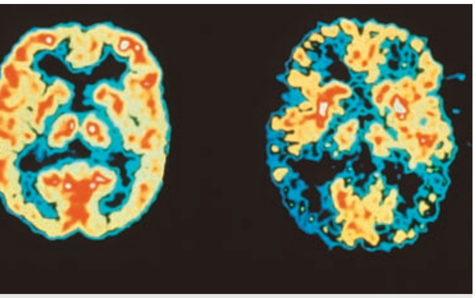

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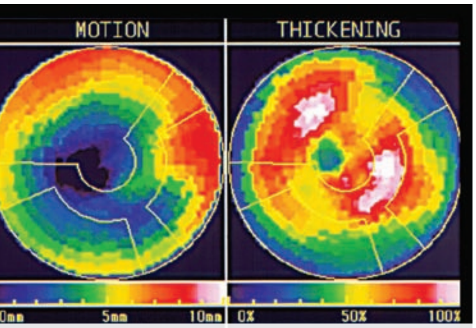

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About the **Authors**

Thomas R. Gilbert has a BS in chemistry from Clarkson and a PhD in analytical chemistry from MIT. After 10 years with the Research Department of the New England Aquarium in Boston, he joined the faculty of Northeastern University, where he is currently an associate professor of chemistry and chemical biology. His research interests are in chemical and science education. He teaches general chemistry and science education courses, and he conducts professional development workshops for K–12 teachers. He has won Northeastern's Excellence in Teaching Award and Outstanding Teacher of First-Year Engineering Students Award. He is a fellow of the American Chemical Society and in 2012 was elected to the American Chemical Society Board of Directors.

Rein V. Kirss received both a BS in chemistry and a BA in history as well as an MA in chemistry from SUNY Buffalo. He received his PhD in inorganic chemistry from the University of Wisconsin, Madison, where the seeds for this textbook were undoubtedly planted. After two years of postdoctoral study at the University of Rochester, he spent a year at Advanced Technology Materials, Inc., before returning to academics at Northeastern University in 1989. He is an associate professor of chemistry with an active research interest in organometallic chemistry.

Natalie Foster is an emeritus professor of chemistry at Lehigh University in Bethlehem, Pennsylvania. She received a BS in chemistry from Muhlenberg College and MS, DA, and PhD degrees from Lehigh University. Her research interests included studying poly(vinyl alcohol) gels by NMR as part of a larger interest in porphyrins and phthalocyanines as candidate contrast enhancement agents for MRI. She taught both semesters of the introductory chemistry class to engineering, biology, and other nonchemistry majors and a spectral analysis course at the graduate level. She is a fellow of the American Chemical Society and the recipient of the Christian R. and Mary F. Lindback Foundation Award for distinguished teaching.

Stacey Lowery Bretz is a University Distinguished Professor in the Department of Chemistry and Biochemistry at Miami University in Oxford, Ohio. She earned her BA in chemistry from Cornell University, MS from Pennsylvania State University, and a PhD in chemistry education research from Cornell University. Stacey then spent one year at the University of California, Berkeley, as a postdoc in the Department of Chemistry. Her research expertise includes the development of assessments to characterize chemistry misconceptions and measure learning in the chemistry laboratory. Of particular interest is method development with regard to the use of multiple representations (particulate, symbolic, and macroscopic) to generate cognitive dissonance, including protocols for establishing the reliability and validity of these measures. She is a fellow of both the American Chemical Society and the American Association for the Advancement of Science. She has been honored with both of Miami University's highest teaching awards: the E. Phillips Knox Award for Undergraduate Teaching in 2009 and the Distinguished Teaching Award for Excellence in Graduate Instruction and Mentoring in 2013.

Geoffrey Davies holds BSc, PhD, and DSc degrees in chemistry from Birmingham University, England. He joined the faculty at Northeastern University in 1971 after doing postdoctoral research on the kinetics of very rapid reactions at Brandeis University, Brookhaven National Laboratory, and the University of Kent at Canterbury. He is now a Matthews Distinguished University Professor at Northeastern University. His research group has explored experimental and theoretical redox chemistry, alternative fuels, transmetalation reactions, tunable metal–zeolite catalysts and, most recently, the chemistry of humic substances, the essential brown animal and plant metabolites in sediments, soils, and water. He edits a column on experiential and study-abroad education in the *Journal of Chemical Education* and a book series on humic substances. He is a fellow of the Royal Society of Chemistry and was awarded Northeastern's Excellence in Teaching Award in 1981, 1993, and 1999, and its first Lifetime Achievement in Teaching Award in 2004.

Preface

Dear Student,

We wrote this book with three overarching goals in mind: to make chemistry interesting, relevant, and memorable; to enable you to see the world from a molecular point of view; and to help you become an expert problem-solver. You have a number of resources available to assist you to succeed in your general chemistry course. This textbook will be a valuable resource, and we have written it with you, and the different ways you may use the book, in mind.

If you are someone who reads a chapter from the first page to the last, you will see that *Chemistry: The Science in Context*, Fifth Edition, introduces the chemical principles within a chapter by using contexts drawn from daily life as well as from other disciplines, including biology, environmental science, materials science, astronomy, geology, and medicine. We believe that these contexts make chemistry more interesting, relevant, understandable, and memorable.

Chemists' unique perspective of natural processes and insights into the properties of substances, from high-performance alloys to the products of biotechnology, are based on understanding these processes and substances at the particulate level (the atomic and molecular level). A major goal of this book is to help you develop this microscale perspective and link it to macroscopic properties.

With that in mind, we begin each chapter with a **Particulate Review** and **Particulate Preview** on the first page. The goal of these tools is to prepare you for the material in the chapter. The Review assesses important prior knowledge you need to interpret particulate images in the chapter. The Particulate Preview asks you to speculate about new concepts you will see in the chapter and is meant to focus your reading.

PARTICULATE **REVIEW**

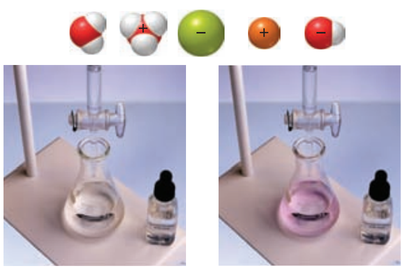
Acid and Base

In Chapter 5 we consider the energy changes that occur during reactions such as the combustion reactions from Chapter 3 and neutralization reactions from Chapter 4.

- Here we see the key molecules and ions involved in the titration of hydrochloric acid with sodium hydroxide. Name each molecule or ion and write its formula.
- The colorless solution in the flask on the left is hydrochloric acid. The colorless solution in the buret is sodium hydroxide. On the right is a picture of the titration after all the acid has been neutralized. Which of the illustrated particles are present in the buret, the flask on the left, and the flask on the right?

(Review Sections 4.5–4.6 if you need help.)

(Answers to Particulate Review questions are in the back of the book.)



(a) (b)

PARTICULATE **PREVIEW**

Breaking Bonds and Energy

When ozone molecules absorb ultraviolet rays (UV rays) from the Sun, the ozone falls apart into oxygen molecules and oxygen atoms according to the chemical reaction depicted here. As you read Chapter 5, look for ideas that will help you answer these questions:

- What role does energy play in breaking the bonds?
- Does bond breaking occur when energy is absorbed? Or does breaking a bond release energy?

$O_3(g) \xrightarrow{\text{UV rays}} O_2(g) + O(g)$

If you want a quick summary of what is most important in a chapter to direct your studying on selected topics, check the **Learning Outcomes** at the beginning of each chapter. Whether you are reading the chapter from first page to last, moving from topic to topic in an order you select, or reviewing material for an exam, the Learning Outcomes can help you focus on the key information you need to know and the skills you should acquire.

Learning Outcomes

LO1 Explain kinetic and potential energies at the molecular level
Sample Exercise 5.1

LO2 Identify familiar endothermic and exothermic processes
Sample Exercise 5.2

LO3 Calculate changes in the internal energy of a system
Sample Exercises 5.3, 5.4

LO4 Calculate the amount of heat transferred in physical or chemical processes
Sample Exercises 5.5, 5.6, 5.7, 5.8, 5.9

LO5 Calculate thermochemical values by using data from calorimetry experiments
Sample Exercises 5.10, 5.11

LO6 Calculate enthalpies of reaction
Sample Exercises 5.12, 5.13, 5.15

LO7 Recognize and write equations for formation reactions
Sample Exercise 5.14

LO8 Calculate and compare fuel and food values and fuel densities
Sample Exercises 5.16, 5.17

In every section, you will find **key terms** in boldface in the text and in a **running glossary** in the margin. We have inserted the definitions throughout the text, so you can continue reading without interruption but quickly find key terms when doing homework or reviewing for a test. All key terms are also defined in the Glossary in the back of the book.

Approximately once per section, you will find a **Concept Test**. These short, conceptual questions provide a self-check opportunity by asking you to stop and answer a question relating to what you just read. We designed them to help you see for yourself whether you have grasped a key concept and can apply it. You will find answers to Concept Tests in the back of the book.

CONCEPT **TEST**

Identify the following systems as isolated, closed, or open: (a) the water in a pond; (b) a carbonated beverage in a sealed bottle; (c) a sandwich wrapped in thermally conducting plastic wrap; (d) a live chicken.

(Answers to Concept Tests are in the back of the book.)

CONNECTION In Chapter 1 we discussed the arrangement of molecules in ice, water, and water vapor.

New concepts naturally build on previous information, and you will find that many concepts are related to others described earlier in the book. We point out these relationships with **Connection** icons in the margins. These reminders will help you see the big picture and draw your own connections between the major themes covered in the book.

At the end of each chapter is a group of **Visual Problems** that ask you to interpret atomic and molecular views of elements and compounds, along with graphs of experimental data. The last Visual Problem in each chapter contains a **visual problem matrix**. This grid consists of nine images followed by a series of questions that will test your ability to identify the similarities and differences among the macroscopic and particulate images.

CHEMTOUR Heating Curves

If you're looking for additional help visualizing a concept, we have almost 100 **ChemTours**, denoted by the ChemTour icon. The ChemTours, available at digital.wwnorton.com/chem5, provide animations of physical changes and chemical reactions to help you envision events at the molecular level. Many ChemTours are interactive, allowing you to manipulate variables and observe resulting changes in a graph or a process. Questions at the end of the ChemTour tutorials offer step-by-step assistance in solving problems and provide useful feedback.

Another goal of the book is to help you improve your problem-solving skills. Sometimes the hardest parts of solving a problem are knowing where to start and distinguishing between information that is relevant and information that is not. Once you are clear on where you are starting and where you are going, planning for and arriving at a solution become much easier.

To help you hone your problem-solving skills, we have developed a framework that is introduced in Chapter 1 and used consistently throughout the book. It is a four-step approach we call **COAST**, which is our acronym for (1) **C**ollect and **O**rganize, (2) **A**nalyze, (3) **S**olve, and (4) **T**hink About It. We use these four steps in *every* Sample Exercise and in the solutions to *odd-numbered* problems in the Student's Solutions Manual. They are also used in the hints and feedback embedded in the Smartwork5 online homework program. To summarize the four steps:

Collect and Organize helps you understand where to begin. In this step we often point out what you must find and what is given, including the relevant information that is provided in the problem statement or available elsewhere in the book.

Analyze is where we map out a strategy for solving the problem. As part of that strategy we often estimate what a reasonable answer might be.

Solve applies our strategy from the second step to the information and relationships identified in the first step to actually solve the problem. We walk you through each step in the solution so that you can follow the logic as well as the math.

Think About It reminds us that calculating or determining an answer is not the last step when solving a problem. Checking whether the solution is reasonable in light of an estimate is imperative. Is the answer realistic? Are the units correct? Is the number of significant figures appropriate? Does it make sense with our estimate from the Analyze step?

Many students use the **Sample Exercises** more than any other part of the book. Sample Exercises take the concept being discussed and illustrate how to apply it to solve a problem. We hope that repeated application of COAST will help you refine your problem-solving skills and become an expert problem-solver. When you finish a Sample Exercise, you'll find a **Practice Exercise** to try on your own. Notice that the Sample Exercises and the Learning Objectives are connected. We think this will help you focus efficiently on the main ideas in the chapter.

Students sometimes comment that the questions on an exam are more challenging than the Sample Exercises in a book. To address this, we have an **Integrating Concepts Sample Exercise** near the end of each chapter. These exercises require you to use more than one concept from the chapter and may expect you to use concepts from earlier chapters to solve a problem. Please invest your time working through these problems because we think they will further enhance your problem-solving skills and give you an increased appreciation of how chemistry is used in the world.

SAMPLE EXERCISE 5.2 Identifying Exothermic and Endothermic Processes **LO2**

Describe the flow of energy during the purification of water by distillation (Figure 5.14), identify the steps in the process as either endothermic or exothermic, and give the sign of q associated with each step. Consider the water being purified to be the system.

Collect and Organize We are given that the water is the system. We must evaluate how the water gains or loses energy during distillation.

Analyze In distillation, energy flows in three steps: (1) liquid water is heated to the boiling point and (2) vaporizes. (3) The vapors are cooled and condense as they pass through the condenser.

impure water —vaporization→ pure water vapor —condensation→ pure water

Solve Energy flows from the surroundings (hot plate) to heat the impure water (the system) to its boiling point and then to vaporize it. Therefore processes 1 and 2 are endothermic. The sign of q is positive for both. Because energy flows from the system (water vapor) into the surroundings (condenser walls), process 3 is exothermic. Therefore, the sign of q is negative.

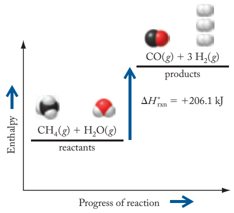
Think About It *Endothermic* means that energy is transferred from the surroundings into the system—the water in the distillation flask. When the water vapor is cooled in the condenser, energy flows from the vapor as it is converted from a gas to a liquid; the process is exothermic.

Practice Exercise What is the sign of q as (a) a match burns, (b) drops of molten candle wax solidify, and (c) perspiration evaporates from skin? In each case, define the system and indicate whether the process is endothermic or exothermic.

(Answers to Practice Exercises are in the back of the book.)

LO5 A **calorimeter**, characterized by its **calorimeter constant** (its characteristic **heat capacity**), is a device used to measure the amount of energy involved in physical and chemical processes. The enthalpy change associated with a reaction is defined by the **enthalpy of reaction** (**ΔH_{rxn}**). (Section 5.6)

LO6 **Hess's law** states that the enthalpy of a reaction (ΔH_{rxn}) that is the sum of two or more other reactions is equal to the sum of the ΔH_{rxn} values of the constituent reactions. It can be used to calculate enthalpy changes in reactions that are hard or impossible to measure directly. (Section 5.7)



If you use the book mostly as a reference and problem-solving guide, we have a learning path for you as well. It starts with the **Summary** and a **Problem-Solving Summary** at the end of each chapter. The first is a brief synopsis of the chapter, organized by Learning Outcomes. Key figures have been added to this Summary to provide visual cues as you review. The Problem-Solving Summary organizes the chapter by problem type and summarizes relevant concepts and equations you need to solve each type of problem. The Problem-Solving Summary also points you back to the relevant Sample Exercises that model how to solve each problem and cross-references the Learning Outcomes at the beginning of the chapter.

PROBLEM-SOLVING SUMMARY

Type of Problem	Concepts and Equations		Sample Exercises
Calculating kinetic and potential energy		(5.2) (5.3)	**5.1**
Identifying endothermic and exothermic processes, and calculating internal energy change (ΔE) and P–V work	For the system: $\Delta E = q + w$ where $w = -P\Delta V$.	(5.5)	**5.2, 5.3, 5.4**
Predicting the sign of ΔH_{sys} for physical and chemical changes	Exothermic: $\Delta H_{sys} < 0$ Endothermic: $\Delta H_{sys} > 0$		**5.5, 5.6**

Following the summaries are groups of questions and problems. The first group is the **Visual Problems**. **Concept Review Questions and Problems** come next, arranged by topic in the same order as they appear in the chapter. Concept Reviews are qualitative and often ask you to explain why or how something happens. Problems are paired and can be quantitative, conceptual, or a combination of both. **Contextual problems** have a title that describes the context in which the problem is placed. **Additional Problems** can come from any section or combination of sections in the chapter. Some of them incorporate concepts from previous chapters. Problems marked with an asterisk (*) are more challenging and often require multiple steps to solve.

We want you to have confidence in using the answers in the back of the book as well as the Student's Solutions Manual, so we continue to use a rigorous triple-check accuracy program for the fifth edition. Each end-of-chapter question and problem has been solved independently by at least three PhD chemists. For the fifth edition the team included Solutions Manual author Bradley Wile and two additional chemistry educators. Brad compared his solutions to those from the two reviewers and resolved any discrepancies. This process is designed to ensure clearly written problems and accurate answers in the appendices and Solutions Manual.

No matter how you use this book, we hope it becomes a valuable tool for you and helps you not only understand the principles of chemistry but also apply them to solving global problems, such as diagnosing and treating disease or making more efficient use of Earth's natural resources.

Changes to the Fifth Edition

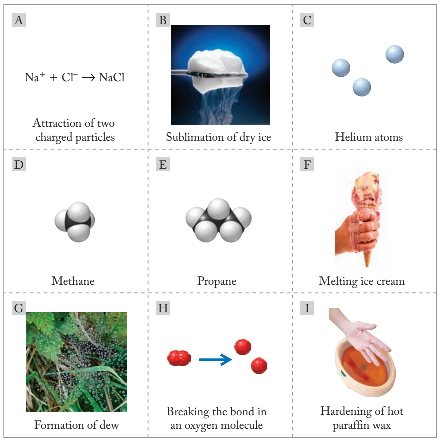
Dear Instructor,

As authors of a textbook we are very often asked: "Why is a fifth edition necessary? Has the science changed that much since the fourth edition?" Although chemistry is a vigorous and dynamic field, most basic concepts presented in an introductory course have not changed dramatically. However, two areas tightly intertwined in this text—pedagogy and context—have changed significantly, and those areas are the drivers of this new edition. Here are some of the most noteworthy changes we made throughout this edition:

- We welcome Stacey Lowery Bretz as our new coauthor. Stacey is a chemistry education researcher, and her insights and expertise about student misconceptions and the best way to address those misconceptions can be seen throughout the book. The most obvious examples are the new **Particulate Review** and **Particulate Preview** questions at the beginning of each chapter. The Review is a diagnostic tool that addresses important prior knowledge students must draw upon to successfully interpret molecular (particulate) images in the chapter. The Review consists of a few questions based on particulate-scale art. The Preview consists of a short series of questions about a particulate image that ask students to *extend* their prior knowledge and *speculate* about material in the chapter. The goal of the Preview is to direct students as they read, making reading more interactive.
- In addition to the Particulate Review and Preview, Stacey authored a new type of visual problem: the **visual problem matrix**. The matrix consists of macroscopic and particulate images in a grid, followed by a series of questions that ask students to identify commonalities and differences across the images based on their understanding. Versions of the Particulate Review, Preview, and the visual matrix problems are in the lecture PowerPoint presentations to use with clickers during lectures. They are also available in Smartwork5 as individual problems as well as premade assignments to use before or after class.

5.8. Use representations [A] through [I] in Figure P5.8 to answer questions a–f.

a. Which processes are exothermic?
b. Which processes have a positive ΔH?
c. In which processes does the system gain energy?
d. In which processes do the surroundings lose energy?
e. Compare a flame of methane [D] at 1000°C to a flame of propane [E] at 1000°C in terms of (i) average kinetic energy and (ii) average speed of the molecules.
f. Which substance(s) would *not* have vibrational motion or rotational motion? Why?



- We evaluated each Sample Exercise, and in simple, one-step Sample Exercises, we have streamlined the prose by combining the Collect and Organize and Analyze step. We revised numerous Sample Exercises throughout the fifth edition on the basis of reviewer and user feedback.
- The treatment of how to evaluate the precision and accuracy of experimental values in Chapter 1 has been expanded to include the identification of outliers by using standard deviations, confidence intervals, and the Grubbs test.
- We have expanded our coverage of aqueous equilibrium by adding a second chapter that doubles the number of Sample Exercises and includes Concept Tests that focus upon the molecules and ions present in titrations and buffers.
- In the fifth edition, functional groups are introduced in Chapter 2 and then seamlessly integrated into chapters as appropriate. For example, carboxylic acids and amines are introduced in Chapter 4 when students learn about acid–base reactions. This pedagogical choice enables us to weave core chemistry concepts into contexts that include a wider variety of environmental and health issues. Our hope is that it provides a stronger foundation for considering Lewis structures with a broader knowledge of the variety of molecules that are possible, as well as emphasizes the importance of structure–function from the very beginning of students' journey through chemistry.
- Given the integration of functional groups into the first 12 chapters, we now have one chapter (Chapter 20) that focuses on organic chemistry and biochemistry by discussing isomers, chirality, and the major classes of large biomolecules.

- Chapter 12, the Solids chapter, has been expanded to include polymers with a focus on biomedical applications, and band theory has been moved from the Solids chapter to the end of Chapter 9 following the discussion of molecular orbital theory.
- We took the advice of reviewers and now have two descriptive chemistry chapters at the end of the book. These chapters focus on main group chemistry and transition metals, both within the context of biological and medical applications.
- We have revised or replaced at least 10 percent of the end-of-chapter problems. We incorporated feedback from users and reviewers to address areas where we needed more problems or additional problems of varying difficulty.
- A new version of Smartwork, Smartwork5, offers more than 3600 problems in a sophisticated and user-friendly platform, and 400 new problems are designed to support the new visualization pedagogy. In addition to being tablet compatible, Smartwork5 integrates with the most common campus learning management systems.
- The nearly 100 ChemTours have been updated to better support lecture, lab, and independent student learning. The ChemTours include images, animations, and audio that demonstrate dynamic processes and help students visualize and understand chemistry at the molecular level. Forty of the ChemTours now contain greater interactivity and are assignable in Smartwork5. The ChemTours are linked directly from the ebook and are now in HTML5, which means they are tablet compatible.

Teaching and Learning Resources

Smartwork5 Online Homework for General Chemistry

digital.wwnorton.com/chem5

Smartwork5 is the most intuitive online tutorial and homework management system available for general chemistry. The many question types, including graded molecule drawing, math and chemical equations, ranking tasks, and interactive figures, help students develop and apply their understanding of fundamental concepts in chemistry.

Every problem in Smartwork5 includes response-specific feedback and general hints using the steps in COAST. Links to the ebook version of *Chemistry: The Science in Context*, Fifth Edition, take students to the specific place in the text where the concept is explained. All problems in Smartwork5 use the same language and notation as the textbook.

Smartwork5 also features Tutorial Problems. If students ask for help in a Tutorial Problem, the system breaks the problem down into smaller steps, coaching them with hints, answer-specific feedback, and probing questions within each step. At any point in a Tutorial, a student can return to and answer the original problem.

Assigning, editing, and administering homework within Smartwork5 is easy. It's tablet compatible and integrates with the most common campus learning management systems. Smartwork5 allows the instructor to search for problems by using both the text's Learning Objectives and Bloom's taxonomy. Instructors can use premade assignment sets provided by Norton authors, modify those assignments, or create their own. Instructors can also make changes in the problems at the question level. All instructors have access to our WYSIWYG (What You See Is What You Get) authoring tools—the same ones Norton authors use. Those intuitive tools make it easy to modify existing problems or to develop new content that meets the specific needs of your course.

Wherever possible, Smartwork5 makes use of algorithmic variables so that students see slightly different versions of the same problem. Assignments are graded automatically, and Smartwork5 includes sophisticated yet flexible tools for managing class data. Instructors can use the class activity report to assess students' performance on specific problems within an assignment. Instructors can also review individual students' work on problems.

Smartwork5 for *Chemistry*, Fifth Edition, features the following problem types:

- End-of-Chapter Problems. These problems, which use algorithmic variables when appropriate, all have hints and answer-specific feedback to coach students through mastering single- and multiple-concept problems based on chapter content. They make use of all of Smartwork5's answer-entry tools.
- ChemTour Problems. Forty ChemTours now contain greater interactivity and are assignable in Smartwork5.
- Visual and Graphing Problems. These problems challenge students to identify chemical phenomena and to interpret graphs. They use Smartwork5's Drag-and-Drop and Hotspot functionality.
- Reaction Visualization Problems. Based on both static art and videos of simulated reactions, these problems are designed to help students visualize what happens at the atomic level—and why it happens.
- Ranking Task Problems. These problems ask students to make comparative judgments between items in a set.
- Nomenclature Problems. New matching and multiple-choice problems help students master course vocabulary.
- Multistep Tutorials. These problems offer students who demonstrate a need for help a series of linked, step-by-step subproblems to work. They are based on the Concept Review problems at the end of each chapter.
- Math Review Problems. These problems can be used by students for practice or by instructors to diagnose the mathematical ability of their students.

Ebook

digital.wwnorton.com/chem5

An affordable and convenient alternative to the print text, Norton Ebooks let students access the entire book and much more: they can search, highlight, and take notes with ease. The Norton Ebook allows instructors to share their notes with students. And the ebook can be viewed on most devices—laptop, tablet, even a public computer—and will stay synced between devices.

The online version of *Chemistry*, Fifth Edition, also provides students with one-click access to the nearly 100 ChemTour animations.

The online ebook is available bundled with the print text and Smartwork5 at no extra cost, or it may be purchased bundled with Smartwork5 access.

Norton also offers a downloadable PDF version of the ebook.

Student's Solutions Manual

by Bradley Wile, Ohio Northern University

The Student's Solutions Manual provides students with fully worked solutions to select end-of-chapter problems using the **COAST** four-step method (**C**ollect and **O**rganize, **A**nalyze, **S**olve, and **T**hink About It). The Student's Solutions Manual contains several pieces of art for each chapter, designed to help students visualize ways to approach problems. This artwork is also used in the hints and feedback within Smartwork5.

Clickers in Action: Increasing Student Participation in General Chemistry

by Margaret Asirvatham, University of Colorado, Boulder

An instructor-oriented resource providing information on implementing clickers in general chemistry courses, *Clickers in Action* contains more than 250 class-tested, lecture-ready questions, with histograms showing student responses, as well as insights and suggestions for implementation. Question types include macroscopic observation, symbolic representation, and atomic/molecular views of processes.

Test Bank

by Chris Bradley, Mount St. Mary's University

Norton uses an innovative, evidence-based model to deliver high-quality and pedagogically effective quizzes and testing materials. Each chapter of the Test Bank is structured around an expanded list of student learning objectives and evaluates student knowledge on six distinct levels based on Bloom's Taxonomy: Remembering, Understanding, Applying, Analyzing, Evaluating, and Creating.

Questions are further classified by section and difficulty, making it easy to construct tests and quizzes that are meaningful and diagnostic, according to each instructor's needs. More than 2500 questions are divided into multiple choice and short answer.

The Test Bank is available with ExamView Test Generator software, allowing instructors to effortlessly create, administer, and manage assessments. The convenient and intuitive test-making wizard makes it easy to create customized exams with no software learning curve. Other key features include the ability to create paper exams with algorithmically generated variables and export files directly to Blackboard, Canvas, Desire2Learn, and Moodle.

Instructor's Solutions Manual

by Bradley Wile, Ohio Northern University

The Instructor's Solutions Manual provides instructors with fully worked solutions to every end-of-chapter Concept Review and Problem. Each solution uses the **COAST** four-step method (**C**ollect and **O**rganize, **A**nalyze, **S**olve, and **T**hink About It).

Instructor's Resource Manual

by Matthew Van Duzor, North Park University, and Andrea Van Duzor, Chicago State University

This complete resource manual for instructors has been revised to correspond to changes made in the fifth edition. Each chapter begins with a brief overview of the text chapter followed by suggestions for integrating the contexts featured in the book into a lecture, summaries of the textbook's Particulate Preview and Review sections, suggested sample lecture outlines, alternative contexts to use with each chapter, and instructor notes for suggested activities from the *Chem-Connections* and *Calculations in Chemistry,* Second Edition, workbooks. Suggested ChemTours and laboratory exercises round out each chapter.

Instructor's Resource Disc

This helpful classroom presentation tool features:

- Stepwise animations and classroom response questions. Developed by Jeffrey Macedone of Brigham Young University and his team, these animations, which use native PowerPoint functionality and textbook art, help instructors to "walk" students through nearly 100 chemical concepts and processes. Where appropriate, the slides contain two types of questions for students to answer in class: questions that ask them to predict what will happen next and why, and questions that ask them to apply knowledge gained from watching the animation. Self-contained notes help instructors adapt these materials to their own classrooms.
- Lecture PowerPoint (Scott Farrell, Ocean County College) slides include a suggested classroom-lecture script in an accompanying Word file. Each chapter opens with a set of multiple-choice questions based on the textbook's Particulate Review and Preview section, and concludes with another set of questions based on the textbook's visual problem matrix.
- All ChemTours.
- *Clickers in Action* clicker questions for each chapter provide instructors with class-tested questions they can integrate into their course.
- Photographs, drawn figures, and tables from the text, available in PowerPoint and JPEG format.

Downloadable Instructor's Resources

digital.wwnorton.com/chem5

This password-protected site for instructors includes:

- Stepwise animations and classroom response questions. Developed by Jeffrey Macedone of Brigham Young University and his team, these animations, which use native PowerPoint functionality and textbook art, help instructors to "walk" students through nearly 100 chemical concepts and processes. Where appropriate, the slides contain two types of questions for students to answer in class: questions that ask them to predict what will happen next and why, and questions that ask them to apply knowledge gained from watching the animation. Self-contained notes help instructors adapt these materials to their own classrooms.

- Lecture PowerPoints.
- All ChemTours.
- Test bank in PDF, Word RTF, and ExamView Assessment Suite formats.
- Solutions Manual in PDF and Word, so that instructors may edit solutions.
- All of the end-of-chapter questions and problems, available in Word along with the key equations.
- Photographs, drawn figures, and tables from the text, available in PowerPoint and JPEG format.
- *Clickers in Action* clicker questions.
- Course cartridges. Available for the most common learning management systems, course cartridges include access to the ChemTours and StepWise animations as well as links to the ebook and Smartwork5.

Acknowledgments

We begin by thanking the people who played the biggest role in getting the whole process started for the fifth edition: you, the users and the reviewers. Your suggestions, comments, critiques, and quality feedback have encouraged us to tackle the revision process to ensure the content, context, and pedagogy work better for you and maximize learning for all your students. Our deepest thanks and gratitude go to you, the users, for sharing your experiences with us. Your comments at meetings, in focus groups, in emails, and during office visits with the Norton travelers help us identify what works well and what needs to be improved pedagogically; these comments, together with sharing the new stories and current real-world examples of chemistry that capture your students' interest, provide the foundation for this revision. We are grateful to you all.

Our colleagues at W. W. Norton remain a constant source of inspiration and guidance. Their passion for providing accurate and reliable content sets a high standard that motivates all of us to create an exceptional and user-friendly set of resources for instructors and students. Our highest order of thanks must go to W. W. Norton for having enough confidence in the idea behind the first four editions to commit to the massive labor of the fifth. The people at W. W. Norton with whom we work most closely deserve much more praise than we can possibly express here. Our editor, Erik Fahlgren, continues to offer his wisdom, guidance, energy, creativity, and most impressively, an endless amount of patience, as he both simultaneously leads and pushes us to meet deadlines. Erik's leadership is the single greatest reason for this book's completion, and our greatest thanks are far too humble an offering for his unwavering vision and commitment. He is the consummate professional and a valued friend.

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This book has benefited greatly from the care and thought that many reviewers, listed here, gave to their readings of earlier drafts. We owe an extra-special thanks to Brad Wile for his dedicated and precise work on the Solutions Manual. He, along with Timothy Chapp and Tim Brewer, are the triple-check accuracy team who solved each problem and reviewed each solution for accuracy. We are deeply grateful to David Hanson for working with us to clarify both our language and our thoughts about thermochemistry. Finally, we greatly appreciate Allen Apblett, Chuck Cornett, Joseph Emerson, Amy Johnson, Edith Kippenhan, Brian Leskiw, Steve Rathbone, Jimmy Reeves, Jason Ritchie, Mary Roslonowski, Thomas Sorensen, and David Winters for checking the accuracy of the myriad facts that form the framework of our science.

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Chemistry

The Science in Context

1

Particles of Matter

Measurement and the Tools of Science

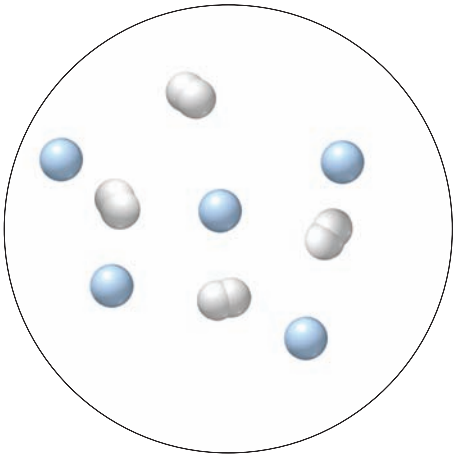
ANCIENT UNIVERSE The colors of the more than 10,000 galaxies in this image give us a glimpse into the universe as it existed about 13 billion years ago. This image was taken by NASA's Hubble Space Telescope.

PARTICULATE **REVIEW**

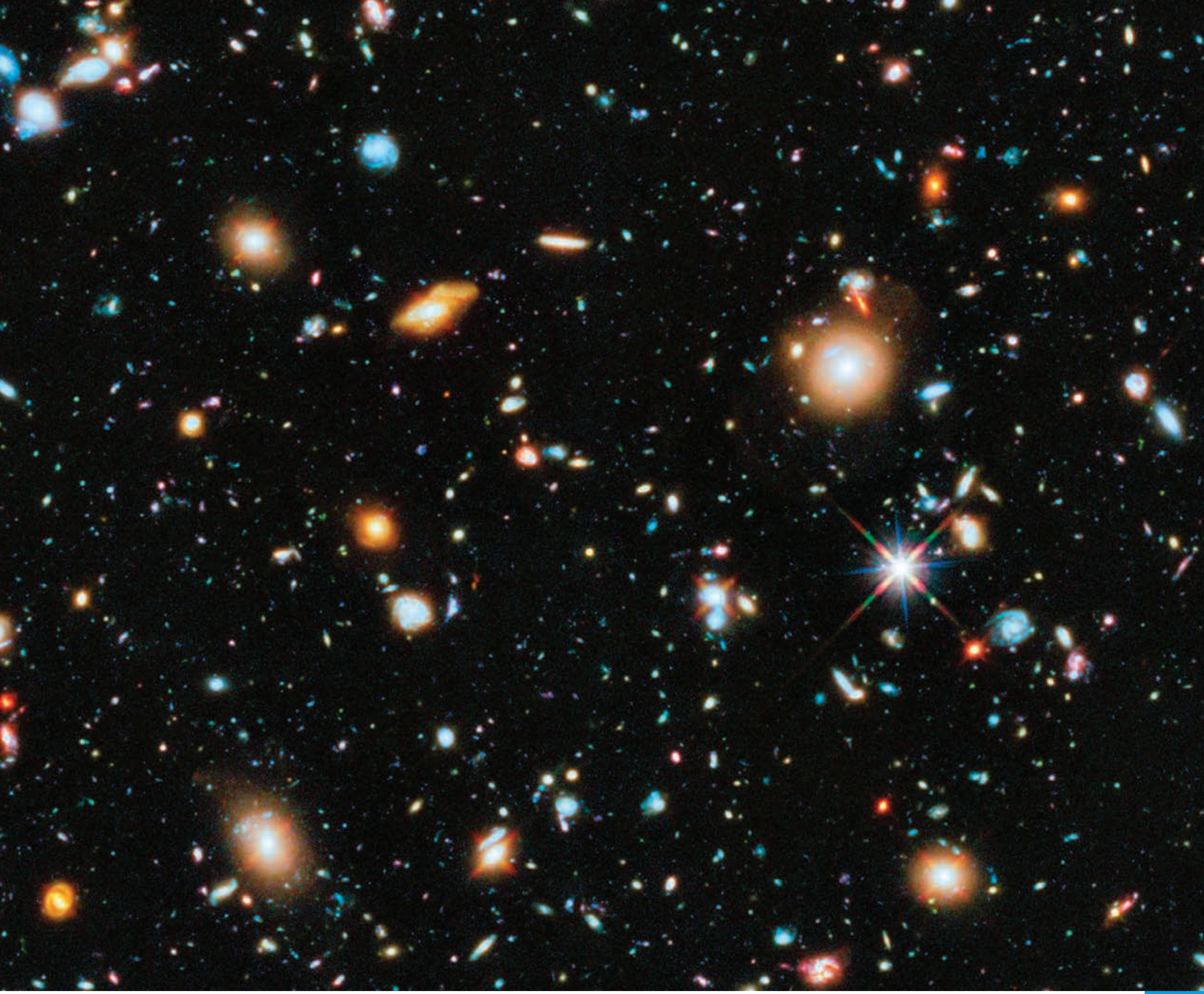
Atoms and Molecules: What's the Difference?

In Chapter 1 we explore how chemists classify different kinds of matter, from elements to compounds to mixtures. Hydrogen and helium were the first two elements formed after the universe began. Chemists use distinctively colored spheres to distinguish atoms of different elements in their drawings and models. For example, hydrogen is almost always depicted as white.

- How many of the following particles are shown in this image?
  - Hydrogen atoms?
  - Hydrogen molecules?
  - Helium atoms?
- Are molecules composed of atoms, or are atoms composed of molecules?



(Answers to Particulate Review questions are in the back of the book.)

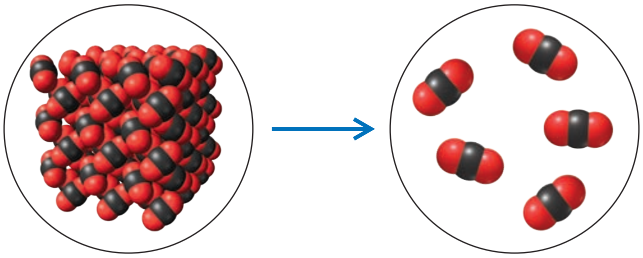


PARTICULATE **PREVIEW**

Matter and Energy

The temperature in outer space is 2.73 K. The temperature of dry ice (carbon dioxide, CO_2) is 70 times warmer, but still cold enough to keep ice cream frozen on a hot summer day. As you read Chapter 1, look for ideas that will help you answer these questions:

- Particulate images of CO_2 as it sublimes are shown here. Which two phases of matter are involved in sublimation?
- What features of the images helped you decide which two phases were involved?
- What is the role of energy in this transformation of matter? Must energy be added or is energy produced?



Learning Outcomes

LO1 Distinguish among pure substances, homogeneous mixtures, and heterogeneous mixtures, and between elements and compounds

LO2 Connect chemical formulas to molecular structures and vice versa

LO3 Distinguish between physical processes and chemical reactions, and between physical and chemical properties
Sample Exercise 1.1

LO4 Use a systematic approach (COAST) to problem solving

LO5 Describe the three states of matter and the transitions between them at the macroscopic and particulate levels
Sample Exercise 1.2

LO6 Describe the scientific method

LO7 Convert quantities from one system of units to another
Sample Exercises 1.3, 1.4, 1.9

LO8 Express uncertain values with the appropriate number of significant figures
Sample Exercise 1.5

LO9 Distinguish between exact and uncertain values, evaluate the precision and accuracy of experimental results, and identify outliers
Sample Exercises 1.6, 1.7, 1.8

1.1 How and Why

For thousands of years, humans have sought to better understand the world around us. For most of that time we resorted to mythological explanations of natural phenomena. Many once believed, for example, that the Sun rose in the east and set in the west because it was carried across the sky by a god driving a chariot propelled by winged horses.

In recent times we have been able to move beyond such fanciful accounts of natural phenomena to explanations based on observation and scientific reasoning. Unfortunately, this movement toward rational explanations has not always been smooth. Consider, for example, the contributions of a man whom Albert Einstein called the father of modern science, Galileo Galilei. At the dawn of the 17th century, Galileo used advanced telescopes of his own design to observe the movement of the planets and their moons. He concluded that they, like Earth, revolved around the Sun. However, this view conflicted with a belief held by many religious leaders of his time that Earth was the center of the universe. In 1633 a religious tribunal forced Galileo to disavow his conclusion that Earth orbited the Sun and banned him (or anyone) from publishing the results of studies that called into question the Earth-centered view of the universe. The ban was not completely lifted until 1835—nearly 200 years after Galileo's death.

In the last century, advances in the design and performance of telescopes have led to the astounding discovery that we live in an expanding universe that probably began 13.8 billion years ago with an enormous release of energy. In this chapter and in later ones, we examine some of the data that led to the theory of the Big Bang and that also explain the formation of the elements that make up the universe, our planet, and ourselves.

Scientific investigations into the origin of the universe have stretched the human imagination and forced scientists to develop new models and new explanations of how and why things are the way they are. Frequently these efforts have involved observing and measuring large-scale phenomena, which we refer to as *macroscopic* phenomena. We seek to explain these macroscopic phenomena through *particulate* representations that show the structure of matter on the scale of atomic and even subatomic particles. In this chapter and those that follow, you will encounter many of these macroscopic–particulate connections. The authors of this book hope that your exploration of these connections will help you better understand how and why nature is the way it is.

1.2 Macroscopic and Particulate Views of Matter

According to a formula widely used in medicine, the ideal weight for a six-foot male is 170 pounds (or 77 kilograms). On average, about 30 of these pounds are fat, with the remaining 140 pounds—including bones, organs, muscle, and blood—classified as lean body mass. These values are measures of the total *mass* of all the *matter* in the body. In general, **mass** is the quantity of matter in any object. **Matter**, in turn, is a term that applies to everything in the body (and in the universe) that has mass and occupies space. **Chemistry** is the study of the composition, structure, and properties of matter.

mass the property that defines the quantity of matter in an object.

matter anything that has mass and occupies space.

chemistry the study of the composition, structure, and properties of matter, and of the energy consumed or given off when matter undergoes a change.

substance matter that has a constant composition and cannot be broken down to simpler matter by any physical process; also called *pure substance*.

physical process a transformation of a sample of matter, such as a change in its physical state, that does not alter the chemical identity of any substance in the sample.

Classes of Matter

The different forms of matter are organized according to the classification scheme shown in Figure 1.1. We begin on the left with pure **substances**, which have a constant composition that does not vary from one sample to another. For example, the composition of pure water does not vary, no matter what its source or how much of it there is. Like all pure substances, water cannot be separated into simpler substances by any physical process. A **physical process** is a transformation of a sample of matter that does not alter the chemical identities of any of the substances in the sample, such as a change in physical state from solid to liquid.

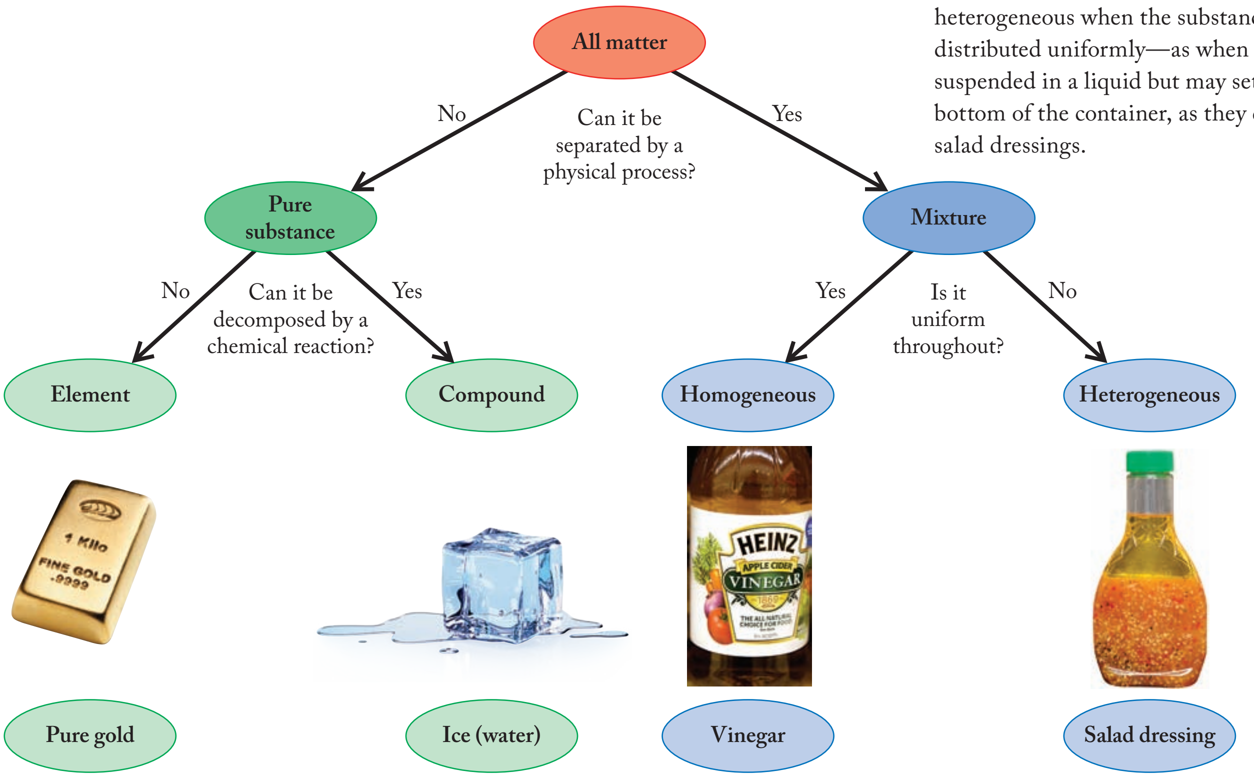
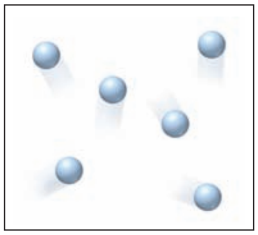
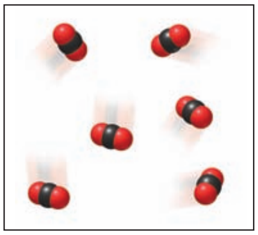


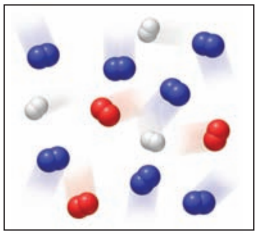
FIGURE 1.1 The two principal classes of matter are pure substances and mixtures. A pure substance may be a compound (such as water) or an element (such as gold). A mixture is homogeneous when the substances are distributed uniformly, as they are in vinegar (a mixture of mostly acetic acid and water). A mixture is heterogeneous when the substances are not distributed uniformly—as when solids are suspended in a liquid but may settle to the bottom of the container, as they do in some salad dressings.



(a) Atoms of helium, an element



(b) Molecules of carbon dioxide, a compound



(c) Mixture of gases

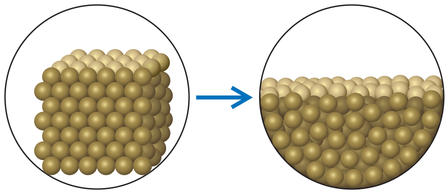
FIGURE 1.2 All matter is made up of either pure substances (of which there are relatively few in nature) or mixtures. (a) The element helium (He), the second most abundant element in the universe, is one example of a pure substance. (b) The compound carbon dioxide (CO_2), the gas used in many fire extinguishers, is also a pure substance. (c) This homogeneous mixture contains three substances: nitrogen (N_2, blue), hydrogen (H_2, white), and oxygen (O_2, red).

Pure substances are subdivided into two groups: elements and compounds (Figure 1.2). An **element** is a pure substance that cannot be broken down into simpler substances. The periodic table inside the front cover shows all the known elements. Only a few of them (including gold, silver, nitrogen, oxygen, and sulfur) occur in nature uncombined with other elements. Instead, most elements in nature are found mixed with other elements in the form of **compounds**, substances whose elements can be separated from one another only by a **chemical reaction**: the transformation of one or more substances into one or more different substances. Compounds typically have properties that are very different from those of the elements of which they are composed. For example, common table salt (sodium chloride) has little in common with either sodium, which is a silver-gray metal that reacts violently when dropped in water, or chlorine, which is a toxic yellow-green gas.

CONCEPT **TEST**

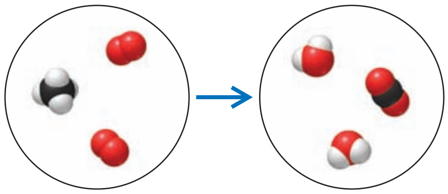
Which photo in Figure 1.3 depicts a physical process? Which photo depicts a chemical reaction? Match each photo to its corresponding particulate representation, using what you know about the difference between a physical process and a chemical reaction.

(a)



(c)

(b)



(d)

FIGURE 1.3 Macroscopic and particulate representations of both a physical process and a chemical reaction.

(Answers to Concept Tests are in the back of the book.)

element a pure substance that cannot be separated into simpler substances.

compound a pure substance that is composed of two or more elements bonded together in fixed proportions and that can be broken down into those elements by a chemical reaction.

chemical reaction the transformation of one or more substances into different substances.

mixture a combination of pure substances in variable proportions in which the individual substances retain their chemical identities and can be separated from one another by a physical process.

Any matter that is not a pure substance is considered a **mixture**, which is composed of two or more substances that retain their own chemical identities. The substances in mixtures can be separated by physical processes, and they are not present in definite proportions. For example, the composition of circulating blood in a human body is constantly changing as it delivers substances involved in energy production and cell growth to the cells and carries away the waste products of life's biochemical processes. Thus blood contains more oxygen and less carbon dioxide when it leaves our lungs than it does when it enters them.

In a **homogeneous mixture**, the substances making up the mixture are uniformly distributed. This means that the first sip you take from a bottle of water has the same composition as the last. (Keep in mind that bottled water contains small quantities of dissolved substances that either occur naturally in the water or are added prior to bottling to give it a desirable taste. Bottled drinking water is not *pure* water.) Homogeneous mixtures are also called **solutions**, a term that chemists apply to homogeneous mixtures of gases and solids as well as liquids. For example, a sample of filtered air is a solution of nitrogen, oxygen, argon, carbon dioxide, and other atmospheric gases. A "gold" ring is actually a solid solution of mostly gold plus other metals such as silver, copper, and zinc.

On the other hand, the substances in a **heterogeneous mixture** are not distributed uniformly. One way to tell that a liquid mixture is heterogeneous is to look for a boundary between the liquids in it (such as the oil and water layers in the bottle of salad dressing in Figure 1.1). Such a boundary indicates that the substances do not dissolve in one another. Another sign that a liquid may be a heterogeneous mixture is that it is not clear (transparent). Light cannot pass through such liquids because it is scattered by tiny solid particles or liquid drops that are *suspended*, but not dissolved, in the surrounding liquid. Human blood, for example, is opaque because the blood cells that are suspended in it absorb and scatter light.

homogeneous mixture a mixture in which the components are distributed uniformly throughout and have no visible boundaries or regions.

solution another name for a homogeneous mixture. Solutions are often liquids, but they may also be solids or gases.

heterogeneous mixture a mixture in which the components are not distributed uniformly, so that the mixture contains distinct regions of different compositions.

atom the smallest particle of an element that cannot be chemically or mechanically divided into smaller particles.

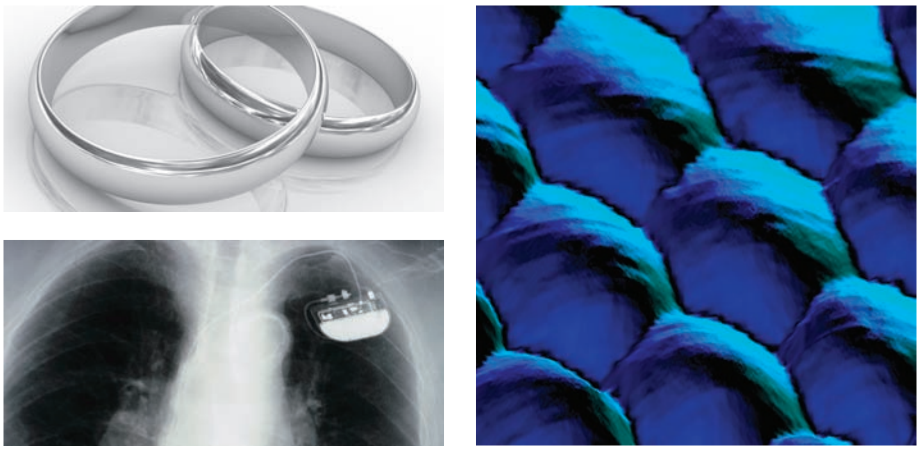
molecule a collection of atoms chemically bonded together in characteristic proportions.

chemical bond a force that holds two atoms or ions in a compound together.

A Particulate View

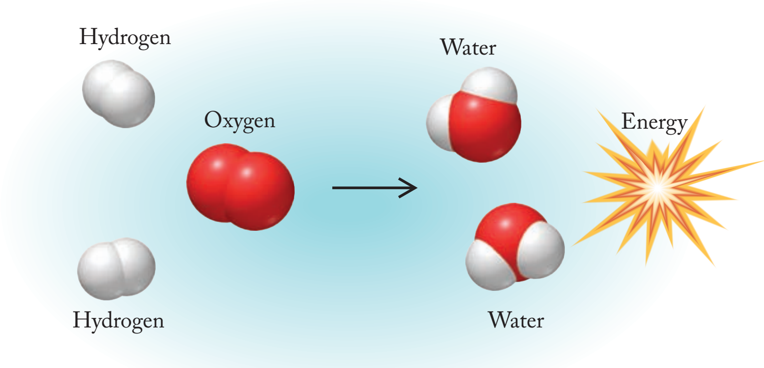
Given that compounds are formed from elements, the question must be asked: Do elements consist of yet smaller particles? The answer is yes. An element consists of just one type of particle, known as an **atom**. For example, elements such as gold and helium consist of individual atoms, yet the gold atoms are different from the helium atoms, as we see in Chapter 2. Atoms cannot be chemically or mechanically divided into smaller particles. Although civilizations as old as the ancient Greeks believed in atoms, people then had no evidence that atoms actually existed. Today, however, we have compelling evidence in the form of images of atoms, such as a surface of platinum (Figure 1.4) that has been magnified over 100 million times by using a device called a scanning tunneling microscope.

Some elements exist as molecules. A **molecule** is an assembly of two or more atoms that are held together in a characteristic pattern by forces called **chemical bonds**. For example, the air we breathe consists mostly of *diatomic* (two-atom)



(a) (b)

FIGURE 1.4 (a) Platinum resists oxidation and is therefore used to make expensive items such as wedding rings and pacemakers. (b) Since the 1980s, scientists have been able to image individual atoms by using an instrument called a scanning tunneling microscope (STM). In this STM image, the fuzzy hexagons (colored blue to be easier to see) are individual platinum atoms. The radius of each atom is 138 picometers (pm), or 138 trillionths of a meter.



$$2\,H_2(g) + O_2(g) \longrightarrow 2\,H_2O(\ell) + \text{Energy}$$

Reactants ⟶ Products

FIGURE 1.5 The reaction between hydrogen and oxygen is depicted with molecular models (white and red spheres) and in the form of a chemical equation. Note that energy is also a product of the reaction.

molecules of nitrogen gas, N_2, and oxygen gas, O_2. The subscripts in the **chemical formulas** of these two gases tell us that their molecules are each composed of two atoms. Other elements also exist as diatomic molecules, including H_2 and elements in column 17 of the periodic table: F_2, Cl_2, Br_2, and I_2.

Most of the molecules in the universe, however, contain atoms of more than one element, meaning that they are compounds. The chemical formula of a molecular compound tells us the number of atoms of each element in one of its molecules. For example, the formula H_2O tells us that pure water is composed of molecules that each contain two hydrogen atoms and one oxygen atom, as shown in Figure 1.5.

The 2:1 ratio of hydrogen to oxygen atoms in molecules of H_2O also reflects the proportions of H_2 gas and O_2 gas that react to form water. These gases *always* react with each other in the same proportion: two molecules of H_2 for every one molecule of O_2. This relationship is illustrated in Figure 1.5 with models of the molecules involved and the chemical equation beneath them. In a **chemical equation**, chemical formulas represent the substances involved in a chemical reaction. The arrow in the middle of a chemical equation separates the reactant(s) from the product(s). In Figure 1.5, the *phase symbol* (g) shows that the reactants are gases and (ℓ) shows that H_2O is a liquid. Solids are denoted by (s).

Note that the reaction between hydrogen and oxygen also produces **energy**, most generally defined as the capacity to do work. If we reverse the process and add enough energy to decompose water into hydrogen and oxygen (Figure 1.6), which is another example of a chemical reaction, we will always obtain two molecules of hydrogen gas for every one molecule of oxygen gas. This consistency illustrates the **law of constant composition**: every sample of a particular compound always contains the same elements combined in the same proportions.

chemical formula notation for representing elements and compounds; consists of the symbols of the constituent elements and subscripts identifying the number of atoms of each element present.

chemical equation notation in which chemical formulas express the identities and their coefficients express the quantities of substances involved in a chemical reaction.

energy the capacity to do work.

law of constant composition the principle that all samples of a particular compound contain the same elements combined in the same proportions.

ion a particle consisting of one or more atoms that has a net positive or negative electrical charge.

cation an ion with a positive charge.

anion an ion with a negative charge.

CONCEPT TEST

A compound with the formula NO is present in the exhaust gases leaving a car's engine. As NO travels through the car's exhaust system, some of it decomposes into nitrogen gas and oxygen gas. What is the ratio of nitrogen molecules to oxygen molecules formed from the decomposition of NO?

(Answers to Concept Tests are in the back of the book.)

Chemical formulas provide information about the ratios of the elements in molecular compounds, but formulas do not tell us how the atoms of each element are bonded to one another within each molecule, nor do they tell us anything about

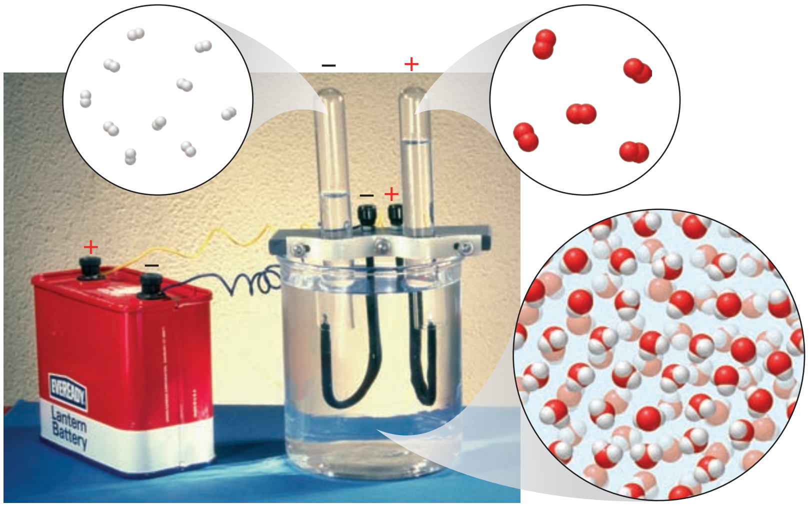


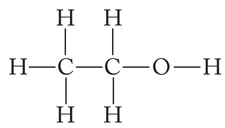
FIGURE 1.6 An electric current passed through water provides enough energy to decompose water into oxygen gas and hydrogen gas. The ratio of the gases produced is always two molecules of hydrogen for every one molecule of oxygen. These fixed proportions illustrate the law of constant composition.

the shapes of molecules. To communicate information about bonding and shape, we need to draw a *structural formula* such as the one for ethanol (C_2H_5OH) in Figure 1.7(a), which uses straight lines to represent the chemical bonds that connect the carbon (C), hydrogen (H), and oxygen (O) atoms within the molecule.

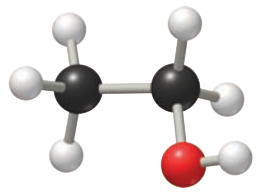
However, a structural formula does not necessarily show how atoms are arranged in three-dimensional space. *Molecular models* provide this 3-D perspective. *Ball-and-stick* molecular models (Figure 1.7b) use spheres to represent atoms and sticks to represent chemical bonds. The advantage of ball-and-stick models is that they show the correct angles between the bonds. However, there are limitations to using models to represent molecules. For example, the sizes of the spheres are not proportional to the sizes of the atoms they represent, and the atoms are spaced far enough apart to accommodate the stick bonds. (In real molecules, the atoms touch each other.) Both of these limitations are overcome with *space-filling* molecular models (Figure 1.7c), in which the spheres are drawn to scale and touch one another as atoms do in real molecules. One limitation of space-filling models is that the bond angles between atoms may be difficult to discern. An additional limitation of both the ball-and-stick and space-filling models is that atoms themselves do not have color. Representing oxygen atoms as red spheres and hydrogen atoms as white spheres is merely a convention used by chemists.

Not all compounds are molecular. Instead, some compounds consist of positively and negatively charged particles called **ions** that are electrostatically attracted to one another. For example, calcium chloride (which is used to melt snow and ice on sidewalks in winter) consists of calcium ions (Ca^{2+}) and chloride ions (Cl^-). The positive ions are called **cations**, and the negative ions are called **anions**. Ions may consist of single atoms like Ca^{2+} and Cl^-, or they may contain two or more atoms bonded together that have an overall positive or negative charge, like the hydroxide ion (OH^-).

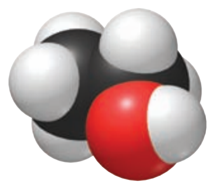
Ethanol



(a) Structural formula



(b) Ball-and-stick model



(c) Space-filling model

FIGURE 1.7 Three ways to represent the arrangement of atoms in a molecule of ethanol: (a) structural formula; (b) ball-and-stick model, where white spheres represent hydrogen atoms, black spheres represent carbon atoms, and red spheres represent oxygen atoms; (c) space-filling model.

1.3 Mixtures and How to Separate Them

As noted in Section 1.2, mixtures can be separated into their component substances by physical processes. Consider, for example, how the components of human blood can be separated. Blood is a heterogeneous mixture of hundreds of