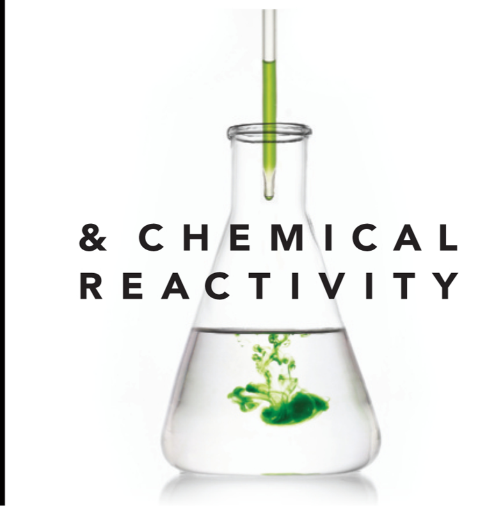
CHEMISTRY & CHEMICAL REACTIVITY 9E



KOTZ
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Periodic Table of the Elements

- MAIN GROUP METALS
- TRANSITION METALS
- METALLOIDS
- NONMETALS

Key	
Uranium	
92	Atomic number
U	Symbol
238.0289	Atomic weight

Period	1A (1)	2A (2)	3B (3)	4B (4)	5B (5)	6B (6)	7B (7)	8B (8)	8B (9)	8B (10)
1	Hydrogen 1 H 1.0079									
2	Lithium 3 Li 6.941	Beryllium 4 Be 9.0122								
3	Sodium 11 Na 22.9898	Magnesium 12 Mg 24.3050								
4	Potassium 19 K 39.0983	Calcium 20 Ca 40.078	Scandium 21 Sc 44.9559	Titanium 22 Ti 47.867	Vanadium 23 V 50.9415	Chromium 24 Cr 51.9961	Manganese 25 Mn 54.9380	Iron 26 Fe 55.845	Cobalt 27 Co 58.9332	Nickel 28 Ni 58.6934
5	Rubidium 37 Rb 85.4678	Strontium 38 Sr 87.62	Yttrium 39 Y 88.9059	Zirconium 40 Zr 91.224	Niobium 41 Nb 92.9064	Molybdenum 42 Mo 95.96	Technetium 43 Tc (97.907)	Ruthenium 44 Ru 101.07	Rhodium 45 Rh 102.9055	Palladium 46 Pd 106.42
6	Cesium 55 Cs 132.9055	Barium 56 Ba 137.327	Lanthanum 57 La 138.9055	Hafnium 72 Hf 178.49	Tantalum 73 Ta 180.9479	Tungsten 74 W 183.84	Rhenium 75 Re 186.207	Osmium 76 Os 190.23	Iridium 77 Ir 192.22	Platinum 78 Pt 195.084
7	Francium 87 Fr (223.02)	Radium 88 Ra (226.0254)	Actinium 89 Ac (227.0278)	Rutherfordium 104 Rf (265)	Dubnium 105 Db (268)	Seaborgium 106 Sg (271)	Bohrium 107 Bh (270)	Hassium 108 Hs (277)	Meitnerium 109 Mt (276)	Darmstadtium 110 Ds (281)

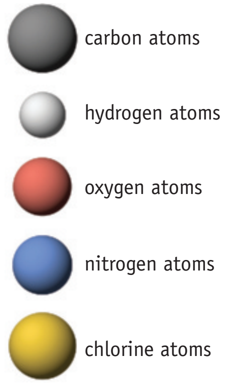
Lanthanides	Cerium 58 Ce 140.116	Praseodymium 59 Pr 140.9076	Neodymium 60 Nd 144.242	Promethium 61 Pm (144.91)	Samarium 62 Sm 150.36	Europium 63 Eu 151.964
Actinides	Thorium 90 Th 232.0381	Protactinium 91 Pa 231.0359	Uranium 92 U 238.0289	Neptunium 93 Np (237.0482)	Plutonium 94 Pu (244.664)	Americium 95 Am (243.061)

Note: Atomic masses are 2009 IUPAC values (up to four decimal places). Numbers in parentheses are atomic masses or mass numbers of the most stable isotope of an element.

1B (11)	2B (12)	3A (13)	4A (14)	5A (15)	6A (16)	7A (17)	8A (18)
							Helium 2 He 4.0026
		Boron 5 B 10.811	Carbon 6 C 12.011	Nitrogen 7 N 14.0067	Oxygen 8 O 15.9994	Fluorine 9 F 18.9984	Neon 10 Ne 20.1797
		Aluminum 13 Al 26.9815	Silicon 14 Si 28.0855	Phosphorus 15 P 30.9738	Sulfur 16 S 32.066	Chlorine 17 Cl 35.4527	Argon 18 Ar 39.948
Copper 29 Cu 63.546	Zinc 30 Zn 65.38	Gallium 31 Ga 69.723	Germanium 32 Ge 72.63	Arsenic 33 As 74.9216	Selenium 34 Se 78.96	Bromine 35 Br 79.904	Krypton 36 Kr 83.798
Silver 47 Ag 107.8682	Cadmium 48 Cd 112.411	Indium 49 In 114.818	Tin 50 Sn 118.710	Antimony 51 Sb 121.760	Tellurium 52 Te 127.60	Iodine 53 I 126.9045	Xenon 54 Xe 131.293
Gold 79 Au 196.9666	Mercury 80 Hg 200.59	Thallium 81 Tl 204.3833	Lead 82 Pb 207.2	Bismuth 83 Bi 208.9804	Polonium 84 Po (208.98)	Astatine 85 At (209.99)	Radon 86 Rn (222.02)
Roentgenium 111 Rg (280)	Copernicium 112 Cn (285)	Ununtrium 113 Uut Discovered 2004	Flerovium 114 Fl (289)	Ununpentium 115 Uup Discovered 2004	Livermorium 116 Lv (292)	Ununseptium 117 Uus Discovered 2010	Ununoctium 118 Uuo Discovered 2002

Gadolinium 64 Gd 157.25	Terbium 65 Tb 158.9254	Dysprosium 66 Dy 162.50	Holmium 67 Ho 164.9303	Erbium 68 Er 167.26	Thulium 69 Tm 168.9342	Ytterbium 70 Yb 173.054	Lutetium 71 Lu 174.9668
Curium 96 Cm (247.07)	Berkelium 97 Bk (247.07)	Californium 98 Cf (251.08)	Einsteinium 99 Es (252.08)	Fermium 100 Fm (257.10)	Mendelevium 101 Md (258.10)	Nobelium 102 No (259.10)	Lawrencium 103 Lr (262.11)

Standard Colors for Atoms in Molecular Models



Ninth Edition

CHEMISTRY & CHEMICAL REACTIVITY

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Brief Contents

Contents

PART TWO ▶ ATOMS AND MOLECULES

PART THREE ▶ STATES OF MATTER

PART FOUR ▶ THE CONTROL OF CHEMICAL REACTIONS

PART FIVE ▶ THE CHEMISTRY OF THE ELEMENTS

List of Appendices A-1

Index/Glossary I-1

Preface

The first edition of this book was conceived over 30 years ago. Since that time there have been eight editions, and over 1 million students worldwide have used the book to begin their study of chemistry. Over the years, and the many editions, our goals have remained the same: to provide a broad overview of the principles of chemistry, the reactivity of the chemical elements and their compounds, and the applications of chemistry. To reach these goals, we have tried to show the close relation between the observations chemists make of chemical and physical changes in the laboratory and in nature and the way these changes are viewed at the atomic and molecular levels.


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Sulfur burns in pure oxygen with a brilliant blue flame.

We have also tried to convey a sense that chemistry not only has a lively history but is also dynamic, with important new developments occurring every year. Furthermore, we have provided some insight into the chemical aspects of the world around us. Indeed, a major objective of this book has always been to provide the tools needed for our students to function as chemically literate citizens. Learning about the chemical world is just as important as understanding some basic mathematics and biology and as important as having an appreciation for history, music, and literature. For example, students should know something about the many materials that are important in our economy and in our daily lives. Furthermore, they should know how chemistry is important in understanding our environment. In this regard, one growing area of chemistry, highlighted throughout the previous edition and this one, is "green" or "sustainable" chemistry.

Looking back over the previous editions, we can see how the book has changed. There have been many new and exciting additions to the contents. In addition, there have been significant advances in the technology of communicating information, and we have taken advantage of those new developments. A desire to make the book even better for our students has been the impetus behind the preparation of each new edition. Over the last two editions we have introduced new approaches to problem solving, new ways to describe contemporary uses of chemistry, new technologies, and improved integration with existing technologies.

Audience for *Chemistry & Chemical Reactivity*

This textbook (both as a printed book and the digital versions) is designed for students interested in further study in science, whether that science is chemistry, biology, engineering, geology, physics, or related subjects. Our assumption is that students in a course using this book have had some preparation in algebra and in general science. Although undeniably helpful, a previous exposure to chemistry is neither assumed nor required.

Philosophy and Approach of *Chemistry & Chemical Reactivity*

We have had several major, but not independent, objectives since the first edition of the book. The first was to write a book that students would enjoy reading and that would offer, at a reasonable level of rigor, chemistry and chemical principles in a format and organization typical of college and university courses today. Second, we wanted to convey the utility and importance of chemistry by introducing the properties of the elements, their compounds, and their reactions.

The American Chemical Society has been urging educators to put "chemistry" back into introductory chemistry courses. We agree wholeheartedly. Therefore, we have tried to describe the elements, their compounds, and their reactions as early and as often as possible by:

- Bringing **material on the properties of elements and compounds** as early as possible into the Examples and Study Questions (and especially the *Applying Chemical Principles* questions) and introducing new principles using realistic chemical situations.

What's New in This Edition

General Comments

As we have done for all of the previous editions, we examined every paragraph for accuracy, clarity, and brevity. Where improvements could be made, paragraphs or entire sections were rewritten. We also wrote or rewrote many chapter-opening stories, *Closer Look* boxes, and *Case Studies*.

Some of the important additions from the 8th edition were retained. In particular, we kept and expanded

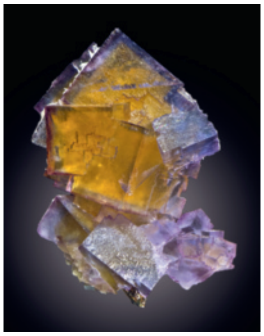
- the Review & Check questions.
- the organization of the Example problems.
- the Strategy Maps.
- an emphasis on green chemistry.
- the *Applying Chemical Principles* problems.

Changes from the 8th to the 9th Edition

A number of changes have been made for the 9th edition. This page *briefly* lists the most important; a more detailed list is given beginning on page xxii.

- Many of the illustrations have been redesigned with an emphasis on bringing information from the caption into the illustration itself.
- We have dropped the special topic coverage provided in the 8th edition from the interchapters and integrated the material into regular chapters.
    - Historical developments have been incorporated into Chapter 2 and elsewhere.
    - Material on solid state chemistry has been added to the chapter on solids (12).
    - The interchapters on fuels and energy and on environmental chemistry are incorporated into a new chapter (20), *Environmental Chemistry—Earth's Environment, Energy, and Sustainability*.
    - The topic of biochemistry has been expanded into a full chapter (24).
- Chapter goals or objectives for each chapter have been recast into three categories that most express what students should get out of the course. These goals are:
    - **UNDERSTAND** chapter concepts.
    - **DO**. Be able carry out calculations, draw molecular structures, and make chemical decisions.
    - **REMEMBER** important facts and chemical concepts.

    The objectives are repeated and amplified at the end of the chapter in the *Chapter Goals Revisited* section.
- Answers to questions in a chapter—Study Questions plus Check Your Understanding, Review & Check, *Case Studies*, and *Applying Chemical Principles*—are collected in Appendix N (rather than scattered over several appendices as in previous editions). This will allow students to more efficiently check their work.
- Over 100 new Study Questions have been added and a similar number have been revised.
- Example problems and end-of-chapter Study Questions that are interactive in OWL have been retained. All questions have been re-examined for clarity and relevance.
- *Applying Chemical Principles* questions have been moved from the very end of the chapter (following all of the Study Questions), to the last text material in the chapter.



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Fluorite crystals (CaF_2).

- Using numerous **photographs** of the elements and common compounds, of chemical reactions, and of common laboratory operations and industrial processes.
- Introducing each chapter with a **discussion of contemporary chemistry** such as the use of copper surfaces in hospitals, energy in common foods, and lithium in car batteries.
- Using numerous *Case Studies* and *Applying Chemical Principles* study questions that delve into practical chemistry.

General Organization

Through its many editions, *Chemistry & Chemical Reactivity* has had two broad themes: *Chemical Reactivity* and *Bonding and Molecular Structure*. The chapters on *Principles of Reactivity* introduce the factors that lead chemical reactions to be successful in converting reactants to products. Under this topic there is a discussion of common types of reactions, the energy involved in reactions, and the factors that affect the speed of a reaction. One reason for the enormous advances in chemistry and molecular biology in the last several decades has been an understanding of molecular structure. The sections of the book on *Principles of Bonding and Molecular Structure* lay the groundwork for understanding these developments. Particular attention is paid to an understanding of the structural aspects of such biologically important molecules as DNA.

Flexibility of Chapter Organization

A glance at the introductory chemistry texts currently available shows that there is a generally accepted order of topics used by most educators. With only minor variations, we have followed that order. That is not to say that the chapters in our book cannot be used in some other order. We have written this book to be as flexible as possible. An example is the **flexibility of covering the behavior of gases** (Chapter 10). It has been placed with chapters on liquids, solids, and solutions (Chapters 10–13) because it logically fits with those topics. However, it can easily be read and understood after covering only the first four chapters of the book.

Similarly, chapters on atomic and molecular structure (Chapters 6–9) could be used in an **atoms-first approach** before the chapters on stoichiometry and common reactions (Chapters 3 and 4). To facilitate this, there is an introduction to energy and its units in Chapter 1.

Also, the chapters on chemical equilibria (Chapters 15–17) can be covered before those on solutions and kinetics (Chapters 13 and 14).

Organic chemistry (Chapter 23) is one of the final chapters in the textbook. However, the topics of this chapter can also be presented to students following the chapters on structure and bonding.

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A fireworks sparkler.

The order of topics in the text was also devised to introduce as early as possible the background required for the laboratory experiments usually performed in introductory chemistry courses. For this reason, chapters on chemical and physical properties, common reaction types, and stoichiometry begin the book. In addition, because an understanding of energy is so important in the study of chemistry, energy and its units are introduced in Chapter 1, and thermochemistry is introduced in Chapter 5.

Organization and Purposes of the Sections of the Book

PART ONE: The Basic Tools of Chemistry

The basic ideas and methods of chemistry are introduced in Part 1. Chapter 1 defines important terms, and the accompanying *Let's Review* section reviews units and mathematical methods. Chapter 2 introduces atoms, molecules, and ions, and the most important organizational device in chemistry, the periodic table. In Chapter 3, we begin to discuss the principles of chemical activity. Writing chemical equations is covered here, and there is a short introduction to equilibrium. Then, in Chapter 4, we describe the numerical methods used by chemists to extract quantitative information from chemical reactions. Chapter 5 is an introduction to the energy involved in chemical processes.

PART TWO: Atoms and Molecules

The current theories of the arrangement of electrons in atoms are presented in Chapters 6 and 7. This discussion is tied closely to the arrangement of elements in the periodic table and to periodic properties. In Chapter 8 we discuss the details of chemical bonding and the properties of these bonds. In addition, we show how to derive the three-dimensional structure of simple molecules. Finally, Chapter 9 considers the major theories of chemical bonding in more detail.

PART THREE: States of Matter

The behavior of the three states of matter—gases, liquids, and solids—is described in Chapters 10–12. The discussion of liquids and solids is tied to gases through the description of intermolecular forces in Chapter 11, with particular attention given to liquid and solid water. In Chapter 13 we describe the properties of solutions, intimate mixtures of gases, liquids, and solids.

PART FOUR: The Control of Chemical Reactions

This section is wholly concerned with the *Principles of Reactivity*. Chapter 14 examines the rates of chemical processes and the factors controlling these rates. Next, we move to Chapters 15–17, which describe chemical equilibrium. After an introduction to equilibrium in Chapter 15, we highlight the reactions involving acids and bases in water (Chapters 16 and 17) and reactions leading to slightly soluble salts (Chapter 17). To tie together the discussion of chemical equilibria and thermodynamics, we explore entropy and free energy in Chapter 18. As a final topic in this section we describe in Chapter 19 chemical reactions involving the transfer of electrons and the use of these reactions in electrochemical cells.

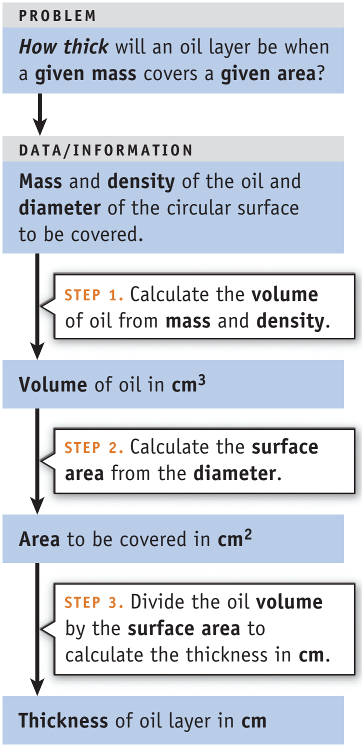
PART FIVE: The Chemistry of the Elements

Although the chemistry of the various elements is described throughout the book, Part 5 considers this topic in a more systematic way. Chapter 20 brings together many of the concepts in earlier chapters into a discussion of *Environmental Chemistry—Earth's Environment, Energy, and Sustainability.* Chapter 21 is devoted to the chemistry of the main group elements, whereas Chapter 22 is a discussion of the transition elements and their compounds. Chapter 23 is a brief discussion of organic chemistry with an emphasis on molecular structure, basic reactions types, and polymers. Chapter 24 is an introduction to biochemistry, and Chapter 25 is an overview of nuclear chemistry.

Features of the Book

Some years ago a student of one of the authors, now an accountant, shared an interesting perspective with us. He said that, while general chemistry was one of his hardest subjects, it was also the most useful course he had taken because it taught him how to solve problems. We were gratified by this perspective. We have always thought that, for many students, an important goal in general chemistry was not only to teach students chemistry but also to help them learn critical thinking and problem-solving skills. Many of the features of the book are meant to support those goals.

Strategy Map for Example 5



Problem-Solving Approach: Organization and Strategy Maps

Worked-out examples are an essential part of each chapter. To better assist students in following the logic of a solution, these problems are organized around the following outline:

Problem
This is the statement of the problem.
What Do You Know?
The information given is outlined.
Strategy
The information available is combined with the objective and we begin to devise a pathway to a solution.
Solution
We work through the steps, both logical and mathematical, to the answer.
Think About Your Answer
We ask if the answer is reasonable or what it means.
Check Your Understanding
This is a similar problem for the student to try. A solution to the problem is in Appendix N.

For many students, a **visual strategy map** can be a useful tool in solving the problem. For example, on pages 42–43, we ask how thick the oil layer would be if you spread a given mass of oil on the surface of water in a dish. The density of the oil is also given. To help see the logic of the problem, the Example is accompanied by the Strategy Map given here. There are approximately 60 such Strategy Maps in the book accompanying Example problems.

Review & Check: Quick Review Questions

In the 8th edition we added multiple choice *Review & Check* questions at the end of almost every section, and these have proved popular. Students can check their understanding of the section by attempting these brief questions. Answers to the questions are in Appendix N.

Chapter Goals/Revisited

The learning goals for each chapter are listed on the first page of each chapter. For this edition, we have organized these around the major tasks facing a student:

- What do you need to **UNDERSTAND** in the chapter.
- What do you need to be able to **DO**.
- What do you need to **REMEMBER** about the materials in the chapter.

The goals are revisited on the last page of the chapter. Each goal is given in more detail, and specific end-of-chapter Study Questions are listed that help students determine if they have met those goals.

End-of-Chapter Study Questions

There are 50 to over 150 Study Questions for each chapter (and answers to the odd-numbered questions are given in Appendix N). They are grouped as follows:

Practicing Skills: These questions are grouped by the topic covered by the questions.
General Questions: There is no indication regarding the type of question.
In the Laboratory: These are problems that may be encountered in a laboratory experiment on the chapter material.
Summary and Conceptual Questions: These questions use concepts from the current chapter as well as preceding chapters.

Study Questions are available in the OWL Online Web Learning system. The OWL system now has over 1900 of the roughly 2200 Study Questions in the book.

Finally, note that some questions are marked with a small red triangle (▲). These are meant to be more challenging than other questions.

Boxed Essays

As in the 8th edition, there are boxed essays titled *A Closer Look* (for a more in-depth look at relevant material), and *Problem Solving Tips*. We have added or revised a number of the *Case Studies*, some of which describe "green" or sustainable chemistry.

Changes for the 9th Edition

Significant changes from the 8th edition to this edition have been outlined in the section on "What's New." In addition, we have produced new photos and new illustrations and have continually tried to improve the writing throughout. The following chapter-by-chapter listing indicates specific changes from the 8th edition of the book to this edition.

Chapter 1 Basic Concepts of Chemistry and Let's Review: The Tools of Quantitative Chemistry

- The introductory story on gold has been rewritten.
- The figure on chemical and physical properties has been redone completely.

Chapter 2 Atoms, Molecules, and Ions

- There is a new introductory story on "seeing atoms" with a scanning-tunneling microscope.
- A new two-page spread *Key Experiments–How Do We Know the Nature of the Atom and Its Components?* has been added. This covers the main ideas from the interchapter on the history of chemistry from the 7th and 8th editions.
- The section in the 8th edition on hydrated compounds is now a *Closer Look* box.

Chapter 3 Chemical Reactions

- There is a new *Closer Look* box, *Alternative Organizations of Reaction Types*. Our reaction organization scheme is slightly different than the one used in Advanced Placement (AP) chemistry, so this box relates our scheme to the AP nomenclature.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Corundum crystal (Al_2O_3).

Chapter 4 Stoichiometry: Quantitative Information about Chemical Reactions

- The introduction to solving stoichiometry problems is laid out in a new way to help students better follow this vitally important topic.

Chapter 5 Principles of Chemical Reactivity: Energy and Chemical Reactions

- We expanded coverage of the first law of thermodynamics with more details on work. This includes a revised *Closer Look* box, a new Example problem, and new Study Questions.
- We updated the data on world energy usage and, in a *Closer Look* box, updated the information on ethanol in gasoline.

Chapter 6 The Structure of Atoms

- A new opening story on charge coupled devices has been added.
- There is a new *Example* problem on using Planck's law.
- A new *Closer Look* box on *Sunburn, Sunscreens, and Ultraviolet Radiation* has been added.
- Information on diamagnetism and paramagnetism has been moved to Chapter 7.

Chapter 7 The Structure of Atoms and Periodic Trends

- More on photoelectron spectroscopy has been incorporated with a new *Closer Look* box and four new Study Questions (33–36).

Chapter 8 Bonding and Molecular Structure

- There is a new *Closer Look* box, *A Triangular View of Chemical Bonding*. In this we introduce the van Arkel-Ketelaar diagram that shows the continuum of bonding models, an important concept in an introductory course.
- The introduction to electron dot structures has been changed to better show the steps involved in their construction, and new examples have been added.
- A new subsection has been added on drawing Lewis structures for organic molecules.

Chapter 9 Bonding and Molecular Structure: Orbital Hybridization and Molecular Orbitals

- Chemists have been rethinking the importance of *d* orbitals in bonding. As we state in Chapter 9, "current research indicates there is little evidence for *d* orbital participation in bonding in hypervalent molecules." This conclusion has been widely accepted in the chemical community, and has been integrated into our discussion of bonding in compounds such as PF_5 and SF_6.
- The *Applying Chemical Principles* question on photoelectron spectroscopy has been retained.

Chapter 10 Gases and Their Properties

- There is a new discussion on the behavior of real gases (Section 10-8).

- A new *Case Study, The Methane Mystery* has been added.
- A new *Closer Look* box was added: *Surface Science and the Need for Ultrahigh Vacuum Systems.*


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Sulfur-containing minerals.

Chapter 11 Intermolecular Forces and Liquids

- In 2011 the International Union of Pure and Applied Chemistry (IUPAC) redefined the concept of hydrogen bonding. The IUPAC perspective has been incorporated, and we have expanded our discussion on hydrogen bonding.
- The *Closer Look* box on supercritical CO_2 was extensively rewritten.

Chapter 12 The Solid State

- There is a new introductory story on jade, the subject of the cover photo.
- The *Case Study* on graphene was extensively rewritten to reflect research and development in this important new area.
- In the section on phase changes (12-6), there is a new *Closer Look* box on *New Memory for Your Computer Based on Phase Changes*.

Chapter 13 Solutions and Their Behavior

- There is a new chapter introduction on *Narcosis and the Bends.*
- A new *Closer Look* box on *Growing Crystals* was added. This is about growing large crystals, something students can do with alum from the supermarket.

Chapter 14 Chemical Kinetics: The Rates of Chemical Reactions

- A *Closer Look* box, *Rate Laws, Rate Constants, and Reaction Stoichiometry*, was added to the chapter.
- A new *Closer Look* box was added, *Thinking About Bond Energies*, which relates bond energies to kinetic parameters.
- Several changes have been made in Section 14-6, Reaction Mechanisms. Many students go on to organic chemistry, so a new *Closer Look* box covers *Organic Bimolecular Substitution Reactions*. A new subsection on chain reactions was added.
- New *Problem Solving Tip 14.1: Determining a Rate Equation.*

Chapter 15 Principles of Chemical Reactivity: Equilibria

- The introductory story on equilibria in an aqueous solution of cobalt(II) ions was rewritten.

Chapter 16 Principles of Chemical Reactivity: The Chemistry of Acids and Bases

- New introductory story on *Alkaloids and Toxins.*

Chapter 17 Principles of Chemical Reactivity: Other Aspects of Aqueous Equilibria

- The introductory story on *Nature's Acids* was rewritten.
- There is increased emphasis on using the Henderson-Hasselbalch equation in buffer calculations.

Chapter 18 Principles of Chemical Reactivity: Entropy and Free Energy

- The introductory article on hydrogen was rewritten.
- The important section on Gibbs free energy (18.6) was carefully examined to reflect the exposition of free energy by J. Quilez in the *Journal of Chemical Education* ("First-Year University Chemistry Textbooks' Misrepresentation of Gibbs Energy," *Journal of Chemical Education*, Vol. 89, 87-93, 2012).
- There is a new *Example* (18.9) on calculating the Gibbs free energy change for a process run under nonstandard conditions. This clarifies the difference between $\Delta_r G$ and $\Delta_r G^\circ$.

Chapter 19 Principles of Chemical Reactivity: Electron Transfer Reactions

- There is a new introduction on lithium ion batteries.

Chapter 20 Environmental Chemistry—Earth's Environment, Energy, and Sustainability

- This new chapter uses concepts developed in earlier chapters to focus on the environment. Some material was taken from the 8th edition interchapters on energy and on the environment. However, all was rewritten and much new material was added.

Chapter 21 The Chemistry of the Main Group Elements

- The *Closer Look* box on *The Reducing Ability of the Alkali Metals* was rewritten.

- A new *Closer Look* box on *Green Cement* was added.
- The *Closer Look* box on *Iodine and Your Thyroid Gland* was moved into this chapter from the nuclear chemistry chapter in the 8th edition.
- A new section (21-11) on noble gases has been added as well as the *Closer Look* box *Predicting the Existence of Xenon Fluorides*.

Chapter 22 The Chemistry of the Transition Elements

- A new introductory story about *Life-Saving Copper* was written for this chapter.
- The *Case Study* on *High-Strength Steel* has been moved to this chapter from its location in the 8th edition (the solids chapter).
- New *Case Study* was added on *The Rare Earths*.
- The 8th edition section on organometallic chemistry has been dropped.
- The concept of chirality is introduced in this chapter (rather than in the organic chemistry chapter as in the 8th edition).

Chapter 23 Carbon: Not Just Another Element

- This introduction to organic chemistry was Chapter 10 in the 8th edition.
- A new *Closer Look* box was added on *Omega-3-Fatty Acids*.
- The information in the *Closer Look* box on glucose, which was in Chapter 10 in the 8th edition, is now included in the new biochemistry chapter (Chapter 24).
- A new *Closer Look* box *Green Chemistry: Recycling PET* was added.
- There is a new *Applying Chemical Principles* essay on BPA (*Bisphenol A)*.

Chapter 24 Biochemistry

- This was an interchapter in the 8th edition. The material is now expanded to include a new section on carbohydrates.
- Many new Study Questions were added.
- There is a new introductory story on *Animal Cloning*.
- A new *Case Study, Antisense Therapy*, was added.
- The *Applying Chemical Principles* problem is about the *Polymerase Chain Reaction*.
- There are three new *Example* problems on drawing peptide structures, determining a complementary sequence of DNA, and determining the amino acid sequence selected by a sequence of DNA.
- There are new *Review & Check* Questions.

Chapter 25 Nuclear Chemistry

- In revising this chapter we incorporated the latest findings in nuclear chemistry and introduced the newest elements.

Alternate Editions

***Chemistry & Chemical Reactivity,* Ninth Edition Hybrid Version with Access (24 months) to OWLv2 with MindTap Reader**
ISBN: 978-1-285-46253-0
This briefer, paperbound version of *Chemistry & Chemical Reactivity*, Ninth Edition does not contain the end-of-chapter problems, which can be assigned in OWL, the online homework and learning system for this book. Access to OWLv2 and the MindTap Reader eBook is included with the Hybrid version. The MindTap Reader is the full version of the text, with all end-of-chapter questions and problem sets.

Supporting Materials

Please visit **http://www.cengage.com/chemistry/kotz/CACR9e** for information about student and instructor resources for this text.

Anchoring Concepts in Chemistry

The American Chemical Society Examinations Institute has been writing assessment examinations for college chemistry for over 75 years. In 2012 the Institute published papers in *The Journal of Chemical Education* on "anchoring concepts" or "big ideas" in chemistry. The purpose was to provide college instructors with a fine-grained content map of chemistry so that instruction can be aligned better with the content of the American Chemical Society examinations. The ACS map begins with "anchoring concepts," which are subdivided into "enduring understandings" and then further broken down into detailed areas.

We believe these ideas are useful to both teachers and students of chemistry and are important enough to include them in this Preface.

The College Board, the publisher of Advanced Placement (AP) examinations, has recently redesigned the AP chemistry curriculum along many of the same ideas. This curriculum is also based on "big ideas" and then "enduring understandings." The latter are broken down into "essential knowledge" and "science practices" and finally into "learning objectives." We have made sure that the present edition of *Chemistry & Chemical Reactivity* has included material that meets many of the criteria of the College Board curriculum while basing the text largely on the "anchoring concepts" of the Examinations Institute.

American Chemical Society Examinations Institute's Anchoring Concepts

1. Atoms (Chapters 1, 2, 6, 7)
Atoms are the building blocks of chemistry. Chapters 1 and 2 describe the basic composition of atoms and the classic experiments that have defined atomic structure. The electronic structure of atoms is described in detail in Chapter 6 in which quantum numbers and atomic orbitals are introduced. This is followed in Chapter 7 by analysis of electron configurations, orbital energy level diagrams, and periodic trends in chemical and physical properties of the elements. We note that Coulomb's law is the underlying implicit and explicit principle in many of these discussions.

2. Bonding (Chapters 8, 9, 12, 23)
Two chapters on covalent bonding follow the discussion of atomic structure. Molecular structure is covered first in Chapter 8, which begins with Lewis structures and then moves on to the determination of electronic and molecular structures using VSEPR guidelines. A detailed discussion of valence bond theory and the introduction of hybridization comes next in Chapter 9, and this is followed by molecular orbital theory at a qualitative level. Bonding in ionic compounds and semiconductors is covered in the chapter on solids (Chapter 12). Bonding in organic compounds is re-emphasized in Chapter 23.

3. Structure and Function (Chapters 11, 12, 16, 24)
The most notable relationship of structure to function is in Chapter 24 (biochemistry) which includes interesting issues such as hemoglobin and sickle cell anemia, and the role of nucleic acids in protein synthesis. However, structure–function relationships are found throughout the book. Consider, for example, the properties of ice and water in Chapter 11, lattice energy and physical properties of ionic compounds in Chapter 12, and the relationships of acid strength and structure (Chapter 16).

4. Intermolecular Interactions (Chapters 10, 11, 24)
Chapter 11 is specifically devoted to this topic; introduced here are ion-dipole, dipole-dipole, and London forces, each based on coulombic (electrostatic) forces of attraction. Hydrogen bonding is given special attention. We also note the importance of intermolecular attractions in real gases (Chapter 10) and biochemical molecules (Chapter 24).

5. Reactions (Chapters 3, 4, 16, 17, 19–24)
Chemical reactivity is a major theme of this book. Chemistry is made up of a wide collection of chemical reactions. Types of reactions and principles of chemical equilibria are introduced in Chapter 3, and quantitative aspects of reactions (chemical stoichiometry) is covered in Chapter 4. In-depth analyses of Brønsted–Lowry acid–base reactions and precipitation reactions are presented in Chapter 16 and 17, and redox reactions are analyzed in depth in the chapter on electrochemistry (19). Reactions important in our environment are covered in Chapter 20, and the chemistry of the main group elements and transition elements is described in Chapters 21 and 22, respectively. Finally, the organic and biochemistry chapters (23 and 24) are organized around structures and reactions.

6. Energy and Thermodynamics (Chapters 1, 5–8, 12–13, 18, 20)
Energy is a pervasive theme of chemistry so some background information is incorporated in Chapter 1.

Thermochemistry and the first law of thermodynamics (heat and work) are presented in Chapter 5. Introduced in this chapter are important topics, including specific heat, internal energy, enthalpy, and experiments involving calorimetry. Energy is revisited in the discussion of atomic structure in Chapter 6, of ionization energy and electron attachment enthalpy in Chapter 7, and of bond energies in Chapter 8. It is once again important in the discussion of solids in Chapter 12 and solutions in Chapter 13.

The second and third laws of thermodynamics are developed in Chapter 18 in which we encounter entropy (briefly mentioned earlier in Chapter 13 on solutions) and especially free energy, which is tied to equilibrium.

Finally, energy resources and usage are key topics in the chapter on the environment (20).

7. Kinetics (Chapter 14, 24)

Chapter 14 is devoted to chemical kinetics. Here we define what is meant by rates and rate laws, and we illustrate examples where rate laws are determined from experimental data. Activation energy is also covered in this chapter. Enzyme kinetics is presented in Chapter 24.

8. Equilibrium (Chapters 3, 15–19)

We first mention equilibrium in Chapter 3, pointing out that all reactions proceed spontaneously to equilibrium and identifying the terms product-favored and reactant-favored. This subject is then covered in depth in a series of three chapters. Chapter 15 is an introduction to equilibrium principles. We describe solution and gas phase equilibria in terms of equilibrium constants. Le Chatelier's principle, which gives an intuitive sense of how stresses affect a system in equilibrium, is introduced here. In Chapters 16 and 17, we describe specific types of equilibria in aqueous solutions, with acid–base and solubility equilibria, and finally in Chapter 18 we tie equilibrium to the thermodynamic function Gibbs free energy. In Chapter 19, we introduce potentiometric measurements as a means of studying chemical equilibrium.

9. Experiments, Measurements, and Data (most chapters throughout the book)

Chemistry is built on experimental results, so it is important to realize that information on this topic occurs throughout the book. We will mention just a few here:

- the classic experiments that determined atomic structure in Chapter 2.
- calorimetry in Chapter 5.
- the use of experimental techniques such as mass spectrometry (Chapter 3) and photoelectron spectroscopy (Chapters 7 and 9) to define the composition and structure of molecules and energy levels in atoms.
- the development of the gas laws in Chapter 10.
- the measurement of rates of reactions in Chapter 14.
- and the measurement of electrochemical potentials in voltaic cells in Chapter 19.

In the end-of-chapter Study Questions there are *In the Laboratory* questions, questions that might occur in a laboratory experiment and that use material in the chapter. And don't overlook the *Applied Chemical Principles* questions, chapter-ending questions that are built around interesting and important experiments.

10. Visualizations (these appear throughout the book)

Visual learners will find this book exciting. Figures are used to illustrate concepts and examples are abundant in every chapter, and we have redesigned many figures to make these even more easily interpreted and informative. Representative examples include visualizations of electromagnetic radiation, colligative properties, dissolving precipitates, reaction mechanisms, chemical equilibria, atomic orbitals, and many, many molecular models.

More information:

K. Murphy, T. Holme, A. Zenisky, H. Caruthers, and K. Knaus, *Journal of Chemical Education*, Volume 89, pages 715-720, 2012. T. Holme and K. Murphy, *ibid*., Volume 89, 721-723, 2012.

Acknowledgments

Preparing this new edition of *Chemistry & Chemical Reactivity* took over 2 years of continuous effort. As in our work on the first eight editions, we have had the support and encouragement of our colleagues at Cengage Publishing and of our families and wonderful friends, faculty colleagues, and students.

CENGAGE LEARNING

The eighth edition of this book was published by Cengage Learning, and we continue with much of the same excellent team we have had in place for several years.

The eighth edition of the book was very successful, in large part owing to the work of Lisa Lockwood as the Product Manager. She has an excellent sense of the market and worked with us in planning this new edition. Maureen Rosener assumed that role as this edition moved into production.

Peter McGahey has been our Content Developer since he joined us to work on the 5th edition. Peter is blessed with energy, creativity, enthusiasm, intelligence, and good humor. He is a trusted friend and confidant and cheerfully answers our many questions during almost-daily phone calls.

No book can be successful without proper marketing. Nicole Hamm (Marketing Director) and Janet del Munro (Market Development Manager) were a great help in marketing the previous edition, and they are back in that role for this edition. They are knowledgeable about the market and have worked tirelessly to bring the book to everyone's attention.

Our team at Cengage Learning is completed with Teresa Trego, Content Project Manager; Lisa Weber, Media Developer; and Elizabeth Woods, Associate Developer. Schedules are very demanding in textbook publishing, and Teresa has helped to keep us on schedule. We certainly appreciate her organizational skills.

Dan Fitzgerald of Graphic World Inc. guided the book through months of production, and Andy Vosburgh of that company was enormously helpful in getting us through the use of new software.

Jill Reichenbach of QBS Learning directed the photo research for the book and was successful in filling our sometimes offbeat requests for particular photos.

Art, Design, and Photography

Many of the color photographs in our book have been beautifully created by Charles D. Winters, and he produced almost 50 new images for this edition. Charlie's work gets better with each edition. We have worked with him for more than 30 years and have become close friends. We listen to his jokes, both new and old—and always forget them.

When the fifth edition was being planned some years ago, we brought in Patrick Harman as a member of the team. Pat designed the first edition of our *Interactive General Chemistry* CD-ROM (published in the 1990s), and we believe its success is in no small way connected to his design skill. For the fifth through the eighth editions of the book, Pat went over almost every figure, and almost every word, to bring a fresh perspective to ways to communicate chemistry. Once again he has worked on designing and producing new illustrations for this edition, and his creativity is obvious in their clarity. Pat has also become a good friend, and we share interests not only in books but in music.

Finally, another fine photographer, Steven Hyatt, has joined us in producing a number of new photos for this edition.

Other Collaborators

We have been fortunate to have a number of other colleagues who have played valuable roles in this project.

- Alton Banks (North Carolina State University) has also been involved for a number of editions preparing the *Student Solutions Manual*. Alton has been very helpful in ensuring the accuracy of the Study Question answers in the book, as well as in their respective manuals.

- John Vincent (University of Alabama-Tuscaloosa) again wrote the *Instructor's Resource Manual* and did an accuracy review.
- Greg Gellene (Texas Tech University) updated and revised the *Study Guide* for this text. Our textbook has had a history of excellent study guides, and this manual follows that tradition.
- Jay Freedman was the development editor for the first edition of the book and his work set the stage for the continuing success of the book. For several editions Jay has also done a masterful job compiling the index/glossary.
- Nathanael Fackler (Nebraska Wesleyan University) produced the *Test Bank* for this edition.
- Daniel Huchital (Florida Atlantic University) was the accuracy reviewer for this edition, and David Shinn of the U.S. Merchant Marine Academy was the accuracy reviewer for the *Student Solutions Manual* and *Instructor's Resource Manual*.
- Nathan Tice (Butler University) prepared a review of green chemistry for us.
- Professor J. Quilez (Departamento de Física y Química, IES Benicalap, Valencia, Spain) reviewed the free energy discussion in Chapter 18.

Participants in Development Surveys

The development of successful books depends on the help of many people within the publishing company as well as colleagues teaching chemistry. The following participated in surveys that gave us guidance in producing the book.

Dmitri Babikov, Marquette University

Yiyan Bai, Houston Community College–Central College

Dean Campbell, Bradley University

Susan Collins, California State University–Northridge

Christopher Collison, Rochester Institute of Technology

David Dearden, Brigham Young University

Emmanuel Ewane, Houston Community College–Northwest College

Mark Fritz, University of Cincinnati

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Patricia Muisener, University of South Florida

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Andrew Price, Temple University

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John C. Kotz, a State University of New York Distinguished Teaching Professor at the College at Oneonta, was educated at Washington and Lee University and Cornell University. He held National Institutes of Health postdoctoral appointments in England and at Indiana University.

He has coauthored three textbooks in several editions *(Inorganic Chemistry, Chemistry & Chemical Reactivity,* and *The Chemical World)* as well as the *General Chemistry Interactive CD-ROM*. His research on organometallic chemistry and electrochemistry has been published in scientific journals.

He has been a Fulbright Lecturer and Research Scholar in Portugal as well as a visiting professor at the University of Wisconsin, Auckland University in New Zealand, and Potchefstroom University in South Africa. He has also made invited presentations on chemistry and education at conferences in the United States, England, Brazil, South Africa, New Zealand, and Argentina.

He received a National Catalyst Award for Excellence in Teaching, the Visiting Scientist Award from the Western Connecticut Section of the American Chemical Society, and the Distinguished Education Award from the Binghamton (NY) Section of the American Chemical Society. In 1998 he was the Estee Lecturer in Chemical Education at the University of South Dakota and in 2007 was the Squibb Lecturer at the University of North Carolina-Asheville. Finally, he was a mentor for the U.S. National Chemistry Olympiad team. His email address is johnkotz@mac.com.

Courtesy Katherine Kotz

(Left to right) **John Kotz, John Townsend, David Treichel, Paul Treichel**

Paul M. Treichel received his B.S. degree from the University of Wisconsin in 1958 and a Ph.D. from Harvard University in 1962. After a year of postdoctoral study in London, he assumed a faculty position at the University of Wisconsin–Madison. He served as department chair from 1986 through 1995 and was awarded a Helfaer Professorship in 1996. He has held visiting faculty positions in South Africa (1975) and in Japan (1995). Retiring after 44 years as a faculty member in 2007, he is currently Emeritus Professor of Chemistry. During his faculty career he taught courses in general chemistry, inorganic chemistry, organometallic chemistry, and scientific ethics. Professor Treichel's research in organometallic and metal cluster chemistry and in mass spectrometry, aided by 75 graduate and undergraduate students, has led to more than 170 papers in scientific journals. He may be contacted by email at treichelpaul@me.com.

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David A. Treichel, Professor of Chemistry at Nebraska Wesleyan University, received a B.A. degree from Carleton College. He earned a M.S. and a Ph.D. in analytical chemistry at Northwestern University. After postdoctoral research at the University of Texas in Austin, he joined the faculty at Nebraska Wesleyan University. His research interests are in the fields of electrochemistry and surface-laser spectroscopy. He may be contacted by email at dat@nebrwesleyan.edu.

About the Cover

Steven Hyatt

The beautiful green stone on the cover of this book is a piece of jade carved in New Zealand. Jade is found in many parts of the world, and, because of its beauty, it has been used for centuries for decorative and religious items. In addition, because it is hard and withstands high temperatures, it has been used for tools such as axe blades. In China in the period from 200 BC to 200 AD, members of royalty were buried in suits made of jade panels sewn with gold thread. In New Zealand the stone is called "pounamu," the name given by the indigenous people of that country, the Maori. To the Maori pounamu has immense spiritual and material value; objects made of jade are among their most prized possessions.

The name "jade" comes from the Spanish *piedra de ijada,* which means "loin stone," a name given it because it was thought to cure kidney diseases.

There are actually two different minerals called jade: jadeite and nephrite. Jadeite is much rarer and a bit harder than nephrite. The two are difficult to tell apart visually, but nephrite has a "silkier" feel in the hand than jadeite, a feature that arises from differences in their underlying silicate structure.

The jade on the book cover and shown here is nephrite with the formula $Ca_2(Mg, Fe)_5(Si_4O_{11})_2(OH)_2$. The green color of nephrite comes from iron(II) ions. As the amount of iron(II) ions can vary from stone to stone, the color can vary from white (low iron content) to deep green (higher iron content).

The nature of jade and the origin of the color are discussed further in Chapters 12 and 22.

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A scale used by gold miners; in an old mining shack in Arizona.

Basic Concepts of Chemistry

Chapter Outline

GOLD! Students beginning a chemistry course often tell us that they don't know anything about chemistry. However, there are many things in our lives that pertain to chemistry, and it's likely you know some things about at least one of the elements, gold.

Gold has been known and prized for millennia. It is one of the rarest of the elements. Wars have been fought over it, and humans have been enslaved to mine it. Gold is extracted from the Earth all over the world, and the oceans are estimated to contain more than 10 million tons.

Gold is a common investment commodity, but its most recognizable uses are in jewelry and dentistry. Statuary is often gilded, that is, covered by a thin layer of gold. We see its use in architecture; the dome of St. Isaac's Cathedral in St. Petersburg, Russia, for example, is covered with 220 pounds of gold in wafer-thin sheets.

Here are few facts about gold:

- Its name in German is the same as in English, but in Spanish it is *oro* and in French it is *l'or;* the chemical symbol for gold is Au, from the Latin word for gold, *aurum*.
- Most gold used in jewelry is not pure gold. Instead, gold is mixed with other metals to strengthen it and

Chapter Goals

See Chapter Goals Revisited (page 20) for Study Questions keyed to these goals.

UNDERSTAND

- Basic concepts applied in science: hypotheses, laws, and theories.
- The basic ideas of kinetic-molecular theory.
- Viewpoints of chemistry: macroscopic, microscopic, symbolic.
- Processes that involve energy changes and how they apply in chemical studies.

DO

- Classify matter.
- Identify physical and chemical properties and changes.

REMEMBER

- The characteristics of chemical building blocks: elements, atoms, compounds, and molecules.
- A list of common physical and chemical properties.
- The principles of green chemistry.

to change its color (and to make an article less expensive). The amount of gold in jewelry is identified by marks stamped on the article. Pure gold is 24 K (24 carat). The label 18 carat (18 K) means that the metal used is 18/24ths gold by weight; 9 K gold is 9/24ths gold.

- Gold is malleable, meaning it can be shaped by pounding. Gold leaf can be made as thin as 0.000127 mm, representing a thickness of about 500 atoms.
- Gold is unaffected by air, water, and most chemicals. This is why it doesn't tarnish. The chemical exception is aqua regia (Latin, *water of kings*), a mixture of hydrochloric and nitric acids, in which gold dissolves.
- Gold is one of the best conductors of electricity, the "gold standard" for use in electrical circuitry.

As you begin your study of chemistry, we encourage you to be aware of things you already know about chemistry. What do you know about elements such as iron, aluminum, copper, and oxygen, or about compounds such as water and carbon dioxide? Throughout this book we will have a lot to say about these and many other interesting and useful chemicals.

Study Questions Related to Chapter Introduction In each chapter there will be at least one Study Question related to the introductory essay. For Chapter 1 this is Study Question 1.47.

In 1991 a hiker in the Alps on the Austrian-Italian border found a well-preserved human body encased in ice. Although it was first thought to be a person who had recently died, a number of scientific studies over more than a decade concluded the man had lived 53 centuries ago and was about 46 years old when he died. He became known as Ötzi the Iceman.

The discovery of the Iceman's body, the oldest natural human mummy, set off innumerable scientific studies that brought together chemists, biologists, anthropologists,

JEAN LOUIS PRADELS/PHOTOPOR/LA DEPECHE DU MIDI/Newscom

(a) The Iceman before the body was removed from the ice within which he had been frozen for almost 53 centuries.

©Handout/Corbis

(b) The body of the Iceman now lies in the Archaeological Museum of South Tyrol in Bolzano, Italy.

Ötzi the Iceman. The name "Ötzi" comes from the Ötz valley, the region of Europe (on the Austrian-Italian border) where the man was found.

paleontologists, and others from all over the world. These studies give us a marvelous view of how science is done. Among the many discoveries made about the Iceman were the following:

- Some investigators looked for food residues in the Iceman's intestines. In addition to finding a few particles of grain, they located tiny flakes of mica believed to come from stones used to grind the grain the man ate. They analyzed these flakes and found their composition was like that of mica in a small area south of the Alps, thus establishing where the man lived in his later years. And, by analyzing animal fibers in his stomach, they determined his last meal was the meat of an Alpine ibex.
- High levels of copper and arsenic were found in his hair. These observations, combined with the discovery that his ax was nearly pure copper, led the investigators to conclude he had been involved in copper smelting.
- One fingernail was still present on his body. Based on its condition, scientists could conclude that he had been sick three times in the 6 months before he died and his last illness had lasted for 2 weeks. Finally, recent images of his teeth showed severe periodontal disease and cavities.
- Australian scientists took samples of blood residues from his stone-tipped knife, his arrows, and his coat. Using techniques developed to study ancient DNA, they found the blood came from four different individuals. The blood on one arrow tip was from two different individuals, suggesting that the man had killed two different people. Perhaps he had killed one person, retrieved the arrow, and used it to kill another.

The many different methods used to reveal the life of the Iceman and his environment are used by scientists around the world, including present-day forensic scientists in their study of accidents and crimes. As you study chemistry and the chemical principles in this book, keep in mind that many areas of science depend on chemistry and that many different careers in the sciences are available.

1-1 Chemistry and Its Methods

Chemistry is about change. It was once only about changing one natural substance into another—wood and oil burn, grape juice turns into wine, and cinnabar (Figure 1.1), a red mineral, ultimately changes into shiny quicksilver (mercury) when heated. The emphasis was largely on finding a recipe to carry out the desired transformation with little understanding of the underlying structure of the materials or explanations for why particular changes occurred. Chemistry is still about change, but now chemists focus on the change of one pure substance, whether natural or synthetic, into another and on understanding that change (Figure 1.2). As you will see, in modern chemistry, we now picture an exciting world of submicroscopic atoms and molecules interacting with each other. We have also developed ways to predict whether or not a particular reaction may occur.

Although chemistry is endlessly fascinating—at least to chemists—why should you study chemistry? Each person probably has a different answer, but many students take a chemistry course because someone else has decided it is an important part of preparing for a particular career. Chemistry is especially useful because it is central to our understanding of disciplines as diverse as biology, geology, materials science, medicine, physics, and some branches of engineering. In addition, chemistry plays a major role in the economy of developed nations, and chemistry and chemicals affect our daily lives in a wide variety of ways. Furthermore, a course in chemistry can help you see how a scientist thinks about the world and how to solve problems. The knowledge and skills developed in such a course will benefit you in many career paths and will help you become a better informed citizen in a world that is becoming technologically more complex—and more interesting.

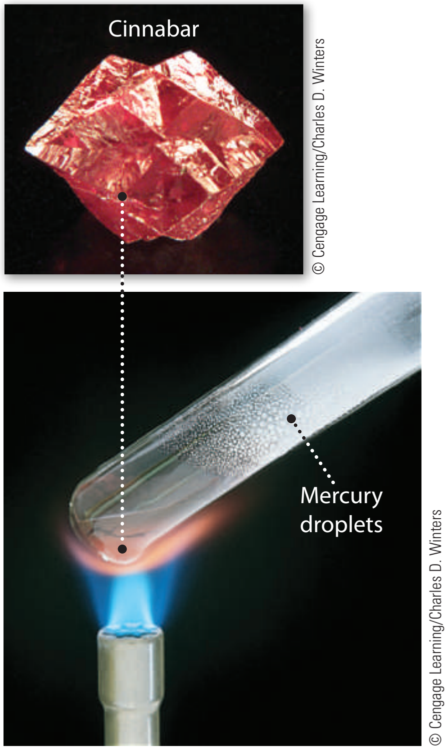

FIGURE 1.1 Cinnabar and mercury. Heating cinnabar (mercury(II) sulfide) in air changes it into orange mercury(II) oxide, which, on further heating, decomposes to the elements mercury and oxygen gas.

Hypotheses, Laws, and Theories

As scientists, we study questions of our own choosing or ones that someone else poses in the hope of finding an answer or discovering some useful information. When the Iceman was discovered, there were many questions that scientists could try to answer, such as where he was from. Considering what was known or assumed

FIGURE 1.2 Forming a chemical compound. Combining sodium metal (Na) and yellow chlorine gas (Cl_2) gives sodium chloride.

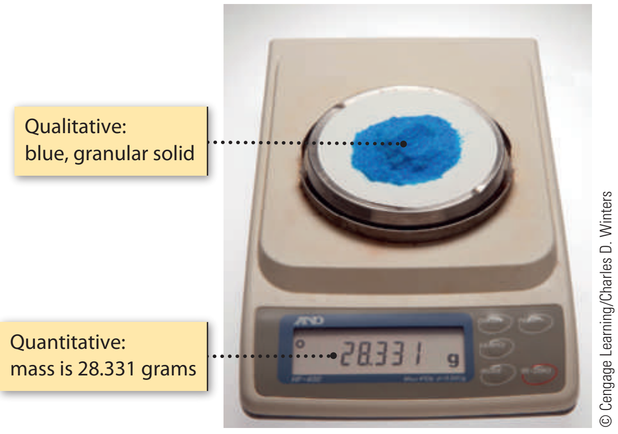

FIGURE 1.3 Qualitative and quantitative observations. Weighing a compound on a laboratory balance.

about humans living in that age, it seemed reasonable to assume that he was from an area on the border of what is now Austria and Italy. That is, regarding his origins, the scientists formed a **hypothesis**, a tentative explanation or prediction in accord with current knowledge.

After formulating one or more hypotheses, scientists perform experiments designed to give results that confirm or invalidate these hypotheses. In chemistry this usually requires that both quantitative and qualitative information be collected. **Quantitative** information is numerical data, such as the mass of a substance or temperature at which it melts (Figure 1.3). **Qualitative** information, in contrast, consists of nonnumerical observations, such as the color of a substance or its physical appearance.

In the case of the Iceman, scientists assembled a great deal of qualitative and quantitative information on his body, his clothing, and his weapons. Among this was information on the ratio of oxygen isotopes in his tooth enamel and bones. Scientists know that the ratio of oxygen isotopes in water and plants differs from place to place. This ratio of isotopes showed that the Iceman must have consumed water from a relatively small location within what is now Italy.

This analysis using oxygen isotopes could be done because it is well known that oxygen isotopes in water vary with altitude in predictable ways. That is, the variation in isotope composition with location can be deemed a law of science. After numerous experiments by many scientists over an extended period of time, these results have been summarized as a **law**—a concise verbal or mathematical statement of a behavior or a relation that seems always to be the same under the same conditions.

We base much of what we do in science on laws because they help us predict what may occur under a new set of circumstances. For example, we know from experience that if the chemical element sodium comes in contact with water, a violent reaction occurs and new substances are formed (Figure 1.4), and we know that the mass of the substances produced in the reaction is exactly the same as the mass of sodium and water used in the reaction. That is, *mass is always conserved in chemical reactions*.

Once enough reproducible experiments have been conducted and experimental results have been generalized as a law or general rule, it may be possible to conceive a theory to explain the observation. A **theory** is a well-tested, unifying principle that explains a body of facts and the laws based on them. It is capable of suggesting new hypotheses that can be tested experimentally.

Sometimes nonscientists use the word *theory* to imply that someone has made a guess and that an idea is not yet substantiated. To scientists, however, a theory is based on carefully determined and reproducible evidence. Theories are the cornerstone of our understanding of the natural world at any given time. Remember,

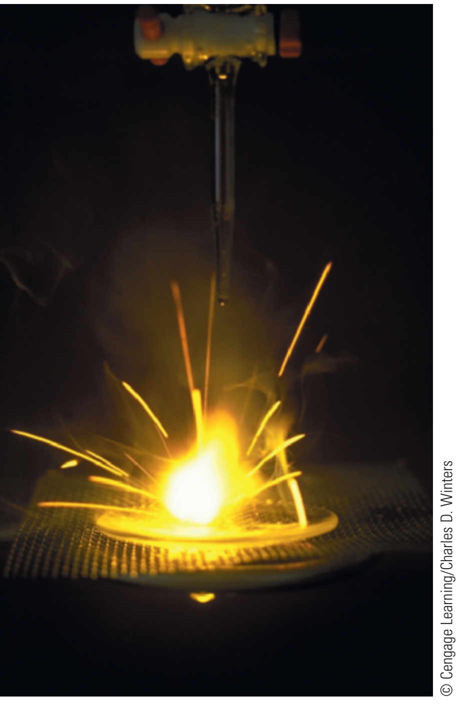

FIGURE 1.4 The metallic element sodium reacts with water.

though, that theories are inventions of the human mind. Theories can and do change as new facts are uncovered.

Goals of Science

Scientists, including chemists, have several goals. Two of these are *prediction* and *control*. We do experiments and seek generalities because we want to be able to predict what may occur under other sets of circumstances. We also want to know how we might control the outcome of a chemical reaction or process.

Two further goals are *understanding* and *explaining*. We know, for example, that certain elements such as sodium react vigorously with water. But why should this be true? To explain and understand this, we need a background in chemical concepts that is developed throughout this book.

Dilemmas and Integrity in Science

You may think research in science is straightforward: Do experiments, collect information, and draw a conclusion. But, research is seldom that easy. Frustrations and disappointments are common enough, and results can be inconclusive. Experiments often contain some level of uncertainty, and spurious or contradictory data can be collected. For example, suppose you do an experiment expecting to find a direct relation between two experimental quantities. You collect six data sets. When plotted on a graph, four of the sets lie on a straight line, but two others lie far away from the line. Should you ignore the last two sets of data? Or should you do more experiments when you know the time they take will mean someone else could publish their results first and thus get the credit for a new scientific principle? Or should you consider that the two points not on the line might indicate that your original hypothesis is wrong and that you will have to abandon a favorite idea you have worked on for many months? Scientists have a responsibility to remain objective in these situations, but sometimes it is hard to do.

It is important to remember that a scientist is subject to the same moral pressures and dilemmas as any other person. To help ensure integrity in science, some simple principles have emerged over time that guide scientific practice:

- Experimental results should be reproducible. Furthermore, these results should be reported in the scientific literature in sufficient detail so that they can be used or reproduced by others.
- Research reports should be reviewed before publication by experts in the field to make sure that the experiments have been conducted properly and that the conclusions drawn are logical.
- Conclusions should be reasonable and unbiased.
- Credit should be given where it is due.

1-2 Sustainability and Green Chemistry

The world's population is about 7.2 billion people, with about 7 million added every month. Each of these new persons needs shelter, food, and medical care, and each uses increasingly scarce resources like fresh water and energy. And each produces by-products in the act of living and working that can affect our environment. With such a large population, these individual effects can have large consequences for our planet. The focus of scientists, planners, and politicians is increasingly turning to a concept of "sustainable development."

James Cusumano, a chemist and former president of a chemical company, said that "On one hand, society, governments, and industry seek economic growth to create greater value, new jobs, and a more enjoyable and fulfilling lifestyle. Yet, on the other, regulators, environmentalists, and citizens of the globe demand that we do

A CLOSER LOOK
Principles of Green Chemistry

Paul Anastas and John Warner enunciated the principles of green chemistry in their book *Green Chemistry: Theory and Practice* (Oxford, 1998). Among these are the ones stated below. As you read *Chemistry & Chemical Reactivity,* we will remind you of these principles, and others, and how they can be applied.

- "It is better to prevent waste than to treat or clean up waste after it is formed."
- New pharmaceuticals or consumer chemicals are synthesized, that is, made by a large number of chemical processes. Therefore, "synthetic methods should be designed to maximize the incorporation of all materials used in the final product."

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- Synthetic methods "should be designed to use and generate substances that possess little or no toxicity to human health or the environment."
- "Chemical products should be designed to [function effectively] while still reducing toxicity."
- "Energy requirements should be recognized for their environmental and economic impacts and should be minimized. Synthetic methods should be conducted at ambient temperature and pressure."
- Raw materials "should be renewable whenever technically and economically practical."
- "Chemical products should be designed so that at the end of their function, they do not persist in the environment or break down into dangerous products."
- "Substances used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires."

so with *sustainable development*—meeting today's global economic and environmental needs while preserving the options of future generations to meet theirs. How do nations resolve these potentially conflicting goals?" This is even more true now than it was in 1995 when Dr. Cusumano made this statement in the *Journal of Chemical Education*.

Much of the increase in life expectancy and quality of life, at least in the developed world, is derived from advances in science. But we have paid an environmental price for it, with increases in gases such as nitrogen oxides and sulfur oxides in the atmosphere, acid rain falling in many parts of the world, and waste pharmaceuticals entering the water supply. Among many others, chemists are seeking answers to these problems, and one response has been to practice *green chemistry.*

The concept of green chemistry began to take root more than 20 years ago and is now leading to new ways of doing things and to lower pollutant levels. By the time you finish this book, you will have been introduced to most of the underlying principles of green chemistry. As you can see in "A Closer Look: Principles of Green Chemistry," they are simple ideas. The challenge is to put them into practice.

1-3 Classifying Matter

This chapter begins our discussion of how chemists think about science in general and about matter in particular. After looking at a way to classify matter, we will turn to some basic ideas about elements, atoms, compounds, and molecules and describe how chemists characterize these building blocks of matter.

States of Matter and Kinetic-Molecular Theory

An easily observed property of matter is its **state**—that is, whether a substance is a solid, liquid, or gas (Figure 1.5). You recognize a material as a solid because it has a rigid shape and a fixed volume that changes little as temperature and pressure change. Like solids, liquids have a fixed volume, but a liquid is fluid—it takes on the shape of its container and has no definite shape of its own. Gases are fluid as well, but the volume of a gas is determined by the size of its container. The volume of a gas varies more than the volume of a liquid with changes in temperature and pressure.

At low enough temperatures, virtually all matter is found in the solid state. As the temperature is raised, solids usually melt to form liquids. Eventually, if the temperature is high enough, liquids evaporate to form gases. Volume changes typically accompany changes in state. For a given mass of material, there is usually a small increase in volume on melting—water being a significant exception—and then a large increase in volume occurs upon evaporation.

The **kinetic-molecular theory of matter** helps us interpret the properties of solids, liquids, and gases. According to this theory, all matter consists of extremely tiny particles (atoms, molecules, or ions) that are in constant motion.

- In solids these particles are packed closely together, usually in a regular array. The particles vibrate back and forth about their average positions, but seldom do particles in a solid squeeze past their immediate neighbors to come into contact with a new set of particles.
- The particles in liquids are arranged randomly rather than in the regular patterns found in solids. Liquids and gases are fluid because the particles are not confined to specific locations and can move past one another.
- Under normal conditions, the particles in a gas are far apart. Gas molecules move extremely rapidly and are not constrained by their neighbors. The molecules of a gas fly about, colliding with one another and with the container walls. This random motion allows gas molecules to fill their container, so the volume of the gas sample is the volume of the container.
- There are net forces of attraction between particles in all states—generally small in gases and large in liquids and solids. These forces have a significant role in determining the properties of matter.

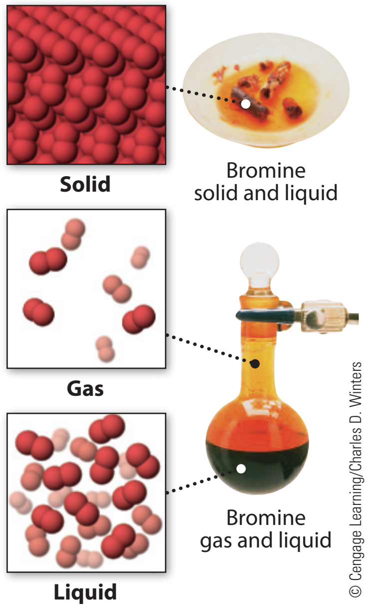

FIGURE 1.5 States of matter—solid, liquid, and gas. Elemental bromine exists in all three states near room temperature.

An important aspect of the kinetic-molecular theory is that the higher the temperature, the faster the particles move. The energy of motion of the particles (their **kinetic energy**, Section 1-8) acts to overcome the forces of attraction between particles. A solid melts to form a liquid when the temperature of the solid is raised to the point at which the particles vibrate fast enough and far enough to push one another out of the way and move out of their regularly spaced positions. As the temperature increases even more, the particles move even faster until finally they can escape the clutches of their comrades and enter the gaseous state. *Increasing temperature corresponds to faster and faster motions of atoms and molecules,* a general rule you will find useful in many future discussions.

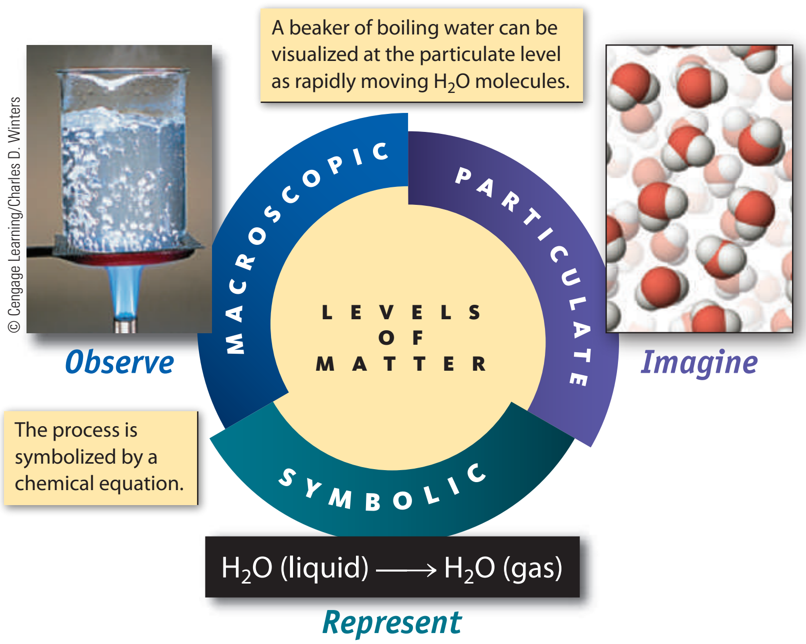

FIGURE 1.6 Levels of matter. We observe chemical and physical processes at the macroscopic level. To understand or illustrate these processes, scientists often imagine what has occurred at the particulate atomic and molecular levels and write symbols to represent these observations.

Matter at the Macroscopic and Particulate Levels

The characteristic properties of gases, liquids, and solids are observed by the unaided human senses. They are determined using samples of matter large enough to be seen, measured, and handled. You can determine, for example, the color of a substance, whether it dissolves in water, whether it conducts electricity, and if it reacts with oxygen. Observations such as these generally take place in the **macroscopic** world of chemistry (Figure 1.6). This is the world of experiments and observations.

Now let us move to the level of atoms, molecules, and ions—a world of chemistry we cannot see. Take a macroscopic sample of material and divide it, again and again, past the point where the amount of sample can be seen by the naked eye, past the point where it can be seen using an optical microscope. Eventually you reach the level of individual particles that make up all matter, a level that chemists refer to as the **submicroscopic** or **particulate** world of atoms and molecules (see Figures 1.5 and 1.6).

Chemists are interested in the structure of matter at the particulate level. Atoms, molecules, and ions cannot be "seen" in the same way that one views the macroscopic world, but they are no less real. Chemists imagine what atoms must look like and how they might fit together to form molecules. They create models to represent atoms and molecules (see Figures 1.5 and 1.6)—where tiny spheres are used to represent atoms—and then use these models to think about chemistry and to explain the observations they have made about the macroscopic world.

It has been said that chemists carry out experiments at the macroscopic level, but they think about chemistry at the particulate level. They then write down their observations as "symbols," the formulas (such as H_2O for water or NH_3 for ammonia molecules) and drawings that signify the elements and compounds involved. This is a useful perspective that will help you as you study chemistry. Indeed, one of our goals is to help you make the connections in your own mind among the symbolic, particulate, and macroscopic worlds of chemistry.

Pure Substances

A chemist looks at a glass of drinking water and sees a liquid. This liquid could be the pure chemical compound water. However, it is also possible the liquid is actually a homogeneous mixture of water and dissolved substances—that is, a **solution**. Specifically, we can classify a sample of matter as being either a pure substance or a mixture (Figure 1.7).

A pure substance has a set of unique properties by which it can be recognized. Pure water, for example, is colorless and odorless. If you want to identify a substance conclusively as water, you would have to examine its properties carefully and compare them against the known properties of pure water. Melting point and boiling point serve the purpose well here. If you could show that the substance melts at 0 °C and boils at 100 °C at atmospheric pressure, you can be certain it is water. No other known substance melts and boils at precisely those temperatures.

A second feature of a pure substance is that it cannot be separated into two or more different species by any physical technique at ordinary temperatures. If it could be separated, our sample would be classified as a mixture.

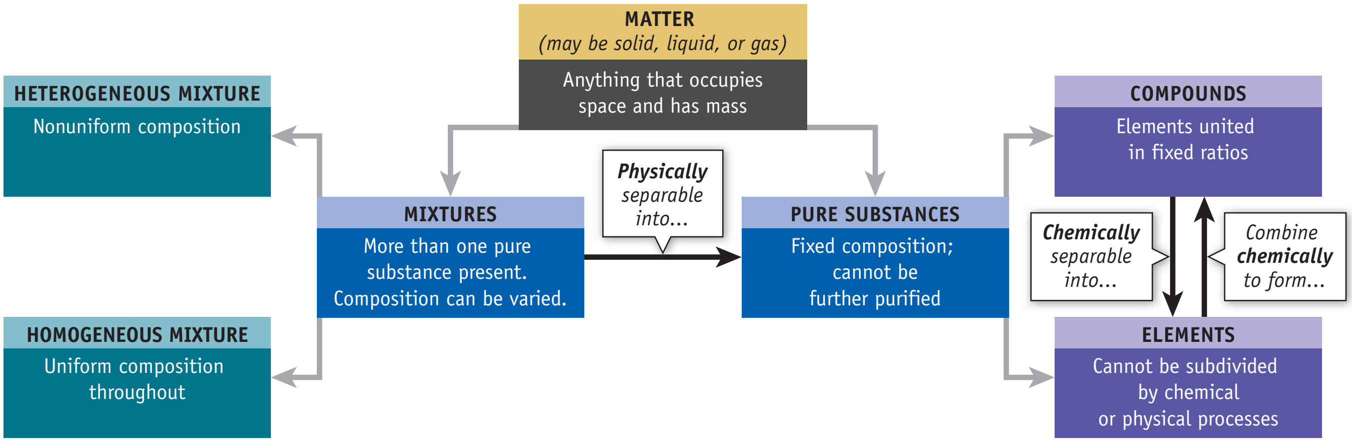

FIGURE 1.7 Classifying matter.

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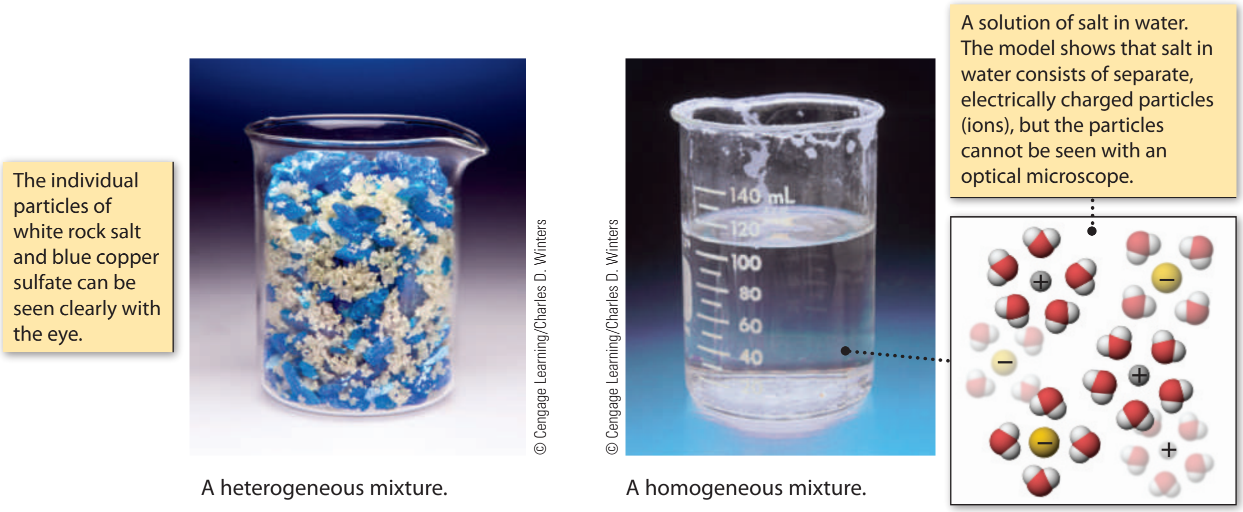

A heterogeneous mixture.

A homogeneous mixture.

FIGURE 1.8 Heterogeneous and homogeneous mixtures.

Mixtures: Heterogeneous and Homogeneous

A mixture consists of two or more pure substances that can be separated by physical techniques. In a **heterogeneous** mixture the uneven texture of the material can often be detected by the naked eye (Figure 1.8). However, keep in mind there are heterogeneous mixtures that may appear completely uniform but on closer examination are not. Milk, for example, appears smooth in texture to the unaided eye, but magnification would reveal fat and protein globules within the liquid. In a heterogeneous mixture the properties in one region are different from those in another region.

A **homogeneous** mixture consists of two or more substances in the same phase (see Figure 1.8). No amount of optical magnification will reveal a homogeneous mixture to have different properties in different regions. Homogeneous mixtures are often called **solutions**. Common examples include air (mostly a mixture of nitrogen and oxygen gases), gasoline (a mixture of carbon- and hydrogen-containing compounds called *hydrocarbons*), and a soft drink in an unopened container.

When a mixture is separated into its pure components, the components are said to be **purified**. Efforts at separation are often not complete in a single step, however, and repetition almost always gives an increasingly pure substance. For example, soil particles can be separated from water by filtration (Figure 1.9). When the mixture

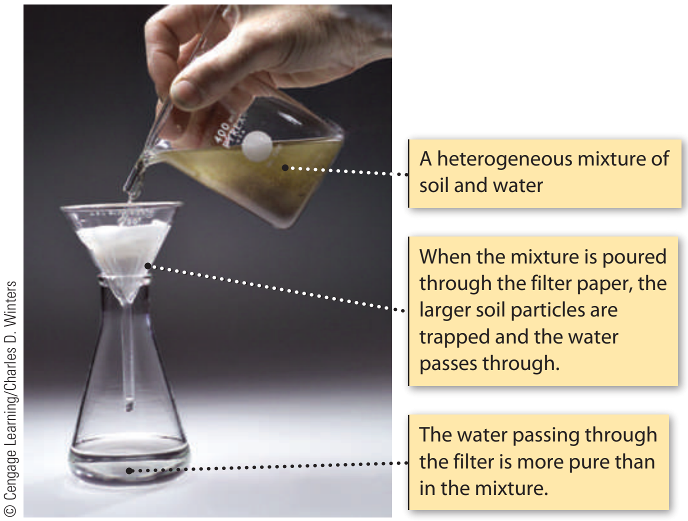

FIGURE 1.9 Purifying a heterogeneous mixture by filtration.