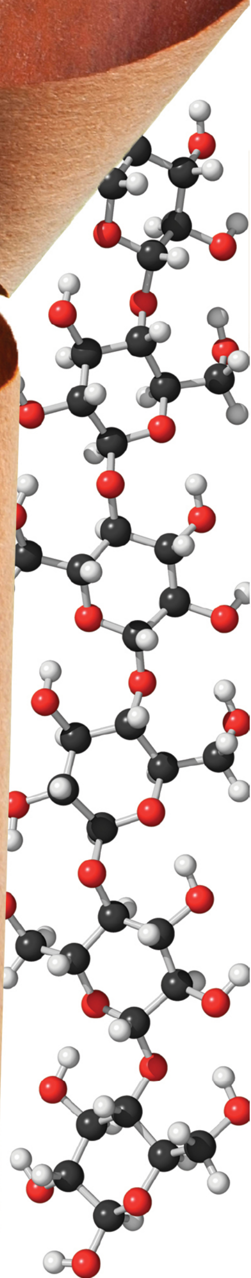
SECOND EDITION

CHEMISTRY

AN ATOMS-FOCUSED APPROACH

GILBERT
KIRSS
FOSTER
BRETZ



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Chemistry

An Atoms-Focused Approach

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W. W. NORTON & COMPANY
NEW YORK • LONDON

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Printed in Canada

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Illustrations: Imagineering—Toronto, ON
Manufacturing: Transcontinental Interglobe

Library of Congress Cataloging-in-Publication Data
Names: Gilbert, Thomas R. | Kirss, Rein V. | Foster, Natalie. | Bretz, Stacey Lowery, 1967-
Title: Chemistry : an atoms-focused approach / Thomas R. Gilbert, Northeastern University, Rein V. Kirss, Northeastern University, Natalie Foster, Lehigh University, Stacey Lowery Bretz, Miami University.
Description: Second edition. | New York : W.W. Norton & Company, Inc., [2018] | Includes index.
Identifiers: LCCN 2016049892 | **ISBN 9780393284218 (hardcover)**
Subjects: LCSH: Chemistry.
Classification: LCC QD33.2 .G54 2018 | DDC 540—dc23 LC record available at https://lccn.loc.gov/2016049892

W. W. Norton & Company, Inc., 500 Fifth Avenue, New York, NY 10110

www.wwnorton.com

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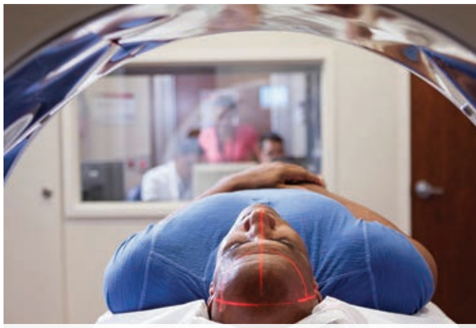

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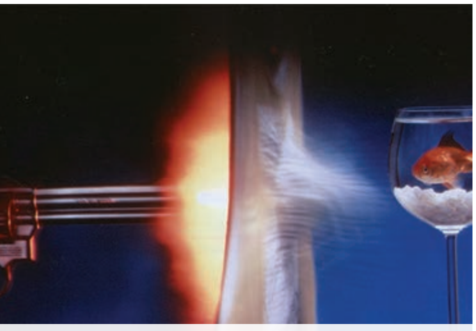

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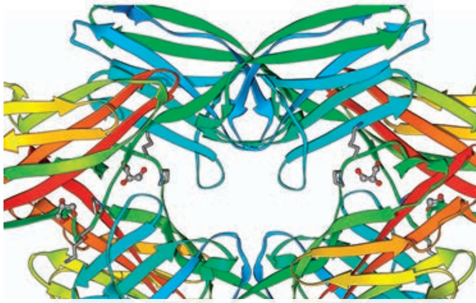

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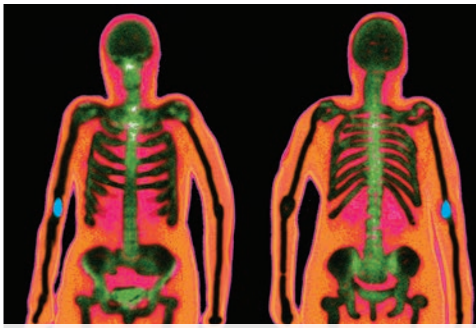

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About the **Authors**

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 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 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 ACS 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 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 the recipient of the Christian R. and Mary F. Lindback Foundation Award for distinguished teaching and a Fellow of the American Chemical Society.

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 (CER) from Cornell University. She then spent one year at the University of California, Berkeley, as a post-doc 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 was the recipient of the E. Phillips Knox Award for Undergraduate Teaching in 2009 and the Distinguished Teaching Award for Excellence in Graduate Instruction and Mentoring in 2013, Miami University's highest teaching awards.

Preface

Dear Student,

They say you can't judge a book by its cover. Still, you may be wondering why we chose to put peeling wallpaper on the cover of a chemistry book. Actually, the cover photo is not wallpaper but the bark of a Pacific Madrone tree, *Arbutus menziesii*. The illustration shows a molecular view of the cellulose that is a principal component of tree's trunk, including its peeling bark and the heartwood beneath it.

Our cover illustrates a central message of this book: the properties of substances are directly linked to their atomic and molecular structures. In our book we start with the smallest particles of matter and assemble them into more elaborate structures: from subatomic particles to single atoms to monatomic ions and polyatomic ions, and from atoms to small molecules to bigger ones to truly gigantic polymers. By constructing this layered particulate view of matter, we hope our book helps you visualize the properties of substances and the changes they undergo during chemical reactions.

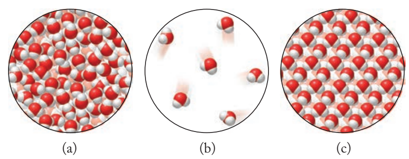
With that in mind, we begin each chapter with a **Particulate Review** and **Particulate Preview** on the very first page. The goal of these tools is to prepare you for the material in the chapter. The Particulate Review assesses important prior knowledge that you need to interpret particulate images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

As you develop your ability to visualize atoms and molecules, you will find that you don't have to resort to memorizing formulas and reactions as a strategy for surviving general chemistry. Instead, you will be able to understand why elements combine to form compounds with particular formulas and why substances react with each other the way they do.

PARTICULATE **REVIEW**

Phase Changes and Energy

In Chapter 9, we explore the energy changes that accompany both physical and chemical changes. Particulate representations of the three phases of water are shown here.



- Which representation depicts the solid phase of water? The liquid? The gaseous?
- Is energy added or released during the physical change from (a) to (b)? What intermolecular forces are involved?
- Describe the energy changes that accompany the physical changes from (a) to (c) and from (c) to (a).

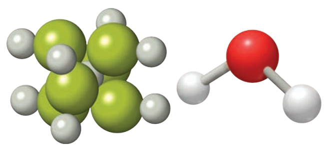
(Review Section 1.4 and Section 6.2 if you need help answering these questions.)

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

PARTICULATE **PREVIEW**

Breaking Bonds and Energy Changes

Calcium chloride, shown in the accompanying figure, is used to melt ice on sidewalks. As you read Chapter 9, look for ideas that will help you understand the energy changes that accompany the breaking and forming of bonds.



- What kind of bonds must be broken for calcium chloride to dissolve in water? Is energy absorbed or released in order to break these bonds?
- Which color spheres represent the chloride ions? Label the polar covalent bonds in water using δ+ and δ−.
- What intermolecular interactions form as the salt dissolves? Is energy absorbed or released as these attractions form?

Context

While our primary goal is for you to be able to interpret and even predict the physical and chemical properties of substances based on their atomic and molecular structures, we would also like you to understand how chemistry is linked to other scientific disciplines. We illustrate these connections using contexts drawn from fields such as biology, medicine, environmental science, materials science, and engineering. We hope that this approach helps you better understand how scientists apply the principles of chemistry to treat and cure diseases, to make more efficient use of natural resources, and to minimize the impact of human activity on our planet and its people.

Problem-Solving Strategies

Another major goal of our book is to help you improve your problem-solving skills. To do this, you first need to recognize the connections between the information provided in a problem and the answer you are asked to find. Sometimes the hardest part of solving a problem is 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 carrying out a solution become much easier.

To help you hone your problem-solving skills, we have developed a framework that we introduce in Chapter 1. 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 to solve the problem. In this step we often rephrase the problem and the answer that is sought, and we identify 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 analysis of the problem from the second step to the information and relations from the first step to actually solve the problem. We walk you through each step in the solution so that you can follow the logic and the math.

Think About It reminds us that an answer is not the last step in solving a problem. We should check the accuracy of the solution and think about the value of a quantitative answer. Is

SAMPLE EXERCISE 9.8 Calculating $\Delta H^\circ_{\text{rxn}}$ Using Hess's Law **LO5**

One reason furnaces and hot-water heaters fueled by natural gas need to be vented is that incomplete combustion can produce toxic carbon monoxide:

Equation A: $2\ CH_4(g) + 3\ O_2(g) \rightarrow 2\ CO(g) + 4\ H_2O(g) \qquad \Delta H^\circ_A = ?$

Use thermochemical equations B and C to calculate ΔH°_A:

Equation B: $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) \qquad \Delta H^\circ_B = -802$ kJ

Equation C: $2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g) \qquad \Delta H^\circ_C = -566$ kJ

Collect and Organize We are given two equations (B and C) with thermochemical data and a third (A) for which we are asked to find ΔH°. All the reactants and products in equation A are present in B and/or C.

Analyze We can manipulate equations B and C algebraically so that they sum to give the equation for which ΔH° is unknown. Then we can calculate the unknown value by applying Hess's law. Methane is a reactant in A and B, so we will use B in the direction written. CO is a product in A but a reactant in C, so we have to reverse C to get CO on the product side. Reversing C means that we must change the sign of ΔH°_C. If the coefficients in B and the reverse of C do not allow us to sum the two equations to obtain equation A, we will need to multiply one or both by appropriate factors.

Solve Comparing equation B as written and the reverse of C:

(B) $CH_4(g) + 2\ O_2(g) \rightarrow CO_2(g) + 2\ H_2O(g) \qquad \Delta H^\circ_B = -802$ kJ

(C, reversed) $2\ CO_2(g) \rightarrow 2\ CO(g) + O_2(g) \qquad -\Delta H^\circ_C = +566$ kJ

with equation A, we find that the coefficient of CH_4 is 2 in A but only 1 in B, so we need to multiply all the terms in B by 2, including ΔH°_B:

(2B) $2\ CH_4(g) + 4\ O_2(g) \rightarrow 2\ CO_2(g) + 4\ H_2O(g) \qquad 2\ \Delta H^\circ_B = -1604$ kJ

When we sum C (reversed) and 2B, the CO_2 terms cancel out and we obtain equation A:

$$
\begin{array}{lrl}
\text{(C, reversed)} & \cancel{2\ CO_2(g)} \rightarrow 2\ CO(g) + \cancel{O_2(g)} & -\Delta H^\circ_C = +566 \text{ kJ} \\
+\ \text{(2B)} & 2\ CH_4(g) + \overset{3}{\cancel{4}}\ O_2(g) \rightarrow \cancel{2\ CO_2(g)} + 4\ H_2O(g) & 2\ \Delta H^\circ_B = -1604 \text{ kJ} \\
\hline
\text{(A)} & 2\ CH_4(g) + 3\ O_2(g) \rightarrow 2\ CO(g) + 4\ H_2O(g) & \Delta H^\circ_A = -1038 \text{ kJ}
\end{array}
$$

Think About It Our calculation shows that incomplete combustion of two moles of methane is less exothermic ($\Delta H^\circ_A = -1038$ kJ) than their complete combustion ($2\ \Delta H^\circ_B = -1604$ kJ), which makes sense because the CO produced in incomplete combustion reacts exothermically with more O_2 to form CO_2. In fact, the value of ΔH°_C for the reaction $2\ CO(g) + O_2(g) \rightarrow 2\ CO_2(g)$ is the difference between -1604 kJ and -1038 kJ.

Practice Exercise It does not matter how you assemble the equations in a Hess's law problem. Show that reactions A and C can be summed to give reaction B and result in the same value for ΔH°_B.

it realistic? Are the units correct? Is the number of significant figures appropriate? Does it agree with our estimate from the Analyze step?

Suggestion: Some Sample Exercises that are based on simple concepts and single-step solutions are streamlined by combining Collect, Organize, and Analyze steps, but the essential COAST features are always maintained.

Many students use the **Sample Exercises** more than any other part of the book. Sample Exercises take the concepts being discussed and illustrate how to apply them to solve problems. We think that repeated application of the COAST framework will help you refine your problem-solving skills, and we hope that the approach will become habit-forming for you. When you finish a Sample Exercise, you'll find a **Practice Exercise** to try on your own. The next few pages describe how to use the tools built into each chapter to gain a conceptual understanding of chemistry and to connect the microscopic structure of substances to their observable physical and chemical properties.

Chapter Structure

As mentioned earlier, each chapter begins with the Particulate Review and Particulate Preview to help you prepare for the material ahead.

If you are trying to decide what is most important in a chapter, check the **Learning Outcomes** listed on the first page. Whether you are reading the chapter from first page to last or reviewing it for an exam, the Learning Outcomes should help you focus on the key information you need and the skills you should develop. You will also see which Learning Outcomes are linked to which Sample Exercises in the chapter.

Learning Outcomes

LO1 Distinguish between isolated, closed and open thermodynamic systems and between endothermic and exothermic processes
Sample Exercise 9.1

LO2 Relate changes in the internal energies of thermodynamic systems to heat flows and work done
Sample Exercises 9.2, 9.3

LO3 Calculate the heat gained or lost during changes in temperature and physical state
Sample Exercises 9.4, 9.5

LO4 Use calorimetry data to calculate enthalpies of reaction and heat capacities of calorimeters
Sample Exercises 9.6, 9.7

LO5 Calculate enthalpies of reaction using Hess's law and enthalpies of formation
Sample Exercises 9.8, 9.9, 9.10

LO6 Estimate enthalpies of reaction using average bond energies
Sample Exercise 9.11

LO7 Estimate enthalpies of solution and lattice energies using the Born–Haber cycle and Hess's law
Sample Exercise 9.12

LO8 Calculate and compare fuel values and fuel densities
Sample Exercises 9.13, 9.14

As you study each chapter, you will find **key terms** in boldface in the text and in a running glossary in the margin. We have deliberately duplicated these definitions so that you can continue reading without interruption but quickly find them when doing homework or studying. All key terms are also defined in the Glossary in the back of the book.

Many concepts are related to others described earlier in the book. We point out these relationships with **Connection** icons in the margins. We hope they enable you to draw your own connections between major themes covered in the book.

CONNECTION In Chapter 1, we defined *energy* as the ability to do work. We also introduced the *law of conservation of energy* and the concept that energy cannot be created or destroyed but can be changed from one form of energy to another.

CHEMTOUR
Bond Polarity and Polar Moelcules

To help you develop your own microscale view of matter, we use **molecular art** to enhance photos and figures, and to illustrate what is happening at the atomic and molecular levels.

If you're looking for additional help visualizing a concept, we have about 100 **ChemTours**, denoted by the ChemTour icon, available online at https://digital.wwnorton.com/atoms2. ChemTours demonstrate dynamic processes and help you visualize events at the molecular level. Many of the ChemTours allow you to manipulate variables and observe the resulting changes.

Concept Tests are short, conceptual questions that serve as self-checks by asking you to stop and answer questions related 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. We have an average of one Concept Test per section and many have visual components. We provide the answers to all Concept Tests in the back of the book.

CONCEPT **TEST**

Suppose two identical pots of water are heated on a stove until the water inside them begins to boil. Both pots are then removed from the stove. One of the two is covered with a tight lid; the other is not, and both are allowed to cool.

a. What type of thermodynamic system—open, closed, or isolated—describes each of the cooling pots?

b. Which pot cools faster? Why?

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

At the end of each chapter is a special Sample Exercise that draws on several key concepts from the chapter and occasionally others from preceding chapters to solve a problem that is framed in the context of a real-world scenario or incident. We call these **Integrated Sample Exercises**. You may find them more challenging than most exercises that precede them in each chapter, but please invest your time in working through them because they represent authentic exercises that will enhance your problem-solving skills.

Also at the end of each chapter are a thematic **Summary** and a **Problem-Solving Summary**. The first is a brief synopsis of the chapter, organized by learning outcomes. Key figures provide visual cues as you review. The Problem-Solving Summary is unique to this general chemistry book—it outlines the different types of problems you should be able to solve, where to find examples of them in the Sample Exercises, and it reminds you of key concepts and equations.

PROBLEM-SOLVING SUMMARY

Type of Problem	Concepts and Equations		Sample Exercises
Identifying endothermic and exothermic processes	During an endothermic process, heat flows into the system from its surroundings ($q > 0$). During an exothermic process, heat flows out from the system into its surroundings ($q < 0$).		**9.1**
Calculating *P–V* work	$w = -P\Delta V$		**9.2**
Relating ΔE, *q*, and *w*	$\Delta E = q + w = q - P\Delta V$	(9.3, 9.4)	**9.3**
Calculating heat transfer (*q*) associated with a change of temperature or state of a substance	Heating either an object: $q = C_P \Delta T$ or a mass (m) of a pure substance: $q = mc_P \Delta T$ or a quantity of a pure substance in moles (n): $q = nc_{P,n} \Delta T$ Melting a solid at its melting point: $q = n\Delta H_{fus}$ Vaporizing a liquid at its boiling point: $q = n\Delta H_{vap}$	 (9.8) (9.9) (9.10) (9.11) (9.12)	**9.4, 9.5**
Calculating C	$q = -q = -C \Delta T$		**9.6, 9.7**

Following the summaries are groups of questions and problems. The first group consists of **Visual Problems**. In many of them, you are asked to interpret a molecular view of a sample or a graph 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, particulate, and symbolic images.

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. Finally, **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 take 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 used a rigorous triple-check accuracy program for this book. Each end-of-chapter question or problem was solved independently by the Solutions Manual author, Karen Brewer, and by two additional chemical educators. Karen compared her 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.

9.8. Use representations [A] through [I] in Figure P9.8 to answer questions a–f.

a. Match two of the particulate images to the phase change for liquid nitrogen in [B].
b. Match two of the particulate images to the phase change for dry ice (solid CO_2) in [H].
c. Which, if any, of the photos correspond to [D]? Are these endothermic or exothermic?
d. Which, if any, of the photos correspond to [F]? Are these endothermic or exothermic?
e. What bonds break when the solid ammonium nitrate in [E] dissolves in water to activate the cold pack?
f. Which particulate images show an element or compound in its standard state?

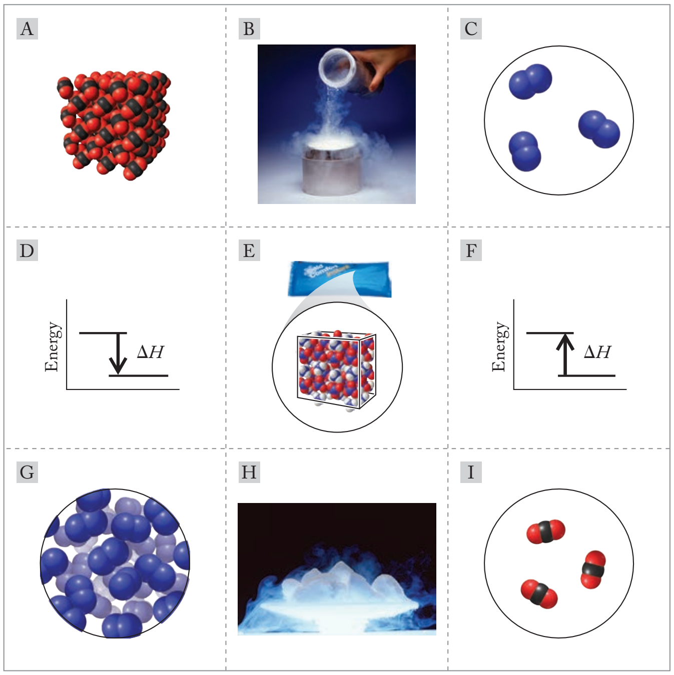


FIGURE P9.8

Dear Instructor,

This book takes an atoms-focused approach to teaching chemistry. Consequently, the sequence of chapters in the book and the sequence of topic in many of the chapters are not the same as in most general chemistry textbooks. For example, we devote the early chapters to providing an in-depth view of the particulate nature of matter including the structure of atoms and molecules and how the properties of substances link directly to those structures.

After two chapters on the nature of chemical bonding, molecular shape, and theories to explain both, we build on those topics as we explore the intermolecular forces that strongly influence the form and function of molecules, particularly those of biological importance.

Once this theoretical foundation has been laid, we examine chemical reactivity and the energetics of chemical reactions. Most general chemistry books don't complete their coverage of chemistry and energy until late in the book. We finish the job in Chapter 12, which means that students already understand the roles of energy and entropy in chemical reactions before they encounter chemical kinetics and the question of how they happen. The kinetics chapter is followed by several on chemical equilibrium, which introduce the phenomenon in terms of what happens when reactions proceed to a measureable extent in both forward and reverse directions and how interactions between and within particles influence the contacts that drive chemical changes.

Changes in the Second Edition

As authors of a textbook, we are very often asked: "Why is a second edition necessary? Has the science changed that much since the first 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 co-author. Stacey is a chemistry education researcher and her insights and expertise about accurate visual representations to support consistent pedagogy as well as about student misconceptions and effective ways to address them are evident 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 element highlighting 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 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. Students are not expected to know the correct answers to the questions posed in the Preview before they start the chapter but are to use them as a guide while reading. Overviews of each Particulate Review and Preview section can be found in the Instructor's Resource Manual and the lecture PowerPoints.
- In addition to the Particulate Review and Preview feature, Stacey authored a new type of visual problem: the **Visual Problem Matrix**. The matrix consists of macroscopic, particulate, and symbolic images in a grid, followed by a series of questions asking students to identify commonalities and differences across the images. Versions of all of these new problems are in the lecture PowerPoint slides to use in group activities and lecture quizzes. They are also available in Smartwork5 as individual problems and in pre-made assignments to use before or after class.
- We evaluated each Sample Exercise and streamlined many of those based on simple concepts and single-step solutions by combining the Collect and Organize and Analyze steps. We revised other Sample Exercises throughout the book based on 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 more rigorous treatment of the variability in data sets and in the identification of outliers.
- 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 on the molecules and ions present during titrations and in buffers.
- 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% 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. Four hundred new problems were 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

Smarkwork5 Online Homework For General Chemistry

digital.wwnorton.com/atoms2

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: An Atoms-Focused Approach,* Second 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. Smartwork5 allows the instructor to search for problems using both the text's Learning Objectives and Bloom's taxonomy. Instructors can use pre-made 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*: *An Atoms-Focused Approach*, Second 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 multi-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/atoms2
An affordable and convenient alternative to the print text, the Norton Ebook lets 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: An Atoms-Focused Approach*, Second 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 Karen Brewer, Hamilton 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 Smartwork.

Clickers in Action: Increasing Student Participation in General Chemistry

by Margaret Asirvatham, University of Colorado, Boulder
This instructor-oriented resource provides 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 Daniel E. Autrey, Fayetteville State 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 Karen Brewer, Hamilton 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 Anthony Fernandez, Merrimack College
This complete resource manual for instructors has been revised to correspond to changes made in the Second 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 Review and Preview sections, suggested sample lecture outlines, alternate contexts to use with each chapter, and instructor notes for suggested activities from the *ChemConnections* 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 the following:

- Stepwise animations and classroom response questions are included. 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 slides (authored by Cynthia Lamberty, Cloud County Community College) 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 Problems matrix.
- All ChemTours are included.
- *Clickers in Action* clicker questions for each chapter provide instructors with class-tested questions they can integrate into their course.
- Labeled and unlabeled photographs, drawn figures, and tables from the text are available in PowerPoint and JPEG.

Downloadable Instructor's Resources

digital.wwnorton.com/atoms2
This password-protected site for instructors includes the following:

- Stepwise animations and classroom response questions are included. 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 are available.
- All ChemTours are included.
- Test bank is available in PDF, Word RTF, and *ExamView* Assessment Suite formats.
- Solutions Manual is offered in PDF and Word, so that instructors may edit solutions.
- All end-of-chapter questions and problems are available in Word along with the key equations.
- Labeled and unlabeled photographs, drawn figures, and tables from the text are available in PowerPoint and JPEG.
- *Clickers in Action* clicker questions are included.

- Course cartridges: Available for the most common learning management systems, course cartridges include access to the ChemTours and StepWise animations, links to the ebook and Smartwork5.

Acknowledgments

Our thanks begin with our publisher, W. W. Norton, for supporting us in writing a book that is written the way we much prefer to teach general chemistry. We especially wish to acknowledge the hard work and dedication of our editor/motivator/taskmaster, Erik Fahlgren. Erik has been an indefatigable source of guidance, perspective, persuasion, and inspiration to all of us.

We are pleased to acknowledge the contributions of an outstanding developmental editor, John Murdzek. John's clear understanding and expertise in science, along with his wry wit, have helped us improve the presentation of core concepts and applied content of the book.

Diane Cipollone is our project editor who crossed t's and dotted i's to make sure each page was attractive and easy to navigate. Assistant editor Arielle Holstein is like a lighthouse in the fog: reliable, competent, and unfailingly patient in managing the constant flood of questions, information, and schedule updates. Thanks as well to Aga Millhouse and Rona Tuccillo for finding just the right photo again and again; production manager Eric Pier-Hocking for his work behind the scenes; Julia Sammaritano for managing the print ancillaries; Chris Rapp for his creative skill in the creation of digital media that enhance effective communication of content and ideas; and Stacy Loyal for her unwavering support and steadfast commitment to getting this book in the hands of potential users ("Serve that ace!"). The entire Norton team is staffed by skilled, dedicated professionals who are delightful colleagues to work with and, as a bonus, to relax with, as the occasion allows.

Many reviewers, listed here, contributed to the development and production of this book. We owe an extra special thanks to Karen Brewer for her dedicated work on the Solutions Manuals and for her invaluable suggestions on how to improve the inventory and organization of problems and concept questions at the end of each chapter. She, along with Timothy Brewer (Eastern Michigan University) and Timothy W. Chapp (Allegheny College), comprised the triple-check accuracy team who helped ensure the quality of the back-of-book answers and Solutions Manuals. Finally, we wish to acknowledge the care and thoroughness of Drew Brodeur, Hill Harman, Julie Henderleiter, Amy Johnson, Brian Leskiw, Richard Lord, Marc Knecht, Thomas McGrath, Anne-Marie Nickel, Jason Ritchie, Thomas Sorensen, Uma Swamy, Rebecca Weber, and Amanda Wilmsmeyer for checking the accuracy of the myriad facts that frame the contexts and the science in the pages that follow.

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Chemistry

An Atoms-Focused Approach

1

Matter and Energy

An Atomic Perspective

BRONZE AGE BATTLE GEAR This Greek shield decoration from the 6th century BCE is made of bronze, which is a mixture of copper and tin atoms. Tin atoms create irregularities in the layers of copper atoms in bronze. As a result, the layers do not pass each other as easily, making bronze objects harder and less easily deformed than copper objects.

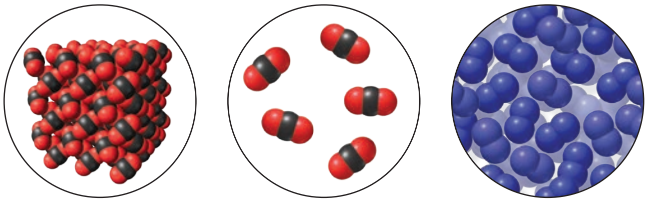
PARTICULATE **REVIEW**

Solids, Liquids, and Gases

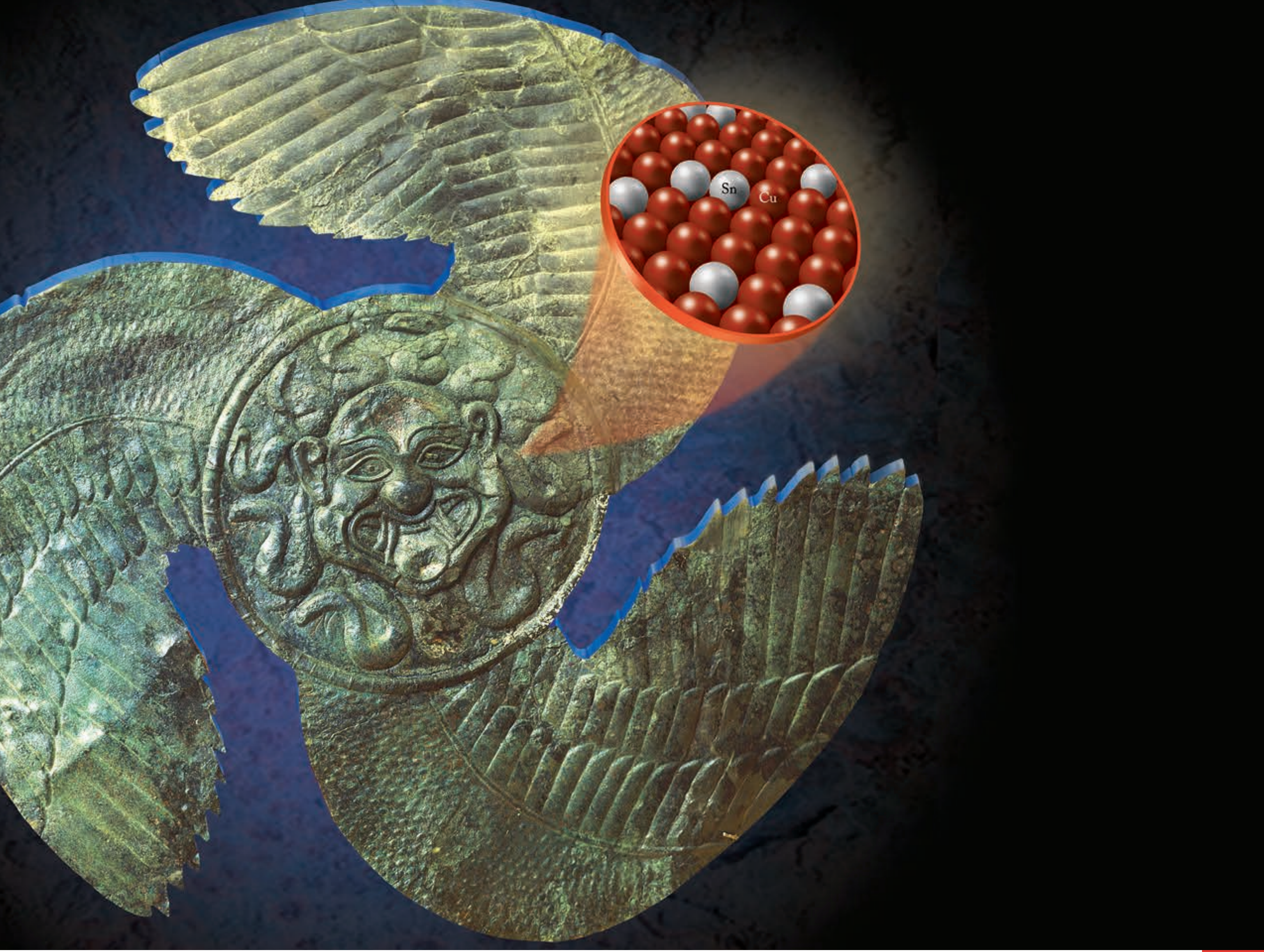
In Chapter 1, we explore the particulate nature of matter. Chemists use colored spheres to represent atoms of different elements. Liquid nitrogen (an element) can be used to make ice cream while dry ice (solid carbon dioxide) is used to keep ice cream cold on a hot day.

- Which representation depicts liquid nitrogen?
- Which representation depicts dry ice?
- Which representation depicts carbon dioxide vapor?

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



(a) (b) (c)

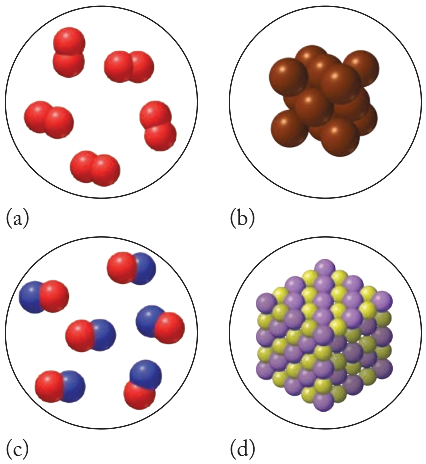


PARTICULATE **PREVIEW**

Elements versus Compounds

The bronze shield on this page is a mixture of copper and tin atoms. Some of the representations shown depict a molecule made of two atoms or an array made from two ions. As you read Chapter 1, look for ideas that will help you answer these questions:

- Which representation depicts molecules of a compound?
- Which representation depicts molecules of an element?
- Which representation depicts a compound consisting of an array of ions?
- Which representation depicts an element consisting of an array of atoms?



Learning Outcomes

LO1 Describe the scientific method

LO2 Apply the COAST approach to solving problems
Sample Exercises 1.1–1.12

LO3 Distinguish between the classes of matter and between the physical and chemical properties of pure substances
Sample Exercises 1.1–1.3

LO4 Describe the states of matter and how their physical properties can be explained by the particulate nature of matter
Sample Exercise 1.4

LO5 Distinguish between heat, work, potential energy, and kinetic energy, and describe the law of conservation of energy

LO6 Use molecular formulas and molecular models to describe the elemental composition and three-dimensional arrangement of the atoms in compounds

LO7 Distinguish between exact and uncertain values and express uncertain values with the appropriate number of significant figures
Sample Exercises 1.5, 1.6

LO8 Accurately convert values from one set of units to another
Sample Exercises 1.7–1.10

LO9 Express the results of experiments in ways that accurately convey their certainty
Sample Exercises 1.11, 1.12

1.1 Exploring the Particulate Nature of Matter

Atoms and Atomism

The chapter-opening photo shows a Greek shield decoration from the 6th century BCE. It's made of bronze, which is a blend of copper and tin. For thousands of years ancient craftsmen produced bronze using furnaces blazing with mixtures of fuel, such as wood or charcoal, and chunks of metal-containing minerals. When the minerals in the furnace contained copper and lesser amounts of tin, the bronze that was produced could be fashioned into tools and weapons that were much stronger and more durable than those made of copper alone.

To ancient metalworkers, turning minerals into metals was more art than science. They knew how to build and operate metal-producing furnaces, called smelters, but they had little understanding of the chemical changes that, for example, converted copper minerals into copper metal. Today we know what those changes are, and we can explain why mixtures of metals such as bronze are much stronger than their parent metals, because *we know the structures of these materials at the atomic level*.

We know, for example, that the atoms in copper metal are arranged in ordered, tightly packed layers, as shown in the opening photo. Copper wire or foil is easily bent because the layers of copper atoms can slide past each other when subjected to an external force. When slightly larger atoms of tin are also present as shown in the magnified view in the opening photo, the resulting imperfections inhibit the layers of copper atoms from sliding past each other. An object made of bronze, therefore, is much harder to bend than if it were made of pure copper. As a result, Bronze Age tools and weapons held their shape better, stayed sharper longer, and, in the case of shields and body armor, provided better protection for warriors in battle.

In this chapter we begin an exploration of how the properties of materials are linked to their atomic-level structure. As we do, we need to acknowledge the Greek philosophers of the late Bronze Age who espoused *atomism*, a belief

atom the smallest particle of an element that retains the chemical characteristics of the element.

scientific theory a concise explanation of widely observed phenomena that has been extensively tested.

element a substance that cannot be separated into simpler substances by any chemical process.

that all forms of matter are composed of extremely tiny, indestructible building blocks called **atoms**. Atomism is an example of a natural philosophy; it is not a **scientific theory**. The difference between the two is that while both seek to explain natural phenomena, scientific theories are concise explanations of natural phenomena based on observation and experimentation, and they are testable. An important quality of a valid scientific theory is that it accurately predicts the results of future experiments and can even serve as a guide to designing those experiments. The ancient Greeks did not have the technology to test whether matter really is made of atoms—but we do.

Consider the images in Figure 1.1. On the bottom is a photograph of silicon (Si) wafers, the material used today to make computer chips and photovoltaic cells. The magnified view above it is a photomicrograph of a silicon wafer produced by an instrument called a scanning tunneling microscope (STM).[1] The fuzzy spheres are individual atoms of silicon, the smallest representative particles of silicon. If you could grind a sample of pure silicon into the finest dust imaginable, the tiniest particle of the dust you could obtain that still had the properties of silicon would be an atom of silicon.

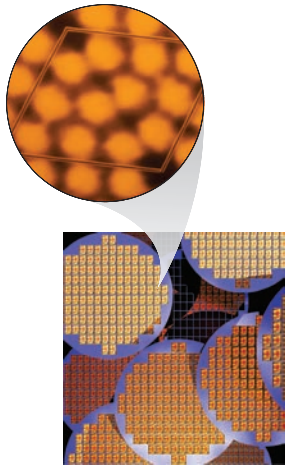


FIGURE 1.1 Silicon wafers are widely used to make computer chips and photovoltaic cells for solar panels. Since the 1980s, scientists have been able to image individual atoms using an instrument called a scanning tunneling microscope (STM). In the STM image (top), the irregular shapes are individual silicon atoms. The radius of each atom is 117 picometers (pm), or 117 trillionths of a meter. Atoms are the tiniest particles of silicon that still retain the chemical characteristics of silicon.

Atomic Theory: The Scientific Method in Action

Scanning tunneling microscopes have been used to image atoms since the early 1980s, but the scientific theory that matter was composed of atoms evolved two centuries earlier during a time when chemists in France and England made enormous advances in our understanding of the composition of matter. Among them was French chemist Antoine Lavoisier (1743–1794), who published the first modern chemistry textbook in 1789. It contained a list of substances that he believed could not be separated into simpler substances. Today we call such “simple” substances **elements** (Figure 1.2). The silicon in Figure 1.1 is an element, as are copper and tin. The periodic table of the elements inside the front cover of this textbook contains over 100 others.

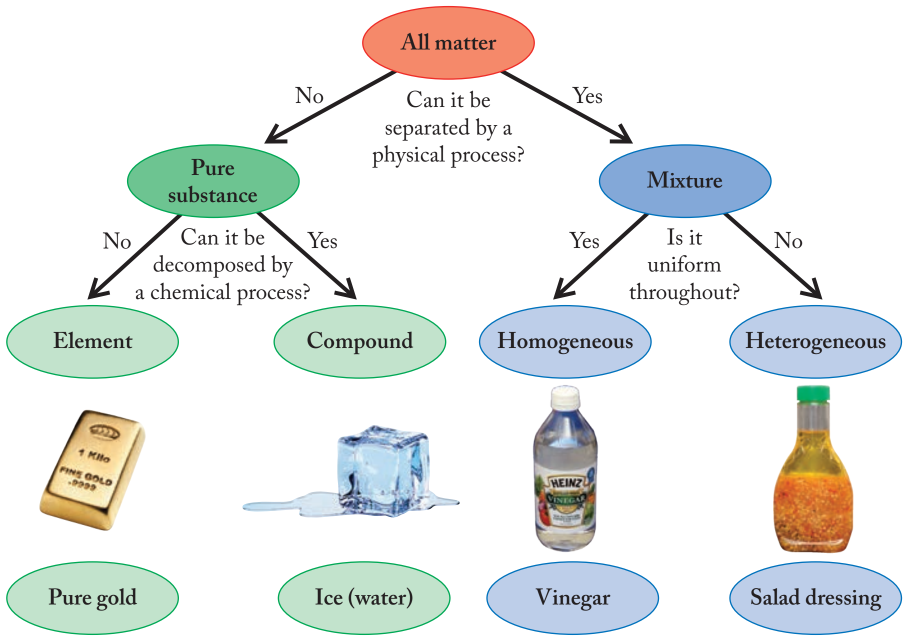


FIGURE 1.2 Matter is classified as shown in this diagram. The two principal categories are pure substances and mixtures. A substance may be a compound (such as water) or an element (such as gold). When the substances making up a mixture are distributed uniformly, as they are in vinegar (a mixture of acetic acid and water), the mixture is homogeneous. When the substances making up a mixture are not distributed uniformly, as in salad dressing, the mixture is heterogeneous.

[1]German physicist Gerd Binnig (b. 1947) and Swiss physicist Heinrich Rohrer (1933–2013) shared the 1986 Nobel Prize in Physics for their development of scanning tunneling microscopy.

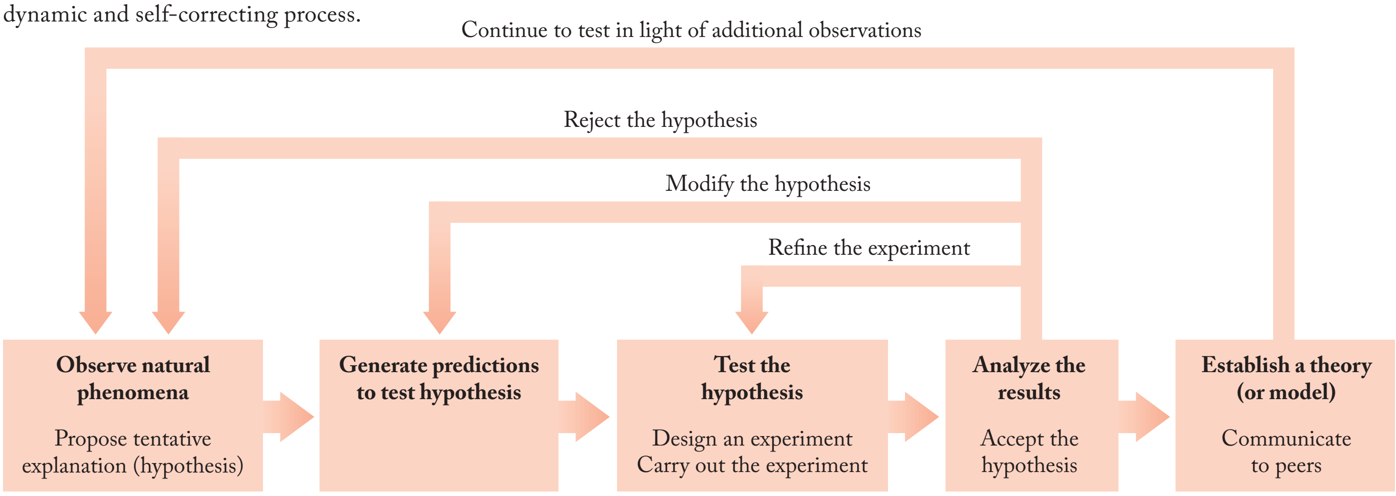
Lavoisier and other scientists conducted experiments that examined the patterns in how elements combined with other elements to form **compounds**. These experiments followed a systematic approach to investigating and understanding natural phenomena known as the **scientific method** (Figure 1.3). When such investigations reveal consistent patterns and relationships, they may be used to formulate concise descriptions of fundamental scientific truths. These descriptions are known as **scientific laws**.

When the French chemist Joseph Louis Proust (1754–1826) studied the composition of compounds containing different metals and oxygen, he concluded that these compounds always contained the same proportions of their component elements. His **law of definite proportions** applies to all compounds. An equivalent law, known as the **law of constant composition**, states that a compound always has the same *elemental composition* by mass no matter what its source. Thus, the composition of pure water is always the same: 11.2% by mass hydrogen and 88.8% by mass oxygen.

When Proust published his law of definite proportions, some of the leading chemists of the time refused to believe it. Their own experiments seemed to show, for example, that the compound that tin formed with oxygen had variable tin content. These scientists did not realize that their samples were actually mixtures of two different compounds with different compositions, which Proust was able to demonstrate. Still, acceptance of Proust's law required more than corroborating results from other scientists; it also needed to be explained by a scientific theory. That is, there needed to be a convincing argument that explained *why* the composition of a compound was always the same.

Scientific laws and theories complement each other in that scientific laws describe natural phenomena and relationships, and scientific theories explain *why* these phenomena and relationships are always observed. Scientific theories usually start out as tentative explanations of why a set of experimental results was obtained or why a particular phenomenon is consistently observed. Such a tentative explanation is called a **hypothesis** (Figure 1.3). An important feature of a hypothesis is that it can be tested through additional observations and experiments. A hypothesis also enables scientists to accurately predict the likely outcomes of future observations and experiments. Further testing and observation might support a hypothesis or disprove it, or perhaps require that it be modified. A hypothesis that withstands the tests of many experiments, accurately explaining further observations and accurately predicting the results of additional experimentation, may be elevated to the rank of scientific theory.

FIGURE 1.3 In the scientific method, observations lead to a tentative explanation, or hypothesis, which leads to more observations and testing, which may lead to the formulation of a succinct, comprehensive explanation called a theory. This process is rarely linear: it often involves looping back, because the results of one test lead to additional tests and a revised hypothesis. Science, when done right, is a dynamic and self-correcting process.



A scientific theory explaining Proust's law of definite proportions was proposed by John Dalton (1766–1844) in 1803. Whereas Proust studied the composition of the solid compounds formed by metals and oxygen, Dalton's own research focused on the composition and behavior of gases. Dalton observed that when two elements combine to form gaseous compounds, they may form two or more different compounds with different compositions. Similarly, Proust had discovered that tin (Sn) and oxygen (O) combined to form one compound that was 88.1% by mass Sn and 11.9% O and a second compound that was 78.8% Sn and 21.2% O. Dalton noted that the ratio of oxygen to tin in the second compound,

$$\frac{21.2\%\ \mathrm{O}}{78.8\%\ \mathrm{Sn}} = 0.269$$

was very close to twice of what it was in the first compound,

$$\frac{11.9\%\ \mathrm{O}}{88.1\%\ \mathrm{Sn}} = 0.135$$

Similar results were obtained with other sets of compounds formed by pairs of elements. Sometimes their compositions would differ by a factor of 2, as with oxygen and tin (and with oxygen and carbon), and sometimes their compositions differed by other factors, but in all cases they differed *by ratios of small whole numbers*. This pattern led Dalton to formulate the **law of multiple proportions**: when two elements combine to make two (or more) compounds, the ratio of the masses of one of the elements, which combine with a given mass of the second element, is always a ratio of small whole numbers. For example, 15 grams of oxygen combines with 10 grams of sulfur under one set of reaction conditions, whereas only 10 grams of oxygen combines with 10 grams of sulfur to form a different compound under a different set of reaction conditions. The ratio of the two masses of oxygen,

$$\frac{15\ \cancel{\text{g oxygen}}}{10\ \cancel{\text{g oxygen}}} = \frac{3}{2}$$

is indeed a ratio of two small whole numbers and is consistent with Dalton's law of multiple proportions.

To explain the laws of definite proportions and multiple proportions, Dalton proposed the scientific theory that *elements are composed of atoms*. Thus, Proust's compound with the O:Sn ratio of 0.135 contains one atom of oxygen for each atom of tin, whereas his compound with twice that O:Sn ratio (0.269) contains *two* atoms of O per atom of Sn. These atomic ratios are reflected in the **chemical formulas** of the two compounds: SnO and SnO_2, in which the subscripts after the symbols represent the relative number of atoms of each element in the substance. The absence of a subscript means the formula contains one atom of the preceding element. Similarly, the two compounds that sulfur and oxygen form have an oxygen ratio of 3:2 because their chemical formulas are SO_3 and SO_2, respectively.

Since the early 1800s, scientists have learned much more about the atomic, and even subatomic, structure of the matter that makes up our world and the universe that surrounds us. Although the laws developed two centuries ago are still useful, Dalton's atomic theory, like many theories, has undergone revisions as new discoveries have been made. Dalton assumed, for example, that all of the atoms of a particular element were the same. We will see in Chapter 2 that atoms have internal components and structures, only some of which are the same for all the atoms of a given element. Atoms can differ in other ways, too, that the scientists of 1800 could not have observed or even imagined.

compound a substance composed of characteristic proportions of two or more elements chemically bonded together.

scientific method an approach to acquiring knowledge based on the observation of phenomena, the development of a testable hypothesis, and additional experiments that test the validity of the hypothesis.

scientific law a concise and generally applicable statement of a fundamental scientific principle.

law of definite proportions the principle that compounds always contain the same proportions of their component elements.

law of constant composition the principle that all samples of a particular compound have the same elemental composition.

hypothesis a tentative and testable explanation for an observation or a series of observations.

law of multiple proportions the principle that, when two masses of one element react with a given mass of another element to form two different compounds, the two masses of the first element have a ratio of two small whole numbers.

chemical formula a notation for representing the elemental composition of a pure substance using the symbols of the elements; subscripts indicate the relative number of atoms of each element in the substance.

1.2 COAST: A Framework for Solving Problems

Throughout the rest of this chapter and this book, you will find Sample Exercises designed to help you better understand chemical concepts and develop your problem-solving skills. Each Sample Exercise follows a systematic approach to problem solving that we encourage you to apply to the Practice Exercises that follow each Sample Exercise and to the end-of-chapter problems. We use the acronym COAST (**C**ollect and **O**rganize, **A**nalyze, **S**olve, and **T**hink about the answer) to represent the four steps in our approach to problem solving. As you read about it here and use it later, keep in mind that COAST is merely a *framework* for solving problems, not a recipe. Use it as a guide to help you develop your own approach to solve each problem.

Collect and Organize First, start by sorting through the information given in the problem and identifying other relevant information. These actions help you understand the problem, including the fundamental chemical principles on which it is based. As part of the collecting and organizing process,

- Identify the key concept of the problem.
- Identify and define the key terms used to express that concept. You may find it useful to restate the problem in your own words.
- Sort through the information given in the problem, separating what is pertinent from what is not.
- Assemble any supplemental information that may be needed, including equations, definitions, and constants.

Analyze The next step is to analyze the information you have collected to determine how to relate it to the answer you seek. Sometimes it is easier to work backward to create the relationships: consider the nature of the answer first, and think about how you might get to it from the information provided in the problem and other sources. If the problem is quantitative and requires a numerical answer, frequently the units of the initial values and the final answer will help you identify how they are connected and which equation (or equations) may be useful.

For some problems, drawing a sketch based on molecular models or an experimental setup may help you visualize how the starting points and final answer are connected. You should also look at the numbers involved and estimate your answer. Having an order-of-magnitude ("ballpark") estimate of your final answer before entering numbers into your calculator provides a check on the accuracy of your calculated answer.

Some Sample Exercises test your understanding of a single concept or their solution involves only a single step. In these exercises we may combine the Collect and Organize and the Analyze steps.

Solve For most conceptual questions, the solution flows directly from your analysis of the problem. To solve quantitative problems, you need to insert the starting values and the appropriate constants into the relevant equations or conversion factors and calculate the answer. In the Solve step, make sure that units are consistent and cancel as needed and that the certainty of the quantitative information is reflected in how many *significant figures* (see Section 1.7) you used.

Think About It Finally, you need to think about your result. Does your answer make sense based on your own experience and what you have just learned? Is the value for a quantitative answer reasonable—is it close to your estimate from the

Analyze step? Are the units correct and the number of significant figures appropriate? Then ask yourself how confident you are that you could solve another problem, perhaps drawn from another context but based on the same chemical concept. You may also think about how this problem relates to other observations you may have made about matter in your daily life.

The COAST approach should help you solve problems in a logical way and avoid certain pitfalls, such as grabbing an equation that seems to have the right variables and simply plugging numbers into it or resorting to trial and error. As you study the steps in each Sample Exercise, try to answer these questions about each step:

- **What** is done in this step?
- **How** is it done?
- **Why** is it done?

After answering the questions, you will be ready to solve the Practice Exercises and end-of-chapter problems in a systematic way.

1.3 Classes and Properties of Matter

All things that are physically real—from the air we breathe to the ground we walk on—are forms of matter. Scientists define **matter** as everything in the universe that has **mass (*m*)** and occupies space. **Chemistry** is the study of the composition, structure, and properties of matter and the changes it undergoes.

Matter is classified based on its composition, as shown in Figure 1.2. The simplest forms of matter—elements and compounds—are pure substances with compositions that do not change unless they are involved in a chemical reaction. They also have distinctive properties. Pure gold, for example (Figure 1.4a), has a distinctive color; it's soft for a metal, it's malleable (it can be hammered into very thin sheets called gold leaf), it's ductile (it can be drawn into thin wires), and it melts at 1064°C. These properties, which characterize a pure substance but are independent of the amount of the substance in a sample, are called **intensive properties**. Other properties, such as the particular length, width, mass, and volume of an ingot of gold, are called **extensive properties** because they depend on how much of the substance is present in a particular sample.

The properties of substances are either *physical* or *chemical*. **Physical properties**, such as those described for gold in the previous paragraph, can be observed or measured without changing the substance into another substance. Another physical property is **density (*d*)**, which is the ratio of the mass (*m*) of a substance or object to its volume (*V*):

$$d = \frac{m}{V} \qquad (1.1)$$

matter anything that has mass and occupies space.

mass (*m*) the property that defines the quantity of matter in an object.

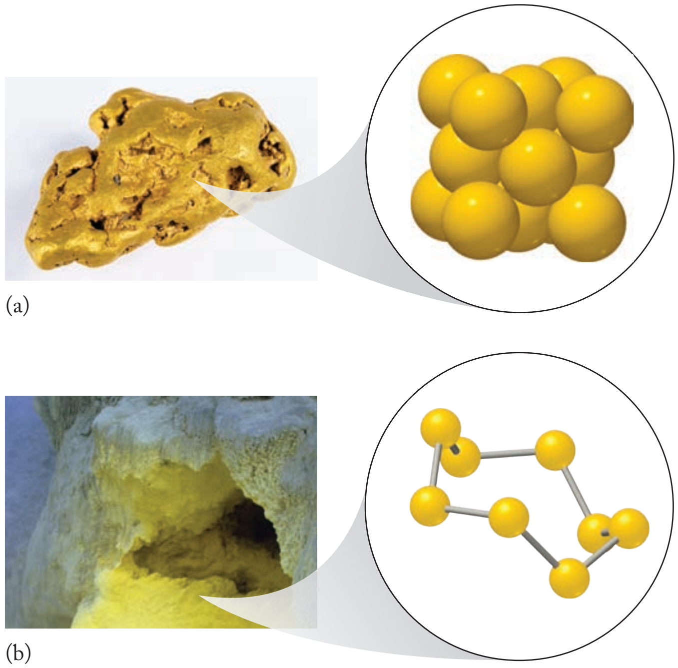
chemistry the study of the composition, structure, and properties of matter and of the energy consumed or given off when matter undergoes a change.

intensive property a property that is independent of the amount of substance present.

extensive property a property that varies with the amount of substance present.

physical property a property of a substance that can be observed without changing the substance into another substance.

density (*d*) the ratio of the mass (*m*) of an object to its volume (*V*).



(a)

(b)

FIGURE 1.4 (a) Gold and (b) sulfur are among the few elements that may occur in nature uncombined with other elements.

CONCEPT TEST

Which of the following properties of a sample of pure iron are intensive? (a) mass, (b) density, (c) volume, (d) hardness

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