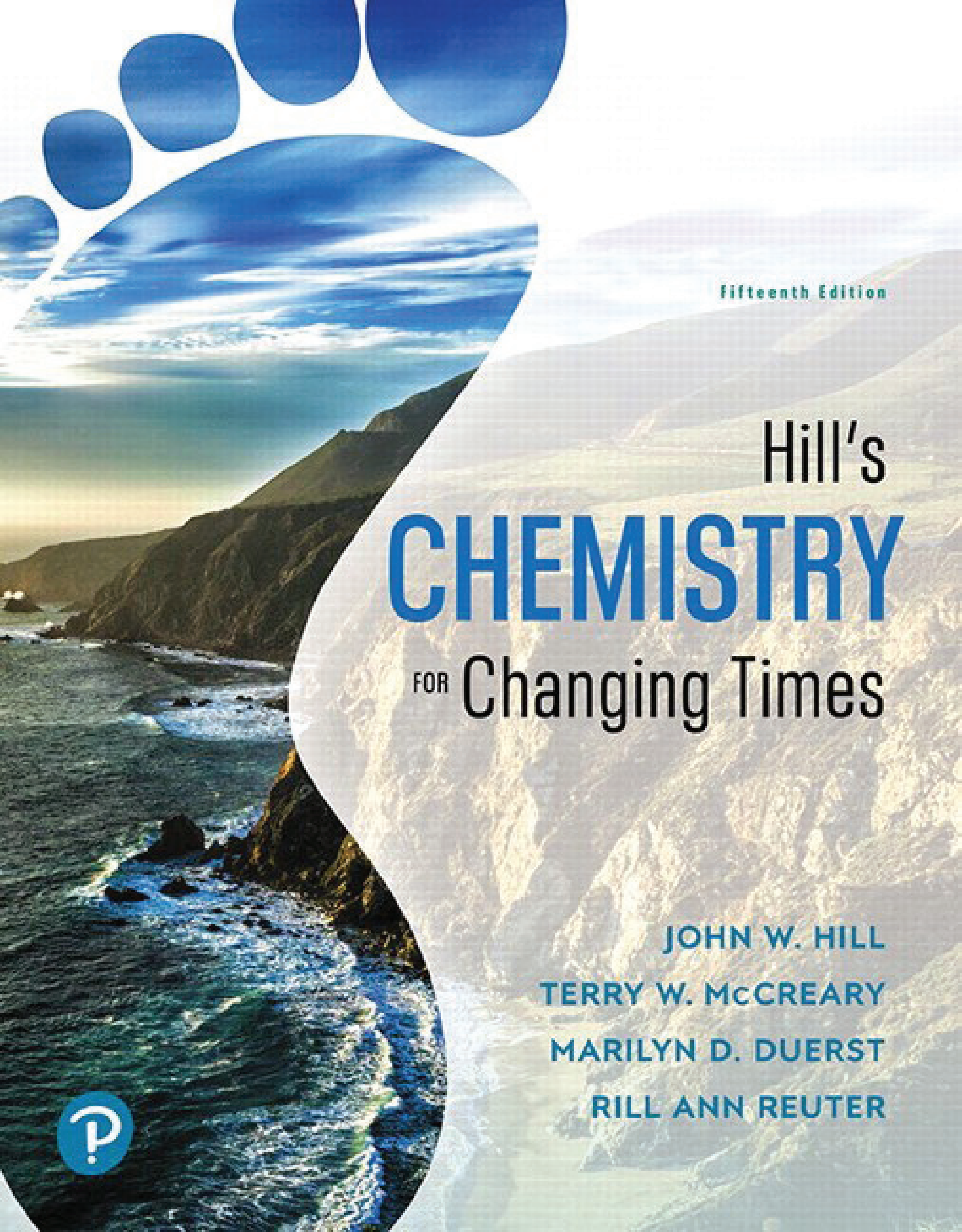

Fifteenth Edition

Hill's CHEMISTRY FOR Changing Times

JOHN W. HILL
TERRY W. McCREARY
MARILYN D. DUERST
RILL ANN REUTER

Hill's

CHEMISTRY

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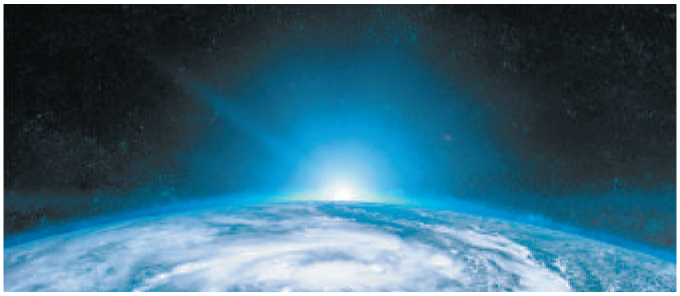

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Green Chemistry

The fifteenth edition of *Chemistry for Changing Times* is pleased to present the green chemistry essays listed below. The topics have been carefully chosen to introduce students to the concepts of green chemistry—a new approach to designing chemicals and chemical transformations that are beneficial for human health and the environment. The green chemistry essays in this edition highlight cutting-edge research by chemists, molecular scientists, and engineers to explore the fundamental science and practical applications of chemistry that is "benign by design." These examples emphasize the responsibility of chemists for the consequences of the new materials they create and the importance of building a sustainable chemical enterprise.

Preface

Chemistry for Changing Times is now in its fifteenth edition. Times have changed immensely since the first edition appeared in 1972 and continue to change more rapidly than ever—especially in the vital areas of biochemistry (neurochemistry, molecular genetics), the environment (sustainable practices, climate change), energy, materials, drugs, and health and nutrition. This book has changed accordingly. We have updated the text and further integrated green chemistry throughout. Green Chemistry essays throughout the text have been updated for relevancy. Learning objectives and end-of-chapter problems are correlated to each essay. In preparing this new edition, we have responded to suggestions from users and reviewers of the fourteenth edition, as well as used our own writing, teaching, and life experiences. The text has been fully revised and updated to reflect the latest scientific developments in a fast-changing world.

New to This Edition

- The *Let's Experiment!* activities (formerly *Chemistry@Home*) have been revised to improve clarity, to maximize success of the experiment, and to increase relevance to everyday life.
- In Chapter 4, a new, clearer approach to drawing Lewis structures is presented.
- Determination of oxidation number in Chapter 8 has been greatly simplified.
- Chapter 9 now includes an introductory section that clearly differentiates between the general properties of organic compounds and the inorganic compounds that were covered in Chapters 1–8. Coverage of thiols, sulfur-containing organic compounds that are important in biochemistry, is also included.
- Chapter 12 now includes discussions of gems and related minerals, salt, and precious metals.
- Chapter 16 (Biochemistry) has had three new sections added. The use of carbohydrates, fats, and protein as foodstuffs is discussed directly after the coverage of structures of these biochemical molecules. Students no longer need to refer back to a previous chapter to find structures of the molecules involved.
- Chapters 17 and 19 have been logically and cohesively combined into a single chapter, "Nutrition, Fitness, and Health."
- A number of the new end-of-chapter problems are multiple-choice premise-and-conclusion problems requiring critical thinking (e.g., "The premise is correct but the conclusion is wrong.").

Revisions

- Almost every worked Example is now accompanied by *two* exercises that are closely related to the material covered in the Example. The B exercise is usually somewhat more challenging than the A exercise.
- More than 25% of the end-of-chapter problems have been revised or replaced in their entirety. Where practical, the revised/replacement problems highlight current events or modern issues that are chemistry-related.
- Brief answers to the odd-numbered end-of-chapter problems are provided in an Answer Appendix. In addition to being vetted by accuracy checkers, those answers have been carefully reviewed by one or more authors.
- Review Questions are now called *Conceptual Questions*, as they deal largely with chapter concepts. Routine end-of-chapter problems are now followed by more challenging problems in a section called *Expand Your Skills*.
- Chapter 14 includes expanded descriptions of some of the unique properties of water, and better organization of water pollutants and ways of purifying water.
- The global perspective has been added or enhanced in many chapters, broadening students' views of some of the challenges facing humanity.

To the Instructor

Our knowledge base has expanded enormously since this book's first edition, never more so than in the last few years. We have faced tough choices in deciding what to include and what to leave out. We now live in what has been called the Information Age. Unfortunately, information is not knowledge; the information may or may not be valid. Our focus, more than ever, is on helping students evaluate information. May we all someday gain the gift of wisdom.

A major premise of this book is that a chemistry course for students who are not majoring in science should be quite different from a course offered to science majors. It must present basic chemical concepts with intellectual honesty, but it need not—probably should not—focus on esoteric theories or rigorous mathematics. It should include lots of modern everyday applications. The textbook should be appealing to look at, easy to understand, and interesting to read.

A large proportion of the legislation considered by the U.S. Congress involves questions having to do with science or technology, yet only rarely does a scientist or engineer enter politics. Most of the people who make important decisions regarding our health and our environment are not trained in science, but it is critical that these decision makers be scientifically literate. In the judicial system, decisions often depend on scientific evidence, but judges and jurors frequently have little education in the sciences. A chemistry course for students who are not science majors should emphasize practical applications of chemistry to problems involving, most notably, environmental pollution, radioactivity, energy sources, and human health. The students who take liberal arts chemistry courses include future teachers, business leaders, lawyers, legislators, accountants, artists, journalists, jurors, and judges.

Objectives

Our main objectives for a chemistry course for students who are not majoring in science are as follows:

- To attract lots of students from a variety of disciplines. If students do not enroll in the course, we can't teach them.
- To help students become literate in science. We want our students to develop a comfortable knowledge of science so that they may become productive, creative, ethical, and engaged citizens.
- To use topics of current interest to illustrate chemical principles. We want students to appreciate the importance of chemistry in the real world.
- To relate chemical problems to the everyday lives of our students. Chemical problems become more significant to students when they can see a personal connection.
- To acquaint students with scientific methods. We want students to be able to read about science and technology with some degree of critical judgment. This is especially important because many scientific problems are complex and controversial.
- To show students, by addressing the concepts of sustainability and green chemistry, that chemists seek better, safer, and more environmentally friendly processes and products.
- To instill an appreciation for chemistry as an open-ended learning experience. We hope that our students will develop a curiosity about science and will want to continue learning throughout their lives.

Questions and Problems

Worked-out Examples and accompanying exercises are given within most chapters.

Each Example carefully guides students through the process for solving a particular type of problem. It is then followed by one or more exercises that allow students to check their comprehension right away. Many Examples are followed by two exercises, labeled A and B. The goal in an A exercise is to apply to a similar situation the method outlined in the Example. In a B exercise, students must often combine that method with other ideas previously learned. Many of the B exercises provide a context closer to that in which chemical knowledge is applied, and they thus serve as a bridge between the Worked Examples and the more challenging problems at the end of the chapter. The A and B exercises provide a simple way for the instructor to assign homework that is closely related to the Examples. Answers to all the in-chapter exercises are given in the Answers section at the back of the book.

Answers to all odd-numbered end-of-chapter problems, identified by blue numbers, are given in the Answers section at the back of the book. The end-of chapter problems include the following:

- Conceptual Questions for the most part simply ask for a recall of material in the chapter.
- A set of matched-pair problems is arranged according to subject matter in each chapter.
- Expand Your Skills Problems are not grouped by type. Some of these are more challenging than the matched-pair problems and often require a synthesis of ideas from more than one chapter. Others pursue an idea further than is done in the text or introduce new ideas.

Acknowledgments

For more than four decades, we have greatly benefited from hundreds of helpful reviews. It would take far too many pages to list all of those reviewers here, but they should know that their contributions are deeply appreciated. For the fifteenth edition, we are especially grateful to the following reviewers:

Accuracy Reviewers

David F. Maynard, *California State University, San Bernardino*

Christine Seppanen, *Riverland Community College*

Green Chemistry Contributors

We are enormously grateful to Thomas Goodwin, Hendrix College, who reviewed and revised the green chemistry essays for the fifteenth edition. We thank him for his dedication to this project. We also thank the team of green chemists listed below who contributed the green essays and helped to integrate each essay's content into the chapter with learning objectives, end-of-chapter problems, summaries, and section references.

Eric Beckman, *University of Pittsburgh*
Amy S. Cannon, *Beyond Benign*
David Constable, *ACS Green Chemistry Institute*
Scott Cummings, *Kenyon College*
Joseph Fortunak, *Howard University*
Tom Goodwin, *Hendrix College*
Michael Heben, *University of Toledo*
Phil Jessop, *Queen's University*
Margaret Kerr, *Worcester State University*
Karen Larson, *Clarke University*
Irv Levy, *Gordon College*
Doris Lewis, *Suffolk University*
Jennifer MacKellar, *ACS Green Chemistry Institute*
Alex Mayer, *Michigan Technological University*
Lallie C. McKenzie, *Chem11 LLC*
Martin Mulvihill, *University of California–Berkeley*
Katie Privett, *Green Chemistry Centre of Excellence York, UK*
Douglas Raynie, *South Dakota State University*
Robert Sheldon, *Delft University of Technology*
Galen Suppes, *University of Missouri*
David Vosburg, *Harvey Mudd College*
John Warner, *Warner Babcock Institute*
Rich Williams, *Environmental Science & Green Chemistry Consulting, LLC*

Reviewers of This Edition

Amy Albrecht, *Charleston Southern University*
Joseph Cradlebaugh, *Jacksonville University*
Jeannie Eddleton, *Virginia Tech*
Katherine Leigh, *Dixie State University*
David Perry, *Charleston Southern University*

We also appreciate the many people who have called, written, or e-mailed with corrections and other helpful suggestions. Cynthia S. Hill prepared much of the original material on biochemistry, food, and health and fitness.

We owe a special debt of gratitude to Doris K. Kolb (1927–2005), who was an esteemed coauthor from the seventh through the eleventh editions. Doris and her husband, Ken, were friends and helpful supporters long before Doris joined the author team. She provided much of the spirit and flavor of the book. Doris's contributions to *Chemistry for Changing Times*—and indeed to all of chemistry and chemical education—will live on for many years to come, not only in her publications, but in the hearts and minds of her many students, colleagues, and friends.

Throughout her career as a teacher, scientist, community leader, poet, and much more, Doris was blessed with a wonderful spouse, colleague, and companion, Kenneth E. Kolb. Over the years, Ken did chapter reviews, made suggestions, and gave invaluable help for many editions. All who knew Doris miss her greatly. Those of us who had the privilege of working closely with her miss her wisdom and wit most profoundly. Let us all dedicate our lives, as Doris did hers, to making this world a better place.

We also want to thank our colleagues at the University of Wisconsin–River Falls, Murray State University, Winona State University, and Bradley University for all their help and support through the years. Thank you to Amy Cannon and Kate Anderson who coordinated the *Let's Experiment*! material. The *Let's Experiment!* demonstrations help bring the subject matter to life for students.

We also owe a debt of gratitude to the many creative people at Pearson who have contributed their talents to this edition. Jessica Moro, Senior Courseware Portfolio Analyst, has been a delight to work with, providing valuable guidance throughout the project. She showed extraordinary skill and diplomacy in coordinating all the many facets of this project. Courseware Director Barbara Yien and Development Editor Ed Dodd contributed greatly to this project, especially in challenging us to be better authors in every way. We treasure their many helpful suggestions of new material and better presentation of all the subject matter. We are grateful to Project Managers Erin Hernandez and Norine Strang and Content Producer Cynthia Abbott for their diligence and patience in bringing all the parts together to yield a finished work. We are indebted to our copyeditor, Mike Gordon, whose expertise helped improve the consistency of the text; and to the proofreader Clare Romeo and accuracy checkers whose sharp eyes caught many of our errors and typos. We also salute our art specialist, Andrew Troutt, for providing outstanding illustrations, and our photo researcher, Jason Acibes, who vetted hundreds of images in the search for quality photos.

Terry W. McCreary would like to thank his wife, Geniece, and children, Corinne and Yvette, for their unflagging support, understanding, and love. Rill Ann Reuter is very thankful to her husband, Larry, and her daughter, Vicki, for their patience and support, especially during this project. Marilyn D. Duerst would like to thank her husband, Richard, for his patience and encouragement, and all six of their daughters, Karin, Sue, Linda, Rebecca, Christine and Sarah, for their enthusiasm and support.

Finally, we also thank all those many students whose enthusiasm has made teaching such a joy. It is gratifying to have students learn what you are trying to teach them, but it is a supreme pleasure to find that they want to learn even more. And, of course, we are grateful to all of you who have made so many helpful suggestions. We welcome and appreciate all your comments, corrections, and criticisms.

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To the Student

Tell me, what is it you plan to do
with your one wild and precious life?
—American poet Mary Oliver (b. 1935)
"The Summer Day," from *New and Selected Poems*
(Boston, MA: Beacon Press, 1992)

Welcome to Our Chemical World!

Learning chemistry will enrich your life—now and long after this course is over—through a better understanding of the natural world, the scientific and technological questions now confronting us, and the choices you will face as citizens in a scientific and technological society.

Skills gained in this course can be exceptionally useful in many aspects of your life. Learning chemistry involves thinking logically, critically, and creatively. You will learn how to use the language of chemistry: its symbols, formulas, and equations. More importantly, you will learn how to obtain meaning from information. The most important thing you will learn is how to learn. Memorized material quickly fades into oblivion unless it is arranged on a framework of understanding.

Chemistry Directly Affects Our Lives

How does the human body work? How does aspirin cure headaches, reduce fevers, and lessen the chance of a heart attack or stroke? How does penicillin kill bacteria without harming our healthy body cells? Is ozone a good thing or a threat to our health? Do we really face climate change, and if so, how severe will it be? Do humans contribute to climate change, and if so, to what degree? Why do most weight-loss diets seem to work in the short run but fail in the long run? Why do our moods swing from happy to sad? Chemists have found answers to questions such as these and continue to seek the knowledge that will unlock other secrets of our universe. As these mysteries are resolved, the direction of our lives often changes—sometimes dramatically. We live in a chemical world—a world of drugs, biocides, food additives, fertilizers, fuels, detergents, cosmetics, and plastics. We live in a world with toxic wastes, polluted air and water, and dwindling petroleum reserves. Knowledge of chemistry will help you better understand the benefits and hazards of this world and will enable you to make intelligent decisions in the future.

We Are All Chemically Dependent

Even in the womb we are chemically dependent. We need a constant supply of oxygen, water, glucose, amino acids, triglycerides, and a multitude of other chemical substances.

Chemistry is everywhere. Our world is a chemical system—and so are we. Our bodies are durable but delicate systems with innumerable chemical reactions occurring constantly within us that allow our bodies to function properly. Learning, exercising, feeling, gaining or losing weight, and virtually all life processes are made possible by these chemical reactions. Everything that we ingest is part of a complex process that determines whether our bodies work effectively. The consumption of some substances can initiate chemical reactions that will stop body functions. Other substances, if consumed, can cause permanent handicaps, and still others can make living less comfortable. A proper balance of the right foods provides the chemicals that fuel the reactions we need in order to function at our best. Learning chemistry will help you better understand how your body works so that you will be able to take proper care of it.

Changing Times

We live in a world of increasingly rapid change. Isaac Asimov (1920–1992), Russian-born American biochemist and famous author of popular science and science fiction books, once said that "The only constant is change, continuing change, inevitable change, that is the dominant factor in society today. No sensible decision can be made any longer without taking into account not only the world as it is, but the world as it will be." We now face some of the greatest problems that humans have ever encountered, and these dilemmas seem to have no perfect solutions. We are sometimes forced to make a best choice among only bad alternatives, and our decisions often provide only temporary solutions. Nevertheless, if we are to choose properly, we must understand what our choices are. Mistakes can be costly, and they cannot always be rectified. It is easy to pollute, but cleaning up pollution is enormously expensive. We can best avoid mistakes by collecting as much information as possible and evaluating it carefully before making critical decisions. Science is a means of gathering and evaluating information, and chemistry is central to all the sciences.

Chemistry and the Human Condition

Above all else, our hope is that you will learn that the study of chemistry need not be dull and difficult. Rather, it can enrich your life in so many ways—through a better understanding of your body, your mind, your environment, and the world in which you live. After all, the search to understand the universe is an essential part of what it means to be human. We offer you a challenge first issued by American educator Horace Mann (1796–1859) in his 1859 address at Antioch College: "Be ashamed to die until you have won some victory for humanity."

In Memoriam

The fifteenth edition of *Chemistry for Changing Times* is dedicated to the memory of John W. Hill, who died of lymphoma on August 7, 2017. The reader may have noticed that the title of the book has been changed to *Hill's Chemistry for Changing Times*. This is a tribute to the professor, gentleman, and our friend, who was the leading edge of liberal arts chemistry for over four decades.

I met John Hill when I was a yet-untenured assistant professor. He had taken a sabbatical to teach here at Murray State University, selecting our consumer-chemistry course as his assignment. John was one of the very few instructors I've known who reveled in teaching what some disparagingly call "chemistry for poets." John enjoyed bringing chemistry to the ordinary student, the one who would most likely take a single science course in her curriculum. And he was very, very good at it.

Not long after he began teaching at University of Wisconsin–River Falls, he was assigned to their liberal arts chemistry course. He had no difficulty preparing notes, but he wasn't satisfied with the textbooks he was able to find. His notes, along with uncounted hours of literature searching and writing, eventually became the first edition of *Chemistry for Changing Times,* in 1972.

The amount of work John put into the earlier editions was staggering. Hand-writing or manually typing the entire manuscript; sending the work to the publisher by snail mail; preparing sketches for figures; reviews, proof pages, figures, and photos obtained and delivered by the same slow process; hand-marking hundreds of proof pages; and crossing his fingers, hoping that he'd not missed anything critical. It's difficult to appreciate that level of effort when we consider the tools we have at our disposal today.

Personally John was a quiet, modest man who enjoyed writing of all sorts, including a few children's books. He loved silly jokes, especially the sort of pun that would elicit a terrible groan from anyone within earshot. I doubt that he ever realized how much of a difference his professional works made to millions (literally) of students. It was a privilege to know him and work with him. John will be greatly missed by all who knew him.

Terry W. McCreary

I first met John Hill in August of 1981, when I applied for a one-year teaching position that suddenly had opened up at the University of Wisconsin–River Falls. In the interview, John quickly observed that I, too, had a passion and the personality for teaching non-science students. I eagerly accepted the position, and one year eventually turned into thirty-four years at UW-RF. During that span of time, I taught the course for non-science majors for more than sixty academic terms, using updated editions of this textbook, and never tired of it.

John and I engaged in numerous discussions over the years about ways to improve and deepen student learning, and how chemical demonstrations could enhance student engagement in the classroom, as that was my forte. He jokingly called me "Mrs. Wizard." We wrote a children's book together nearly twenty years ago that included experiments for the readers to perform at home, which was great fun. John was a soft-spoken man, with infinite patience and a closet full of T-shirts with silly science-related sayings, which he unashamedly wore to class. It was truly a pleasure and honor to be a colleague of John W. Hill.

Marilyn D. Duerst

My work with John Hill initially began with a review I did for an earlier edition of *Chemistry for Changing Times.* Indeed, I did not actually meet him in person until after I had worked on several editions of the book, but we had many informative exchanges first via snail mail and then over the phone and e-mail. I always enjoyed those discussions, and they were often very thought-provoking.

John worked hard not only to present students with correct information, but also to present it in a clear and unambiguous way. Rather than just presenting the bald facts, as so many books do, *Chemistry for Changing Times* also includes considerable historical information about how those facts were determined, helping students to understand why we know what we know.

Chemistry was not a static subject for John. He constantly looked for information about new developments and how they affect our everyday lives. Understanding the role and relevance of chemistry is important for all of us, including non-science students. We are all citizens of this world, and our actions will affect future generations.

It was my privilege to have the opportunity to work with John W. Hill.

Rill Ann Reuter

About the Authors

John W. Hill

John Hill received his Ph.D. from the University of Arkansas. As an organic chemist, he published more than 50 papers, most of which have an educational bent. In addition to *Chemistry for Changing Times*, he authored or coauthored several introductory-level chemistry textbooks, all of which have been published in multiple editions. He presented over 60 papers at national conferences, many relating to chemical education. He received several awards for outstanding teaching and was active in the American Chemical Society, both locally and nationally.

Terry W. McCreary

Terry McCreary received his Ph.D. in analytical chemistry from Virginia Tech. He has taught general and analytical chemistry at Murray State University since 1988 and was presented with the Regents Excellence in Teaching Award in 2008. He is a member of the Kentucky Academy of Science and has served as technical editor for the *Journal of Pyrotechnics*. McCreary is the author of several laboratory manuals for general chemistry and analytical chemistry, as well as *General Chemistry* with John Hill, Ralph Petrucci, and Scott Perry, and *Experimental Composite Propellant*, a fundamental monograph on the preparation and properties of solid rocket propellant. In his spare time, he designs, builds, and flies rockets with the Tripoli Rocketry Association, of which he was elected president in 2010. He also enjoys gardening, machining, woodworking, and astronomy.

Marilyn D. Duerst

Marilyn D. Duerst majored in chemistry, math, and German at St. Olaf College, graduating in 1963, and earned an M.S. from the University of California–Berkeley in 1966. For over five decades, her talents in teaching have flourished in every venue imaginable, with students aged four to 84, but were focused on non-science majors, preservice and inservice teachers. She taught at the University of Wisconsin–River Falls from 1981 to 2015; in 2006 she was presented with the Outstanding Teaching Award. Now a Distinguished Lecturer in Chemistry, emerita, from UW–RF, she is a Fellow of the American Chemical Society, an organization in which she has long been active both locally and nationally, particularly in outreach activities to the public. In 1999, she co-authored a book for children with John W. Hill entitled *The Crimecracker Kids and the Bake-shop Break-in*. Marilyn is a birder, rockhound, and nature photographer; she collects sand, minerals and elements, has traveled four continents, and studied a dozen languages.

Rill Ann Reuter

Rill Ann Reuter earned her B.A. in Chemistry from Connecticut College and her M.S. in Biochemistry from Yale University. She worked in academic research laboratories at Yale University, Princeton University, and the University of Massachusetts Medical School for 12 years, with a primary emphasis on nucleic acid research. After moving to Minnesota in 1980, she taught at Saint Mary's University of Minnesota, the College of Saint Teresa, and Winona State University and did research on photosynthesis. She retired from Winona State in 2015 as Professor Emerita of Chemistry. Over the years, she has taught large numbers of general chemistry, non-science, and pre-nursing students. She was active in local and regional science fairs for 35 years and is a member of the American Chemical Society. She has a keen interest in history, politics, and classical music.

About Our Sustainability Initiatives

Pearson recognizes the environmental challenges facing this planet, as well as acknowledges our responsibility in making a difference. Along with developing and exploring digital solutions to our market's needs, Pearson has a strong commitment to achieving carbon-neutrality. As of 2009, Pearson became the first carbon- and climate-neutral publishing company. Since then, Pearson remains strongly committed to measuring, reducing, and offsetting our carbon footprint.

The future holds great promise for reducing our impact on Earth's environment, and Pearson is proud to be leading the way. We strive to publish the best books with the most up-to-date and accurate content, and to do so in ways that minimize our impact on Earth. To learn more about our initiatives, please visit https://www.pearson.com/social-impact.html.

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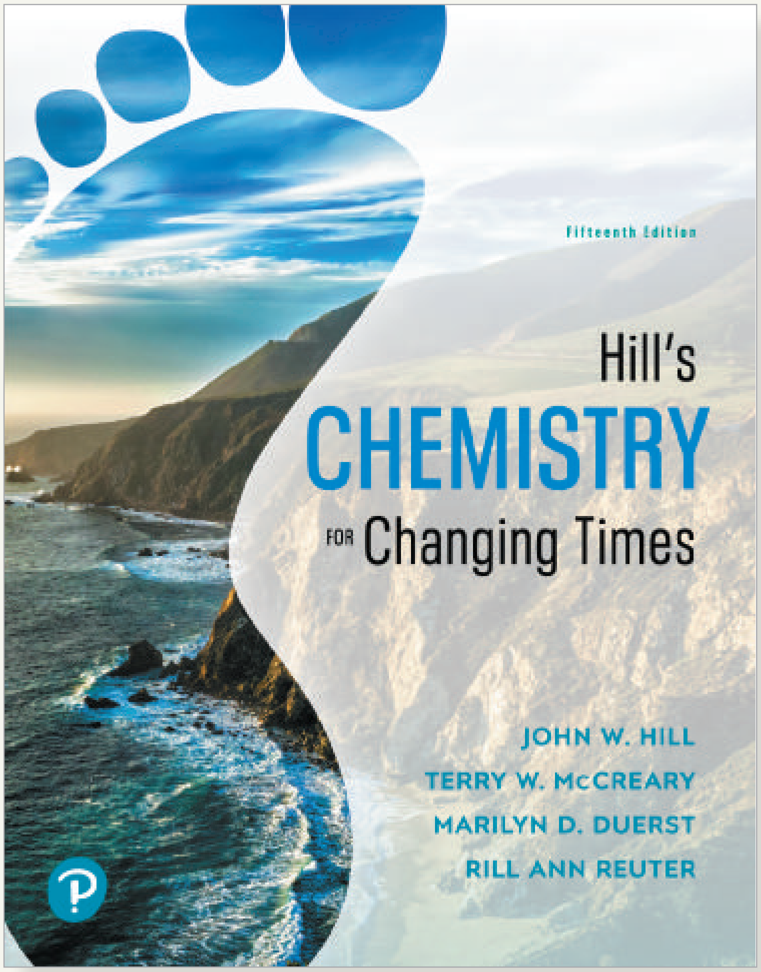
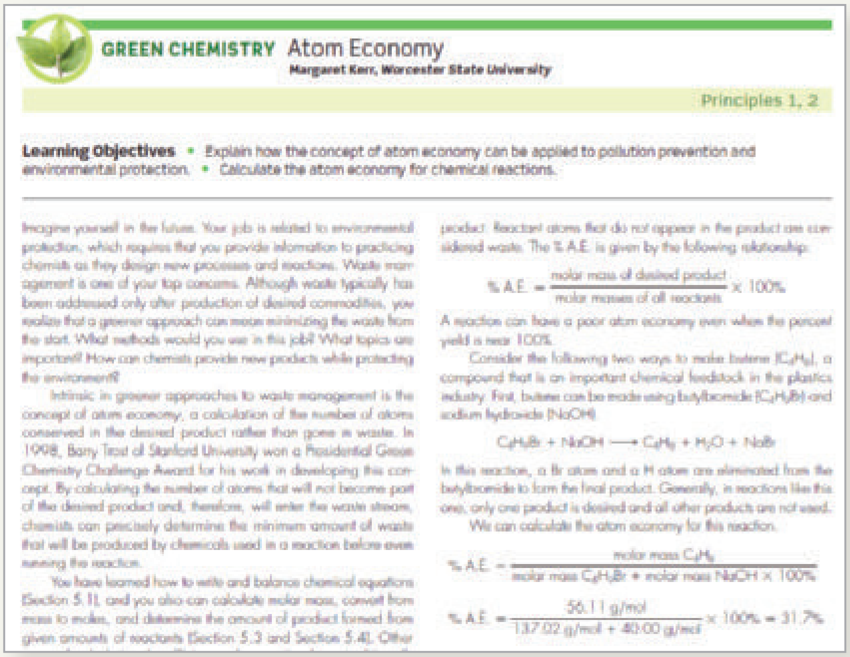
Engage students with contemporary and relevant applications of chemistry

Hill's Chemistry for Changing Times **has defined the liberal arts chemistry course and remains the most visually appealing and readable introduction to the subject. For the 15th Edition, new co-authors Marilyn D. Duerst and Rill Ann Reuter join author Terry W. McCreary to introduce new problem types that engage and challenge students to develop skills they will use in their everyday lives, including developing scientific literacy, analyzing graphs and data, and recognizing fake vs. real news. New up-to-date applications focus on health, wellness, and the environment, helping non-science and allied-health majors to see the connections between the course materials and their everyday lives. Enhanced digital tools and additional practice problems in Mastering Chemistry and the Pearson eText ensure students master the basic content needed to succeed in this course.**



Connect chemistry



GREEN CHEMISTRY Atom Economy

Margaret Kerr, Worcester State University

Principles 1, 2

Learning Objectives • Explain how the concept of atom economy can be applied to pollution prevention and environmental protection. • Calculate the atom economy for chemical reactions.

Imagine yourself in the future. Your job is related to environmental protection, which requires that you provide information to practicing chemists as they design new processes and reactions. Waste management is one of your top concerns. Although waste typically has been addressed only after production of desired commodities, you realize that a greener approach can mean minimizing the waste from the start. What methods would you use in this job? What topics are important? How can chemists provide new products while protecting the environment?

Intrinsic in greener approaches to waste management is the concept of atom economy, a calculation of the number of atoms conserved in the desired product rather than gone in waste. In 1998, Barry Trost of Stanford University won a Presidential Green Chemistry Challenge Award for his work in developing this concept. By calculating the number of atoms that will not become part of the desired product and, therefore, will enter the waste stream, chemists can precisely determine the minimum amount of waste that will be produced by chemicals used in a reaction before even running the reaction.

You have learned how to write and balance chemical equations (Section 5.1), and you also can calculate molar mass, convert from mass to moles, and determine the amount of product formed from given amounts of reactants (Section 5.3 and Section 5.4). Other

product. Reactant atoms that do not appear in the product are considered waste. The % A.E. is given by the following relationship:

$$\% \text{ A.E.} = \frac{\text{molar mass of desired product}}{\text{molar masses of all reactants}} \times 100\%$$

A reaction can have a poor atom economy even when the percent yield is near 100%.

Consider the following two ways to make butene (C_4H_8), a compound that is an important chemical feedstock in the plastics industry. First, butene can be made using butylbromide (C_4H_9Br) and sodium hydroxide (NaOH).

$$C_4H_9Br + NaOH \longrightarrow C_4H_8 + H_2O + NaBr$$

In this reaction, a Br atom and a H atom are eliminated from the butylbromide to form the final product. Generally, in reactions like this one, only one product is desired and all other products are not used.

We can calculate the atom economy for this reaction.

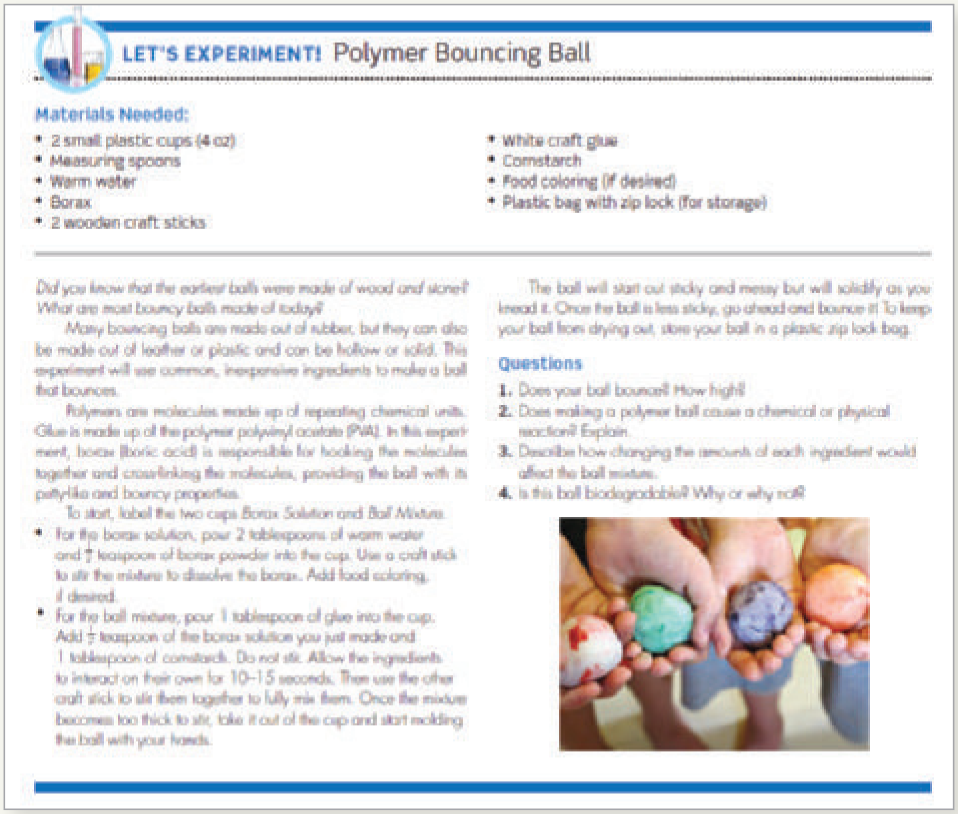
$$\% \text{ A.E.} = \frac{\text{molar mass } C_4H_8}{\text{molar mass } C_4H_9Br + \text{molar mass NaOH} \times 100\%}$$

$$\% \text{ A.E.} = \frac{56.11 \text{ g/mol}}{137.02 \text{ g/mol} + 40.00 \text{ g/mol}} \times 100\% = 31.7\%$$

pg.162

UPDATED! Green Chemistry Essays reflect current events and recent scientific findings that provide students with a way to interpret environmental issues through a chemical perspective. The essays emphasize recycling as a theme throughout the book and include discussions on problems of atmospheric pollution and preservation of the benign greenhouse effect. Auto-graded assessments tied to the essays are now available in the Mastering™ Chemistry end-of-chapter materials.

Let's Experiment!, located at the end of each chapter, provide students with safe and interesting activities they can do on their own to observe how chemistry is relevant to their day-to-day lives. Videos of the experiments are available in the Pearson eText and assignable in Mastering Chemistry.



LET'S EXPERIMENT! Polymer Bouncing Ball

Materials Needed:

- 2 small plastic cups (4 oz)
- Measuring spoons
- Warm water
- Borax
- 2 wooden craft sticks
- White craft glue
- Cornstarch
- Food coloring (if desired)
- Plastic bag with zip lock (for storage)

Did you know that the earliest balls were made of wood and stone? What are most bouncy balls made of today?

Many bouncing balls are made out of rubber, but they can also be made out of leather or plastic and can be hollow or solid. This experiment will use common, inexpensive ingredients to make a ball that bounces.

Polymers are molecules made up of repeating chemical units. Glue is made up of the polymer polyvinyl acetate (PVA). In this experiment, borax (boric acid) is responsible for hooking the molecules together and crosslinking the molecules, providing the ball with its puttylike and bouncy properties.

To start, label the two cups *Borax Solution* and *Ball Mixture*.

- For the borax solution, pour 2 tablespoons of warm water and $\frac{1}{8}$ teaspoon of borax powder into the cup. Use a craft stick to stir the mixture to dissolve the borax. Add food coloring, if desired.
- For the ball mixture, pour 1 tablespoon of glue into the cup. Add $\frac{1}{2}$ teaspoon of the borax solution you just made and 1 tablespoon of cornstarch. Do not stir. Allow the ingredients to interact on their own for 10–15 seconds. Then use the other craft stick to stir them together to fully mix them. Once the mixture becomes too thick to stir, take it out of the cup and start molding the ball with your hands.

The ball will start out sticky and messy but will solidify as you knead it. Once the ball is less sticky, go ahead and bounce it! To keep your ball from drying out, store your ball in a plastic zip lock bag.

Questions

1. Does your ball bounce? How high?
2. Does making a polymer ball cause a chemical or physical reaction? Explain.
3. Describe how changing the amounts of each ingredient would affect the ball mixture.
4. Is this ball biodegradable? Why or why not?

pg. 334

to the real world

WHY IT MATTERS

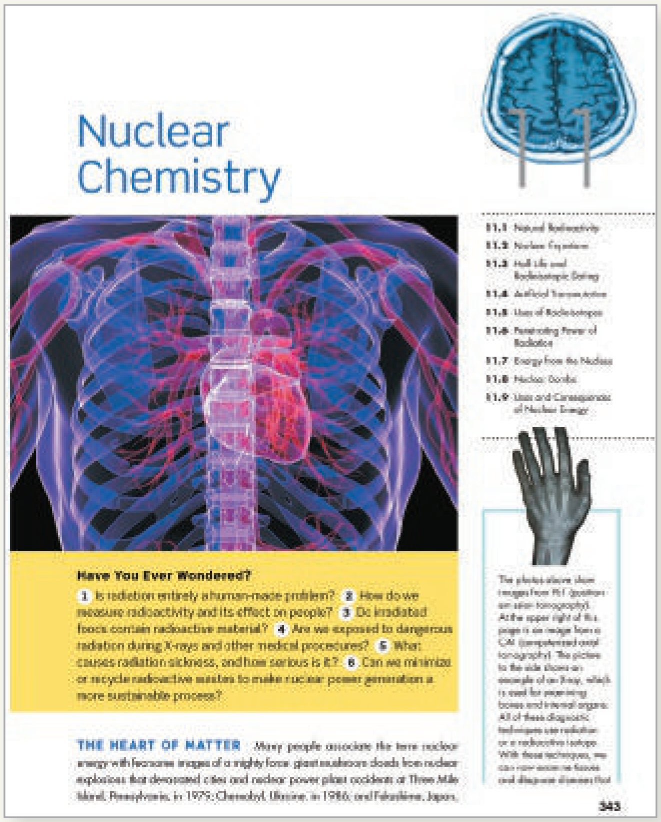
The incandescent light bulb is very inefficient with respect to the energy it uses; as much as 95% of the electric energy it uses is changed to heat, not light. Though compact fluorescent bulbs, containing mercury, were popular for about a decade, now LED bulbs are taking over the light bulb market. They are more expensive, but supposedly will last 10 to 20 years, and use a lot less energy for the same brightness effect. Use of such bulbs will be a "greener" way to light your surroundings.

WHY IT MATTERS

An isotonic, or "normal," intravenous solution must have the proper concentration of solute to avoid damage to blood cells. High concentrations cause blood cells to shrivel (*crenation*) as water is drawn out of them by osmosis. Low concentrations cause the cells to swell (*hemolysis*) and even burst.

pgs. 79, 160

REVISED AND UPDATED! Why It Matters presents contemporary, relevant, and up-to-date applications with a concentration on health, wellness, and the environment to resonate with non-science and allied-health majors taking the course.



pg. 335

REVISED AND UPDATED! Chapter Openers concentrate on wellness applications such as diet, exercise, supplements, natural remedies, and medications to help students connect chemistry with their everyday lives.

Build students' critical thinking and

Critical Thinking Exercises

Apply knowledge that you have gained in this chapter and one or more of the FLaReS principles (Chapter 1) to evaluate the following statements or claims.

12.1. An economist has said that we need not worry about running out of copper, because it can be made from other metals.

12.2. A citizen testifies against establishing a landfill near his home, claiming that the landfill will leak substances into the groundwater and contaminate his well water.

12.3. A citizen lobbies against establishing an incinerator near her home, claiming that plastics burned in the incinerator will release hydrogen chloride into the air.

12.4. An environmental activist claims that we could recycle all goods, leaving no need for the use of raw materials to make new ones.

12.5. A salesperson tells you that *ceramics* is just a fancy word for glass.

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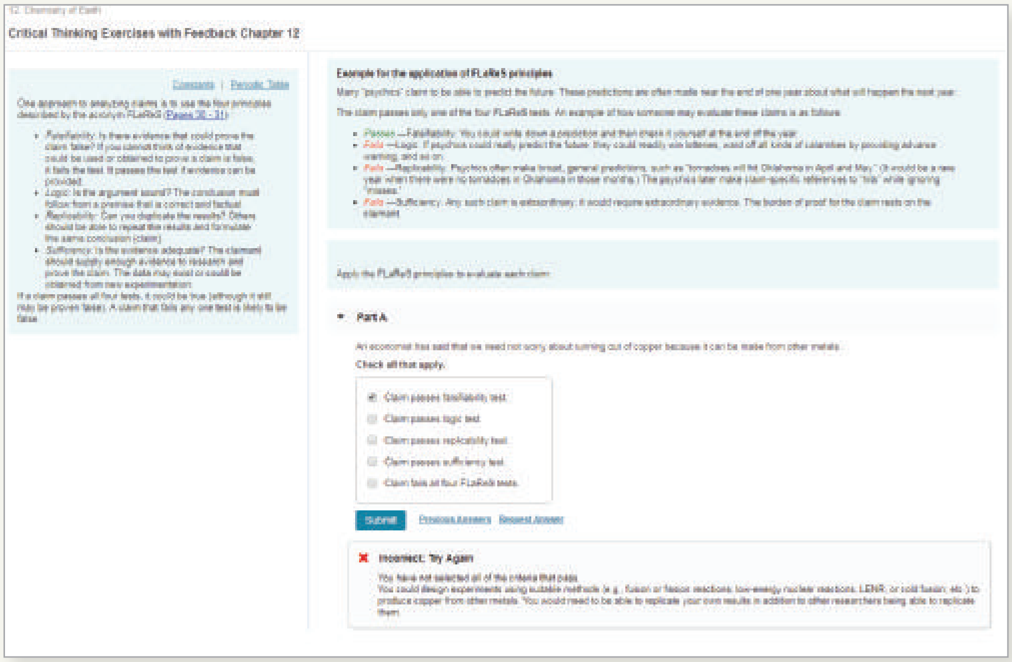
Critical Thinking Exercises encourage students to think critically about the scientific process and evaluate whether specific statements they might see in their daily lives meet the rational and objective standards of scientific rigor as outlined by the FLaReS method (Falsifiability, Logic, Replicability, Sufficiency).

These items are also assignable in Mastering Chemistry with answer-specific feedback designed to help students understand the scientific process.



problem-solving skills

EXAMPLE 6.1 Determining Intermolecular Forces

What is the major kind of force that exists between (a) NH_2Cl molecules; (b) CF_4 molecules; and (c) an H_2O molecule and an H_2S molecule?

Solution

a. NH_2Cl molecules are similar to NH_3 molecules, in that they are both trigonal pyramidal and polar. They also have the requirements for hydrogen bonding: H covalently bonded to N in one molecule, and N in a polar bond (NH bond) in a neighboring molecule. The major force is therefore hydrogen bonding.

b. Despite the fact that CF_4 molecules contain highly electronegative fluorine atoms, they are nonpolar because the fluorine atoms are symmetrically arranged around the carbon atom, similar to CH_4. Therefore, the only forces that exist between CF_4 molecules are dispersion forces.

c. Both H_2O and H_2S are bent molecules with polar bonds, so both are polar. Water molecules have hydrogen atoms covalently bonded to oxygen. However, H_2S does not contain N, O, or F atoms in a polar bond. Therefore, the major force here is a dipole–dipole force.

› Exercise 6.1A

What is the major kind of force between (a) SiH_4 molecules and (b) SF_2 molecules?

› Exercise 6.1B

What is the major kind of force between a H_3CCHO molecule (H and O bonded to C) and a water molecule?

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NEW! Examples throughout the book guide students through the process for solving a particular type of problem. Every Example in the book follows a consistent model with two follow-up exercises—the first requires the student to apply a similar situation to the method outlined in the Example, and the second asks the student to combine that method with ideas previously learned.

REVISED! End-of-Chapter problems expand their application of chemistry and its relevance to students. Additional Problems immediately follow the End-of-Chapter Problems, giving instructors one set of "traditional" problems and a follow-up set of more applied, contemporary problems.

Expand Your Skills

73. Evaluate each of the following as possible scientific hypotheses.
    a. If the temperature of a cup of tea is increased, then the quantity of sugar that can be dissolved in it will be increased.
    b. If the rate of photosynthesis, as measured by the quantity of oxygen produced, is related to the wavelength (color) of light, then light of different colors will cause a plant to make different quantities of oxygen.
    c. If the rate of metabolism in animals is related to the temperature, then raising the surrounding temperature will cause an increase in animal metabolism.
    d. If I meditate hard enough, I will pass this chemistry exam.

74. The nucleus of a hydrogen atom is 1.75 fm in diameter. The atom is larger than the nucleus by a factor of about 145,000. (a) Use exponential notation to express each measurement in terms of an SI base unit. (b) What is the volume of a hydrogen nucleus in fm^3? Of a hydrogen atom in nm^3? The volume of a sphere of radius $r = 4/3\ \pi r^3$.

75. A certain chemistry class is 1.00 microcenturies (μcen) long. What is its length in minutes?

76. A unit of beauty, a *helen*, thought to have been invented by British mathematician W.A.H. Rushton, is based on Helen of Troy (from Christopher Marlowe's play *Doctor Faustus*, which described her as having "the face that launched a thousand ships"). How many ships could be launched by a face with 1.00 millihelens of beauty?

gram of ice, and (b) swallowing the ice and allowing it to melt in his stomach "uses up" that same amount of food energy. Although both (a) and (b) are correct, the diet does not work. Explain. (*Hint:* See page 30 for a discussion of energy units, then calculate the amount of energy in food calories needed to melt a kilogram of ice.)

79. A particular brand of epoxy glue is used by mixing two volumes of liquid epoxy resin (density 2.25 g/mL) with one volume of liquid hardener (density 0.94 g/mL) before application. If the epoxy glue is to be prepared by mass rather than volume, what mass in grams of hardener must be mixed with 10.0 g of resin?

For Problems 80 and 81, classify each numbered statement as (a) an experiment, (b) a hypothesis, (c) a scientific law, (d) an observation, or (e) a theory. (It is not necessary to understand the science involved to do these problems.)

80. In the early 1800s, many scientific advances came from the study of gases. (1) For example, Joseph Gay-Lussac reacted hydrogen and oxygen to produce water vapor, and he reacted nitrogen and oxygen to form either dinitrogen oxide (N_2O) or nitrogen monoxide (NO). Gay-Lussac found that hydrogen and oxygen react in a 2:1 volume ratio and that nitrogen and oxygen can react in 2:1 or 1:1 volume ratios depending on the product. (2) In 1808, Gay-Lussac published a paper in which he stated that the relative volumes of gases in a chemical reaction are present in the ratio of small integers provided that all gases are measured at the same temperature and pressure. (3) In 1811, Amedeo

pg. 37

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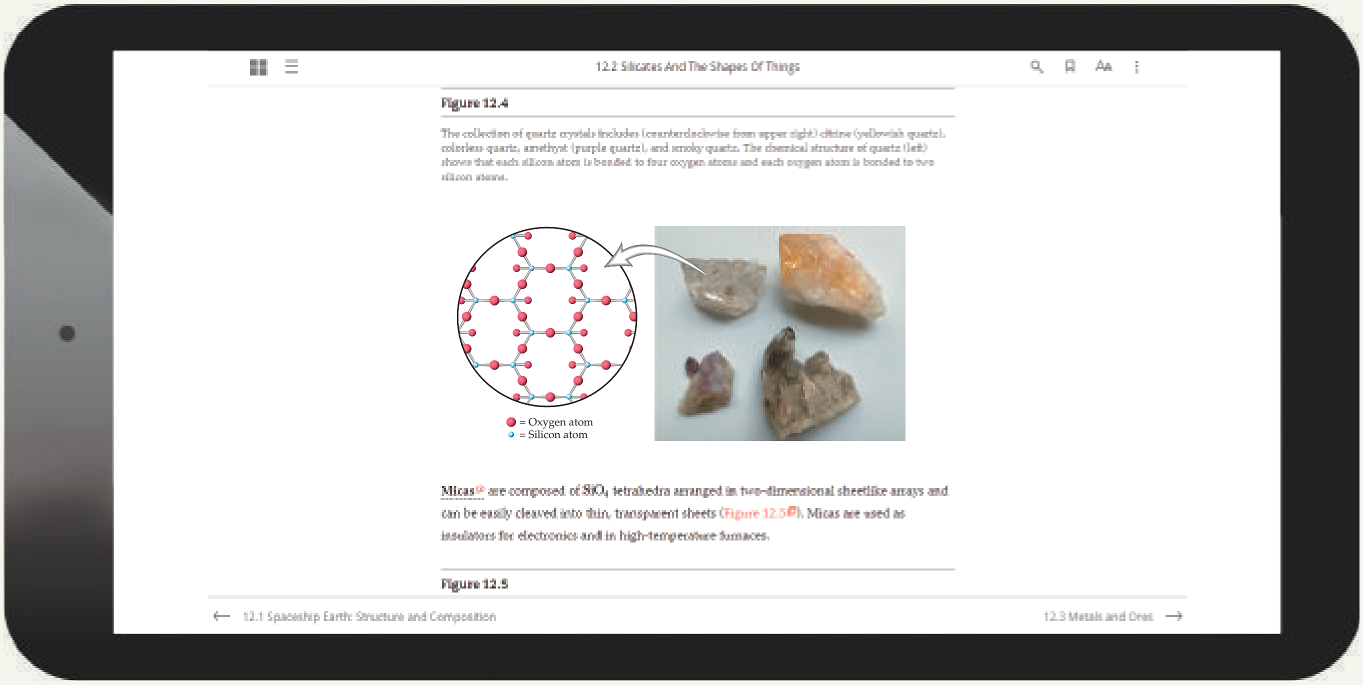
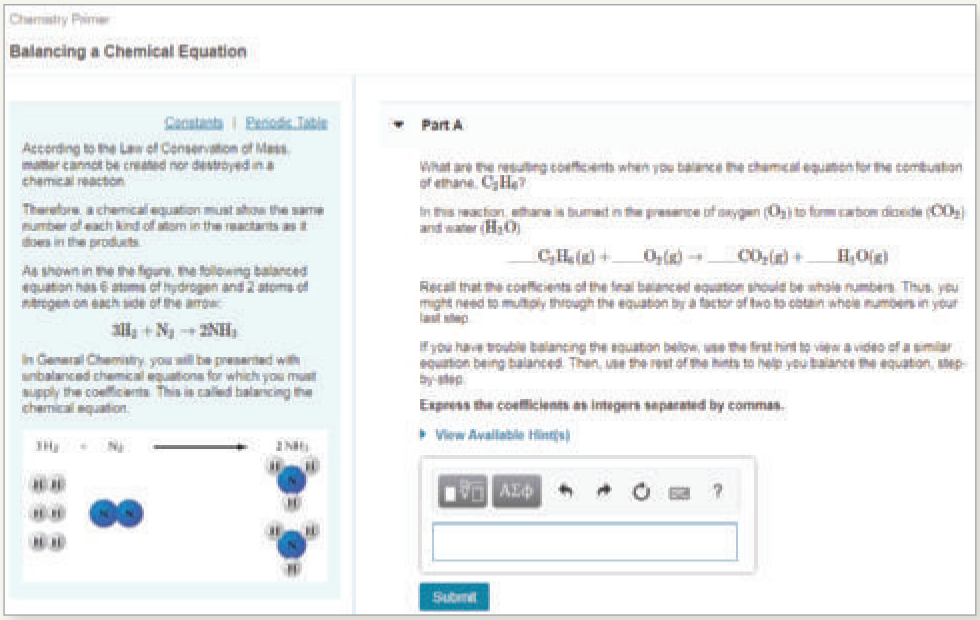
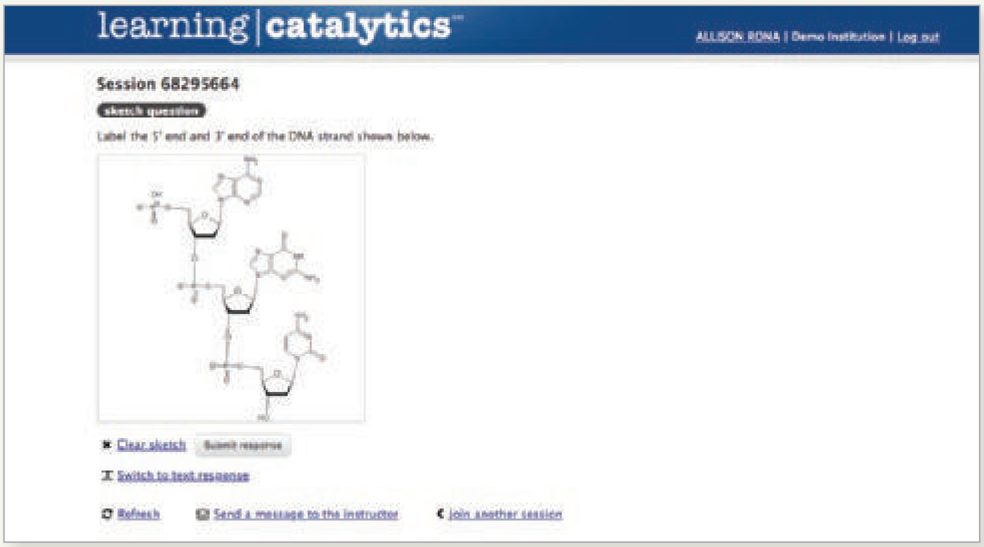


Reach every student with Mastering Chemistry



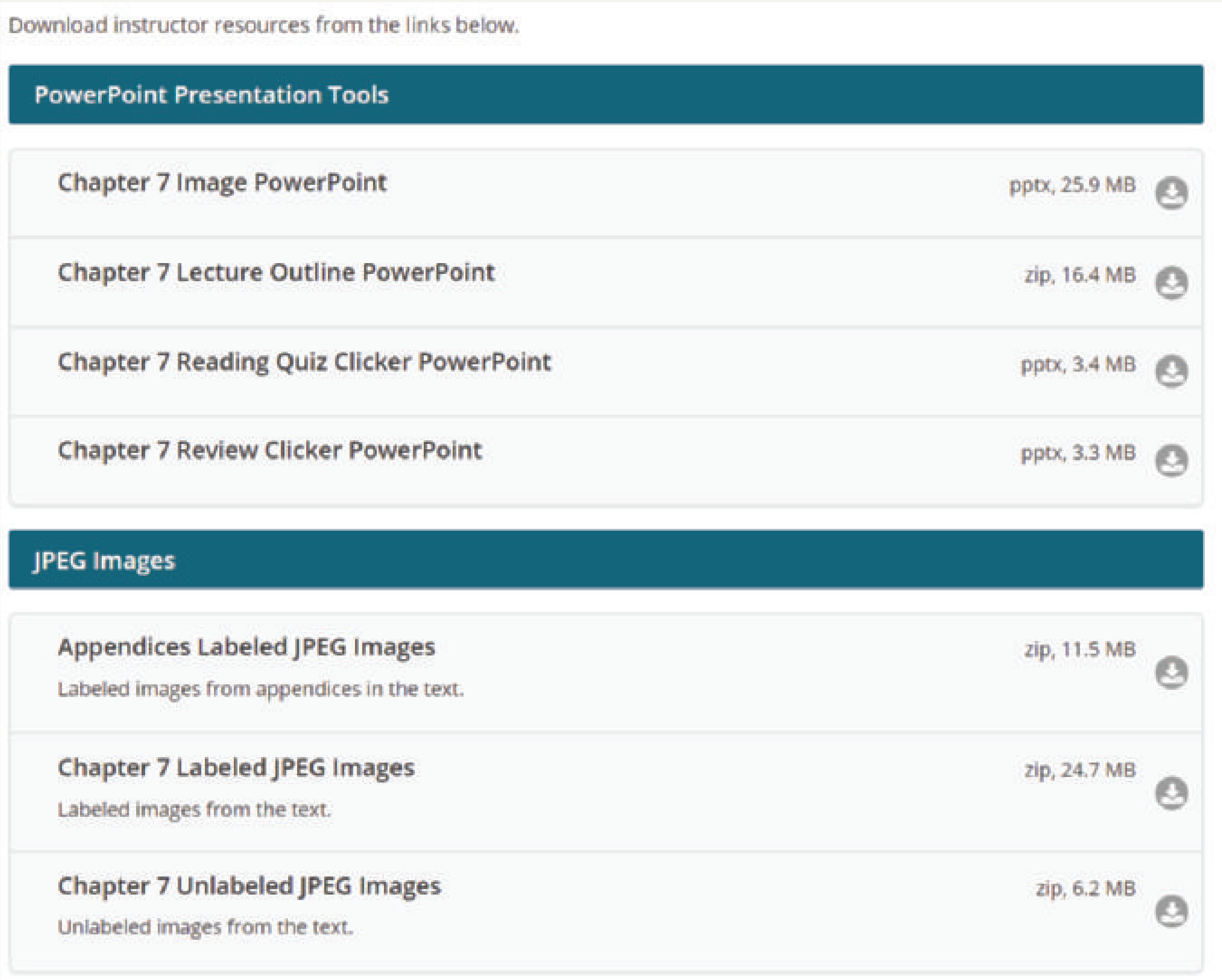
The Chemistry Primer in Mastering Chemistry helps students remediate their chemistry math skills and prepare for their first college chemistry course. Scaled to students' needs, remediation is only suggested to students that perform poorly on an initial assessment. Remediation includes tutorials, wrong-answer specific feedback, video instruction, and stepwise scaffolding to build students' abilities.

With Learning Catalytics, you'll hear from every student when it matters most. You pose a variety of questions that help students recall ideas, apply concepts, and develop critical-thinking skills. Your students respond using their own smartphones, tablets, or laptops. You can monitor responses with real-time analytics and find out what your students do — and don't — understand, to help students stay motivated and engaged.



Instructor support you can rely on

Hill's Chemistry for Changing Times **includes a full suite of instructor support materials in the Instructor Resources area in Mastering Chemistry. Resources include lecture presentations, images, reading quizzes, clicker questions, and worked examples in PowerPoint; all images from the text; videos and activities; virtual lectures; and a test bank.**



Chemistry

1

Have You Ever Wondered?

1 Why should I study chemistry? **2** Is it true that chemicals are bad for us? **3** Why do scientists so often say "more study is needed"? **4** Why do scientists bother with studies that have no immediate application? **5** Can we change lead into gold?

You will find an answer to each of these questions at the appropriate point within this chapter. Look for the answers in the margins.

Chemistry is everywhere, not just in laboratories. Did you know that a kitchen is a laboratory where you eat the product? Cornstarch thickens a stir-fry dish, bread dough rises, a delicious brown crust forms on meat, all because of chemistry! Every natural and manufactured product you can think of, from solar cells to quartz crystals, is a result of chemistry.

A SCIENCE FOR ALL SEASONS Join us on a journey toward a horizon of infinite possibilities. We will explore chemistry, a field of endeavor that pervades every aspect of our lives. Look around you. Everything you see is made of chemicals: the food we eat, the air we breathe, the clothes we wear, the buildings that shelter us, the vehicles we ride in, and the medicines that help keep us healthy.

Everything we *do* also involves chemistry. Whenever we eat a sandwich, bathe, listen to music, drive a car, or ride a bicycle, we use chemistry. Even when we are asleep, chemical reactions go on constantly throughout our bodies.

Chemistry also affects society as a whole. Developments in health and medicine involve a lot of chemistry. The astounding advances in biotechnology—such as

▲ Organic foods are not chemical-free. In fact, they are made entirely of chemicals!

genetic engineering, new medicines, improvements to nutrition, and much more—have a huge chemical component. Understanding and solving environmental problems require knowledge and application of chemistry. The worldwide issues of ozone depletion and climate change involve chemistry.

So, what exactly is chemistry anyway? We explore that question in some detail in Section 1.5. And just what is a chemical? The word *chemical* may sound ominous, but it is simply a name for any material. Gold, water, salt, sugar, air, coffee, ice cream, a computer, a pencil—all are chemicals or are made entirely of chemicals.

Material things undergo changes. Sometimes these changes occur naturally—maple leaves turn yellow and red in autumn. Often, we change material things intentionally, to make them more useful, as when we light a candle or cook an egg. Most of these changes are accompanied by changes in energy. For example, when we burn gasoline, the process releases energy that we can use to propel an automobile. Chemistry helps to define life. How do we differentiate a living collection of chemicals from the same assembly of chemicals in a dead organism or sample of inanimate matter that was never alive? A living set of molecules can replicate itself and has a way to harvest energy from its surroundings.

Our bodies are marvelous chemical factories. They take the food we eat and turn it into skin, bones, blood, and muscle, while also generating energy for all of our activities. This amazing chemical factory operates continuously, 24 hours a day, for as long as you live. Chemistry affects your own life in every moment, and it also transforms society as a whole. Chemistry shapes our civilization.

1.1 Science and Technology: The Roots of Knowledge

Learning Objectives • Define *science*, *chemistry*, *technology*, and *alchemy*. • Describe the importance of green chemistry and sustainable chemistry.

1 Why should I study chemistry?

Chemistry is a part of many areas of study and affects everything you do. Knowledge of chemistry helps you to understand many facets of modern life.

Chemistry is a *science*, but what is science? **Science** is essentially a process, a search for understanding of and explanations for natural phenomena through careful observation and experimentation. It is the primary means by which we obtain new knowledge. Science accumulates knowledge about nature and our physical world, and it generates theories that we use to explain that knowledge. **Chemistry** is that area of knowledge that deals with the behavior of matter and how it interacts with other matter and with some forms of energy.

Science and technology often are confused with one another. **Technology** is the application of knowledge for practical purposes. Technology arose in prehistoric times, long before science. The discovery of fire was quickly followed by cooking foods, baking pottery, and smelting ores to produce metals such as copper. The discovery of fermentation led to beer and winemaking. Such tasks were accomplished without an understanding of the scientific principles involved.

About 2500 years ago, Greek philosophers attempted to formulate *theories* of chemistry—rational explanations of the behavior of matter. These philosophers generally did not test their theories by experimentation. Nevertheless, their view of nature—attributed mainly to Aristotle—dominated Western thinking about the workings of the material world for the next 20 centuries.

The experimental roots of chemistry lie in **alchemy**, a primitive form of chemistry that originated in the Arab world around 700 C.E. and spread to Europe in the Middle Ages. Alchemists searched for a "philosopher's stone" that would turn cheaper metals into gold and for an elixir that would bring eternal life. Although they never achieved these goals, alchemists discovered many new chemical substances and perfected techniques, such as distillation and extraction, that are still used today.

Toward the end of the Middle Ages, a real science of chemistry began to see light. The behavior of matter began to be examined through experimentation. Theories that arose from that experimentation gradually pushed aside the authority of early philosophers. The 1800s saw a virtual explosion of knowledge as more scientists studied the behavior of matter in breadth and depth. Through the 1950s and early 1960s, science in general and chemistry in particular saw increasing relevance in our lives. Laboratory-developed fertilizers, alloys, drugs, and plastics were incorporated into everyday living. DuPont, one of the largest chemical companies in the world, used its slogan "Better Living Through Chemistry" with great effect through the 1970s.

For most of human history, people exploited Earth's resources, unfortunately giving little thought to the consequences. Rachel Carson (1907–1964), a biologist, was an early proponent of environmental awareness. The main theme of her book *Silent Spring* (1962) was that our use of chemicals to control insects was threatening to destroy all life—including ourselves. People in the pesticide industries and their allies strongly denounced Carson as a propagandist, though some scientists rallied to support her. By the late 1960s, however, the threatened extinction of several species of birds and the disappearance of fish from many rivers, lakes, and areas of the ocean caused many scientists to move into Carson's camp. Popular support for Carson's views became overwhelming.

In response to growing public concern, chemists have in recent years developed the concept of **green chemistry**, which uses materials and processes that are intended to prevent or reduce pollution at its source. This approach was further extended in the first decade of the twenty-first century to include the idea of **sustainable chemistry**—chemistry designed to meet the needs of the present generation without compromising the needs of future generations. Sustainability preserves resources and aspires to produce environmentally friendly products from renewable resources.

Chemicals themselves are neither good nor bad. Their misuse can indeed cause problems, but properly used, chemicals have saved countless millions of lives and have improved the quality of life for the entire planet. Chlorine and ozone kill bacteria that cause dreadful diseases. Drugs and vaccinations relieve pain and suffering. Fertilizers such as ammonia increase food production, and petroleum provides fuel for heating, cooling, lighting, and transportation. In short, chemistry has provided ordinary people with necessities and luxuries that were not available even to the mightiest rulers in ages past. Chemicals are essential to our lives—life itself would be impossible without chemicals.

▲ Rachel Carson's *Silent Spring* was one of the first publications to point out a number of serious environmental issues.

2 Is it true that chemicals are bad for us?

Everything you can see, smell, taste, or touch is either a chemical or is made of chemicals. Chemicals are neither good nor bad, objectively. They can be put to good use, bad use, or anything in between.

▲ A century ago, contaminated drinking water was often the cause of outbreaks of cholera and other diseases. Modern water treatment uses chemicals to remove solid matter and kill disease-causing bacteria, making water safe to drink.

SELF-ASSESSMENT Questions

Select the best answer or response.

1. Which of the following would *not* be a technological advancement made possible by understanding chemistry?
   a. Cooking pans coated with a nonstick surface like Teflon®
   b. The ability to change lead or other metals into gold
   c. Lengthening the life span of human beings using medicines
   d. Alternate fuel sources to lessen our dependence on petroleum

2. Alchemy is
   a. philosophical speculation about nature
   b. chemistry that is concerned with environmental issues
   c. the forerunner of modern chemistry
   d. the application of knowledge for practical purposes

3. The main theme of Rachel Carson's *Silent Spring* was that life on Earth could be destroyed by
   a. botulism **b.** nuclear war **c.** overpopulation **d.** pesticides

4. A goal of green chemistry is to
a. produce cheap green dyes
b. provide great wealth for corporations
c. reduce pollution
d. turn deserts into forests and grasslands

5. Which of the following chemicals are bad?
a. Trinitrotoluene (TNT)
b. Hydrogen cyanide
c. Botulism toxin
d. None of these

Answers: 1, b; 2, c; 3, d; 4, c; 5, d

1.2 Science: Reproducible, Testable, Tentative, Predictive, and Explanatory

Learning Objective • Define *hypothesis*, *scientific law*, *scientific theory*, and *scientific model*, and explain their relationships in science.

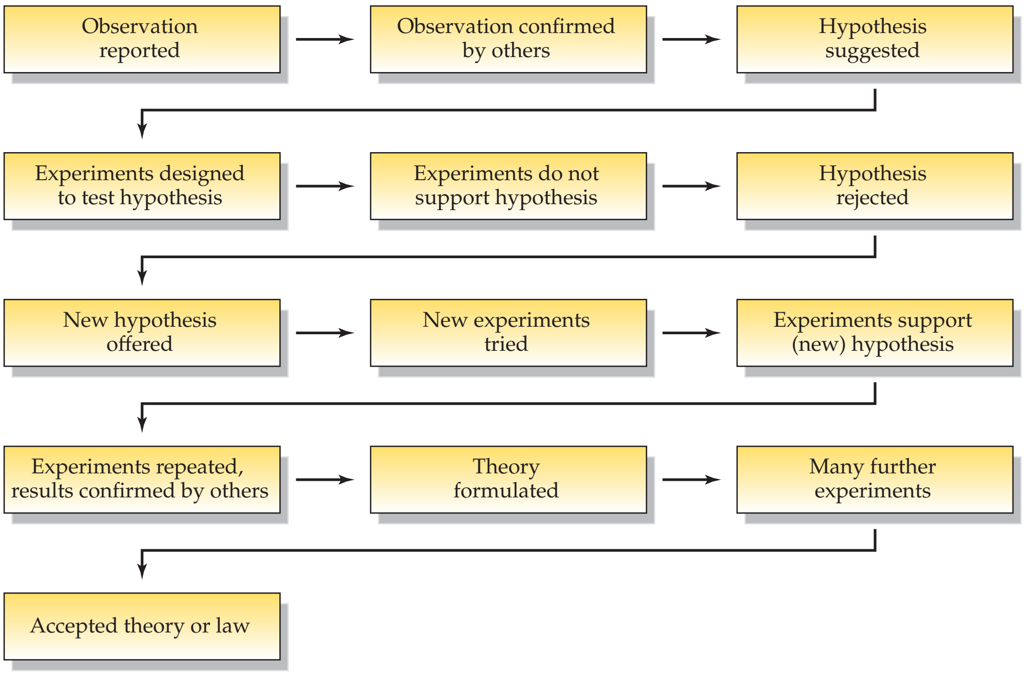
We have defined science, but science has certain characteristics that distinguish it from other studies.

Scientists often disagree about what is and what will be, but does that make science merely a guessing game in which one guess is as good as another? Not at all. Science is based on *evidence*, on observations and experimental tests of our assumptions. However, it is not a collection of unalterable facts. We cannot force nature to fit our preconceived ideas. Science is good at correcting errors; establishing truths is somewhat more challenging, for science is an unfinished work. The things we have learned from science fill millions of books and scholarly journals, but what we know pales in comparison with what we do not yet know.

Scientific Data Must Be Reproducible

Scientists collect data by making careful observations. Data must be *reproducible*—the data reported by a scientist must also be observable by other scientists. Careful measurements are required, and conditions are thoroughly controlled and described. Scientific work is not fully accepted until it has been verified by other scientists, a process called *peer review*.

Observations, though, are just the beginning of the intellectual processes of science. There are many different paths to scientific discovery, one of which is shown in Figure 1.1. However, there is no general set of rules. Science is not a straightforward process for cranking out discoveries.



▶ **Figure 1.1** A possible scientific process. It may be many years from "Observation reported" to "Accepted theory or law." Obtaining new objective knowledge often takes much time and effort.

Scientific Hypotheses Are Testable

Scientists do not merely state what they feel may be true. They develop *testable* **hypotheses** (educated guesses; *hypothesis*, in the singular) as tentative explanations of observed data. They test these hypotheses by designing and performing experiments. Experimentation distinguishes science from the arts and humanities. In the humanities, people still argue about some of the same questions that were debated thousands of years ago: What is truth? What is beauty? These arguments persist because the proposed answers cannot be tested and confirmed objectively.

Like artists and poets, scientists are often imaginative and creative. The tenets of science, however, are *testable*. Experiments can be devised to answer most scientific questions. Ideas can be tested and thereby either verified or rejected. Some ideas may be accepted for a while, but rejected when further studies are performed. For example, it was long thought that exercise caused muscles to tire and become sore from a buildup of lactic acid. Recent findings suggest instead that lactic acid *delays* muscle tiredness and that the cause of tired, sore muscles may be related to other factors, including leakage of calcium ions inside muscle cells, which weakens contractions. Through many experiments, scientists have established a firm foundation of knowledge, allowing each new generation to build on the past.

Large amounts of scientific data are often summarized in brief verbal or mathematical statements called **scientific laws**. For example, Robert Boyle (1627–1691), an Irishman, conducted many experiments on gases. From these experiments, he established *Boyle's law*, which said that the volume of the gas decreased when the pressure applied to the gas was increased. Mathematically, Boyle's law can be written as $PV = k$, where P is the pressure on a gas, V is its volume, and k is a constant. If P is doubled, V will be cut in half. Scientific laws are *universal*. Under the specified conditions, they hold everywhere in the observable universe.

3 Why do scientists so often say, "More study is needed"?

More data help scientists refine a hypothesis so that it is better defined, clearer, or more applicable.

Scientific Theories Are Tentative and Predictive

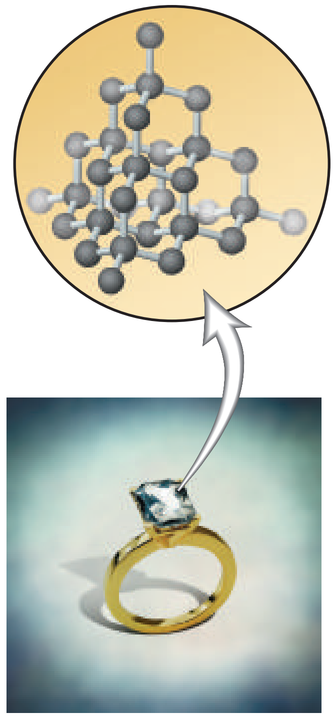
Scientists organize the knowledge they accumulate on a framework of detailed explanations called theories. A **scientific theory** represents the best current explanation for a phenomenon. In essence, a law says, "this is what happens," while a theory says, "this is *why* it happens."

Some people think that science is absolute, but nothing could be further from the truth. A theory is always *tentative*. Theories may have to be modified or even discarded as a result of new observations. For example, the atomic theory proposed in the early 1800s was extensively modified as we learned that atoms are made up of even smaller particles. The body of knowledge that is a large part of science is rapidly growing and always changing.

Theories organize scientific knowledge and are also useful for their *predictive* value. Predictions based on theories are tested by further experiments, both by the original investigators and by other scientists. Theories that make successful predictions are usually widely accepted by the scientific community. A theory developed in one area is often found to apply in others.

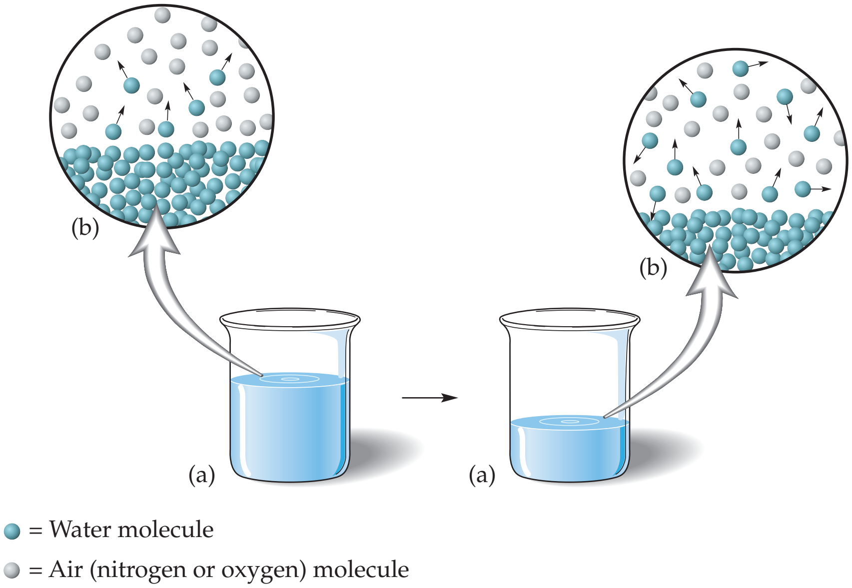
Scientific Models Are Explanatory

Scientists often use models to help *explain* complicated phenomena. A **scientific model** uses tangible items or pictures to represent invisible processes. For example, the invisible particles of a gas can be visualized as marbles or pool balls, or as dots or circles on paper.



▲ A molecular model of diamond shows the tightly linked, rigid structure that explains why diamonds are so hard.

We know that when a glass of water is left standing for a period of time, the water disappears through the process of evaporation (Figure 1.2). Scientists explain evaporation with the *kinetic-molecular theory*, which proposes that a liquid is composed of tiny particles called molecules that are in constant motion and are held together by forces of attraction. The molecules collide with one another like pool balls on a pool table. Sometimes, a "hard break" in pool causes one ball to fly off the



▲ **Figure 1.2** The evaporation of water. (a) When a container of water is left standing open to the air, the water slowly disappears. (b) Scientists explain evaporation with a model that shows the motion of molecules.

table. Likewise, some of the molecules of a liquid gain enough energy through collisions to overcome the attraction to their neighbors, escape from the liquid, and disperse among the widely spaced molecules in air. The water in the glass gradually disappears. This model gives us more than a name for evaporation; it gives us an understanding of the phenomenon.

When performing experiments, developing theories, and constructing models, it is important to note that an apparent connection—a *correlation*—between two items is not necessarily evidence that one *causes* the other. For example, many people suffer from allergies in the fall, when goldenrod is in bloom. However, research has shown that the main cause of these allergies is ragweed pollen. There is a correlation between the blooming of goldenrod and autumnal allergies, but goldenrod pollen is not the cause. Ragweed happens to bloom at the same time.

The Limitations of Science

Some people say that we could solve many of our problems if we would only attack them using the methods of science. Why can't the procedures of the scientist be applied to social, political, ethical, and economic problems? And why do scientists disagree over environmental, social, and political issues?

What Science Is—and Is Not

Responsible news media generally try to be fair, presenting both sides of an issue regardless of where the prevailing evidence lies. In science, the evidence often indicates that one side is simply wrong. Scientists strive for accuracy, not balance. The idea of a flat Earth is not given equal credence to that of a (roughly) spherical Earth. Only ideas that have survived experimental testing and peer review are considered valid. Ideas that are beautiful, elegant, or even sacrosanct can be invalidated by experimental data. For example, until 1543, the idea that the Sun revolved around the Earth was considered sacrosanct.

Science is not a democratic process. Majority rule does not determine what constitutes sound science. Science does not accept notions that are proven false or remain untested by experiment.

Disagreement often results from the inability to control *variables*. A **variable** is something that can change over the course of an experiment. If, for example, we wanted to study in the laboratory how the volume of a gas varies with changes in pressure, we could hold constant factors such as temperature and the amount and kind of gas. If, on the other hand, we wanted to determine the effect of low levels of a particular pollutant on the health of a human population, we would find it almost impossible to control such variables as individuals' diets, habits, and exposure to other substances, all of which affect health. Although we could make observations, formulate hypotheses, and conduct experiments on the health effect of the pollutant, interpretation of the results would be difficult and subject to disagreement.

SELF-ASSESSMENT Questions

Select the best answer or response.

1. To gather information to support or discredit a hypothesis, a scientist
   a. conducts experiments
   b. consults an authority
   c. establishes a scientific law
   d. formulates a scientific theory
2. The statement "mass is always conserved when chemical changes occur" is an example of a scientific
   a. experiment
   b. hypothesis
   c. law
   d. theory
3. A successful theory
   a. can be used to make predictions
   b. eventually becomes a scientific law
   c. is not subject to further testing
   d. is permanently accepted as true
4. Which of the following is *not* a hypothesis?
   a. A quarter is heavier than a nickel.
   b. Ice floats on water because of the air bubbles that get trapped during the freezing process.
   c. Oxygen reacts with silver to form tarnish.
   d. Synthetic hormones have the same effect in an organism as the naturally occurring ones.
5. Which of the following is a requirement of scientific research?
   a. It must be approved by a committee of scientists and politicians.
   b. It must benefit the Earth and improve human life.
   c. It must be experimentally tested and peer reviewed for validity.
   d. It must be balanced and weigh the pros and cons of the results.
6. Social problems are difficult to solve because it is difficult to
   a. control variables
   b. discount paranormal events
   c. form hypotheses
   d. formulate theories

Answers: 1, a; 2, c; 3, a; 4, a; 5, c; 6, a

1.3 Science and Technology: Risks and Benefits

Learning Objectives • Define *risk* and *benefit*, and give an example of each. • Estimate a desirability quotient from benefit and risk data.

Most people recognize that society has benefited from science and technology, but many seem not to realize that there are risks associated with every technological advance. How can we determine when the benefits outweigh the risks? One approach, called **risk–benefit analysis**, involves the estimation of a *desirability quotient* (DQ).

$$\text{DQ} = \frac{\text{Benefits}}{\text{Risks}}$$

A **benefit** is anything that promotes well-being or has a positive effect. Benefits may be economic, social, or psychological. A **risk** is any hazard that can lead to loss or injury. Some of the risks associated with modern technology have led to disease, death, economic loss, and environmental deterioration. Risks and benefits may involve one individual, a group, or society as a whole.

Every technological advance has both benefits and risks. For example, a car provides the benefit of rapid, convenient transportation. But driving a car involves risk—individual risks of injury or death in a traffic accident and societal risks such as pollution and climate change. When one considers the number of people who drive cars, it is clear that most people consider the benefits of driving a car to outweigh the risks.

Weighing the benefits and risks connected with a product is more difficult when considering a group of people. For example, pasteurized low-fat milk is a safe, nutritious beverage for many people of northern European descent. Some people in this group can't tolerate lactose, the sugar in milk. And some are allergic to milk proteins. But since these problems are relatively uncommon among people of northern European descent, the benefits of milk are large and the risks are small, resulting in a large DQ for this group. However, adults of other ethnic backgrounds often are lactose-intolerant, and for them, milk has a small DQ.

Other technologies provide large benefits and present large risks. For these technologies the DQ is uncertain. An example is the conversion of coal to liquid fuels. Most people find liquid fuels to be very beneficial in transportation, home heating, and industry. There are great risks associated with coal conversion, however, including risks

WHY IT MATTERS

For most people of northern European ancestry, pasteurized low-fat milk is a wholesome food. Milk's benefits far outweigh its risks. Other ethnic groups have high rates of lactose intolerance among adults, and the desirability quotient for milk is much smaller.

to coal-mine workers, air and water pollution, and exposure of conversion plant workers to toxic chemicals. The result, again, is an uncertain DQ and political controversy.

There are yet other problems in risk–benefit analysis. Some technologies benefit one group of people while presenting a risk to another. For example, gold plating and gold wires in computers and other consumer electronics benefit the consumer, providing greater reliability and longer life. But when the devices are scrapped, small-scale attempts to recover the gold often produce serious pollution in the area of recovery. Difficult political decisions are needed in such cases.

Other technologies provide current benefits but present future risks. For example, although nuclear power now provides useful electricity, improperly stored wastes from nuclear power plants might present hazards for centuries. Thus, the use of nuclear power is controversial.

Science and technology obviously involve *both* risks and benefits. The determination of benefits is almost entirely a social judgment. Although risk assessment also involves social and personal decisions, it can often be greatly aided by scientific investigation. Understanding the chemistry behind many technological advancements will help you make a more accurate risk–benefit analysis for yourself, your family, your community, and the world.

CONCEPTUAL EXAMPLE 1.1 Risk–Benefit Analysis

The drug ketorolac is a prescription NSAID (non-steroidal anti-inflammatory drug) that is said to be as effective as some opioids for treating moderate to severe pain. However, because of the side effects and potential for stroke and heart attack, the FDA recommends it for short-term use only. Do risk–benefit analyses of the use of ketorolac in treating the pain of **(a)** a 24-year-old male following an appendectomy and **(b)** a 52-year-old female who suffers from high blood pressure and the chronic pain of arthritis.

Solution

a. Pain from an appendectomy or similar procedure is generally short-term, and the likelihood of stroke or a heart attack in the short term for a young, healthy person is probably low. The DQ is probably moderate to high.

b. Treating the pain of a chronic condition, such as arthritis, would require long-term use of the drug. Also, the patient's age and high blood pressure probably make a stroke or heart attack much more likely. Also, there are other drugs that may not be as effective but are much safer to use long-term. The DQ is low in this case.

› Exercise 1.1A

Chloramphenicol is a powerful antibacterial drug that often destroys bacteria unaffected by other drugs. It is highly dangerous to some individuals, however, causing fatal aplastic anemia in about 1 in 30,000 people. Do risk–benefit analyses of administering chloramphenicol to **(a)** sick farm animals, resulting in milk and meat which might contain residues of the drug, and **(b)** a person with Rocky Mountain spotted fever facing a high probability of death or permanent disability.

› Exercise 1.1B

The drug thalidomide was introduced in Europe in the 1950s as a sleeping aid. It was found to be a *teratogen*, a substance that causes birth defects, and it was removed from the market after children whose mothers took it during pregnancy were born with deformed limbs. Recently, thalidomide has been investigated as an effective treatment for the lesions caused by leprosy and for Kaposi's sarcoma (a form of cancer often diagnosed in patients with AIDS). Do risk–benefit analyses of prescribing thalidomide for treatment of leprosy in **(a)** women aged 25–40 and **(b)** women aged 55–70.

Risks of Death

Our perception of risk often differs from the actual risk we face. Some people fear flying but readily assume the risk of an automobile trip. The odds of dying from various causes are listed in Table 1.1.

TABLE 1.1 Approximate Lifetime Risks of Death in the United States

Action	Lifetime Risk[a]			Details/Assumptions
All causes	1	or	1 in 1	We all die of something.
Cigarettes	0.25	or	1 in 4	Cigarette smoking, 1 pack/day
Heart disease	0.20	or	1 in 5	Heart attacks, congestive heart failure
All cancers	0.14	or	1 in 7	All cancers
Motor vehicles	0.01	or	1 in 100	Death in motor vehicle accident
Home accidents	0.01	or	1 in 100	Home accident death
Natural forces	0.0003	or	1 in 3360	Heat, cold, storm, earthquakes, etc.
Peanut butter (aflatoxin)	0.00060	or	1 in 1700	4 tablespoons peanut butter a day
Airplane accidents	0.00005	or	1 in 20,000	Death in aircraft crashes
Terrorist attack	0.00077	or	1 in 1300	One 9/11-level attack per year [b]
Terrorist attack	0.000077	or	1 in 13,000	One 9/11-level attack every 10 years

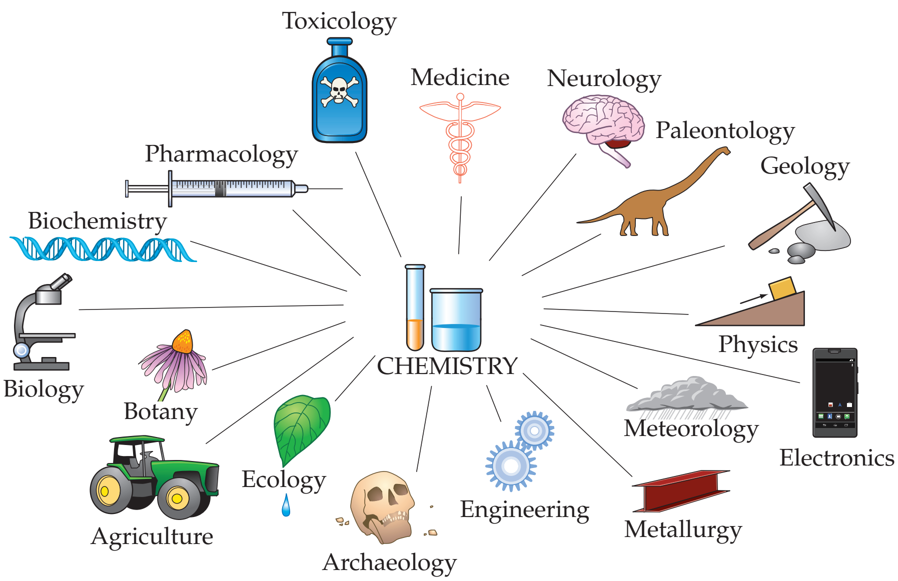
[a]The odds of dying of a particular cause in a given year are calculated by dividing the population by the number of deaths by that cause in that year.

[b]Unlikely scenario

Science is a unified whole. Common scientific laws apply everywhere and on all levels of organization. The various areas of science interact and support one another. Accordingly, chemistry is not only useful in itself but is also fundamental to other scientific disciplines. The application of chemical principles has revolutionized biology and medicine, has provided materials for powerful computers used in mathematics, and has profoundly influenced other fields, such as the production of new materials. The social goals of better health, nutrition, and housing are dependent to a large extent on the knowledge and techniques of chemists. Recycling of basic materials—paper, glass, and metals—involves chemical processes.

Chemistry is indeed a central science (Figure 1.3). There is no area of our daily lives that is not affected by chemistry. Many modern materials have been developed by chemists, and even more amazing materials are in the works.

Chemistry is also important to the *economies* of industrial nations. In the United States, the chemical industry makes thousands of consumer products, including personal-care products, agricultural products, plastics, coatings, soaps, and detergents. It produces 80% of the materials used to make medicines. The U.S. chemical industry is one of the country's largest industries, with sales of more than $800 billion in 2016, accounting for about 10% of all U.S. exports. It employs more than 826,000 workers,



▼ **Figure 1.3** Chemistry has a central role among the sciences.

including scientists, engineers, and technicians, and generates nearly 11% of all U.S. patents. Contrary to the popular belief that chemicals are highly dangerous, workers in the chemical industry are five times safer than the average worker in the U.S. manufacturing sector.

SELF-ASSESSMENT Questions

Select the best answer or response.

1. Our perception of risk is
a. always based on sound science
b. always higher than actual risk
c. always lower than actual risk
d. often different from actual risk

2. Among the following, the highest risk of death (see Table 1.1) is associated with
a. heart disease **b.** peanut butter
c. cancer **d.** automobile accidents

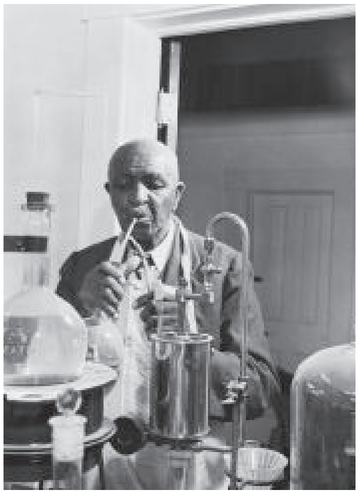
3. Chemistry is called "the central science" because
a. the chemical industry is based mainly in the U.S. Midwest
b. it is the core course in all college curricula
c. it is fundamental to other scientific disciplines
d. it is the source of many environmental problems

4. The U.S. chemical industry is
a. patently unsafe
b. the source of nearly all pollution
c. the source of many consumer products
d. unimportant to the U.S. economy

Answers: 1, d; 2, a; 3, c; 4, c

1.4 Solving Society's Problems: Scientific Research

Learning Objective • Distinguish basic research from applied research.



▲ George Washington Carver (1864–1943), research scientist, in his laboratory at Tuskegee Institute.

Chemistry is a powerful force in shaping society today. Chemical research not only plays a pivotal role in other sciences, but it also has a profound influence on society as a whole. There are two categories of research: *applied research* or *basic research*. The two often overlap, and it isn't always possible to label a particular project as one or the other.

Applied Research

Some chemists test polluted soil, air, and water. Others analyze foods, fuels, cosmetics, detergents, and drugs. Still others synthesize new substances for use as drugs or pesticides or formulate plastics for new applications. These activities are examples of **applied research**—work oriented toward the solution of a particular problem in an industry or the environment.

Among the most monumental accomplishments in applied research were those of George Washington Carver. Born in slavery, Carver attended Simpson College and later graduated from Iowa State University. A botanist and agricultural chemist, Carver taught and did research at Tuskegee Institute. He developed more than 300 products from peanuts, from peanut butter to hand cleaner to insulating board. He created other new products from sweet potatoes, pecans, and clay. Carver also taught Southern farmers to rotate crops and to use legumes to replenish the nitrogen removed from the soil by cotton crops. His work helped to revitalize the economy of the South.

Basic Research: The Search for Knowledge

Many chemists are involved in **basic research**, the search for knowledge for its own sake. Some chemists work out the fine points of atomic and molecular structure. Others measure the intricate energy changes that accompany complex chemical reactions. Some synthesize new compounds and determine their properties. Done for the sheer joy of unraveling the secrets of nature and discovering order in our universe, basic research is characterized by the absence of any predictable, marketable product.

Lack of a product doesn't mean that basic research is useless. Far from it! Findings from basic research often *are* applied at a later time, though this is not the main goal of the researcher. In fact, most of our modern technology is based on results obtained in basic research. For example, in the 1940s and 1950s Gertrude Elion (1918–1999) and George Hitchings (1905–1998) examined the role of compounds called *purines* in cell chemistry. This led to the discovery of new drugs that facilitate organ transplants and treat gout, malaria, herpes, cancer, and AIDS. Basic research in the 1960s involving a device called the *maser* led to the development of today's global positioning system (GPS). In the 1920s, basic research led to discovery of *nuclear spin*, a property of certain atomic nuclei. This work led to the development of *magnetic resonance imaging* (MRI), used by virtually every hospital today to view internal body structure. Without the base of factual information obtained from basic research, technological innovation would be haphazard and slow.

Applied research is carried out mainly by industries seeking immediate gain by developing a novel, better, or more salable product. The ultimate aim of such research is usually profit for the stockholders. Basic research is conducted mainly at universities and research institutes. Most support for this research comes from federal and state governments and foundations, although some larger industries also support it.

4 Why do scientists bother with studies that have no immediate application?

The results of basic research may not have an immediate practical use. However, basic research extends our understanding of the world and can be considered an investment in the future. And basic research often *finds* a practical application. For example, *zone refining* is a method developed in the early twentieth century for producing extremely pure solids. It had little practical application until the advent of integrated circuits. Zone refining is now used to produce the ultrapure silicon needed for every electronic device on Earth.

SELF-ASSESSMENT Questions

Classify each of the following as (a) applied research or (b) basic research.

1. A chemist develops a faster-acting and longer-lasting asthma remedy.
2. A researcher investigates the effects of different acids on the breakdown of starches.
3. A scientist seeks to extract biologically active compounds from sea sponges.
4. Scientists create rBST to improve milk production in cows.

Answers: 1, a; 2, b; 3, b; 4, a

1.5 Chemistry: A Study of Matter and Its Changes

Learning Objective • Differentiate: mass and weight; physical and chemical changes; and physical and chemical properties.

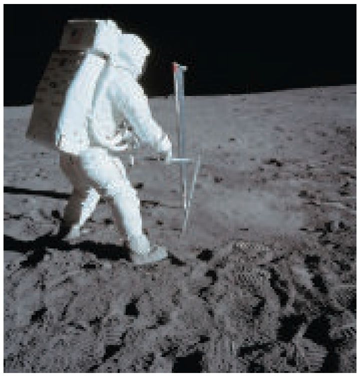
As we have noted, chemistry is often defined as the study of matter and the changes it undergoes. Because the entire physical universe is made up of matter and energy, the field of chemistry extends from atoms to stars, from rocks to living organisms. Now let's look at matter a little more closely.

Matter is the stuff that makes up all material things. It is anything that occupies space and has mass. Scientifically, **mass** is a measure of the *inertia* of an object; the greater the mass of an object, the greater is its inertia, meaning that it is more difficult to change the object's velocity. You can easily deflect a fist-sized tennis ball coming toward you at 30 meters per second, but you would have difficulty stopping an iron cannonball of that size moving at the same speed. A cannonball has more mass than a tennis ball of equal size. Wood, sand, water, air, and people all occupy space and have mass and are, therefore, matter.

The mass of an object does not vary with location. An astronaut has the same mass on the moon, or in "weightless" orbit, as on Earth. In contrast, **weight** measures a force. On Earth, it measures the force of attraction between our planet and the mass in question. On the moon, where gravity is one-sixth that on Earth, an astronaut weighs only one-sixth as much as on Earth (Figure 1.4). Weight varies with gravity; mass does not. Nonetheless, in this book we often will use the term "weight" to mean "mass" for two reasons. First, it can be a bit awkward or confusing to say, "The student massed about 15 grams of sugar," rather than "The student weighed about 15 grams of sugar." Second, most chemical reactions occur under constant gravity on the surface of the Earth, so weight remains virtually the same anywhere on Earth. Ordinarily the American units of ounces and pounds are used when expressing weight in this book; grams, kilograms, etc., refer to mass.

WHY IT MATTERS

Gertrude Elion won a Nobel Prize for her basic research on purines. Her work has led to many applications in pharmaceuticals and medicine. Many important modern applications started out with basic research. In 1991, Elion became the first woman to be inducted into the National Inventors Hall of Fame.



▲ **Figure 1.4** Although Astronaut Harrison Schmitt's moon suit weighs as much on Earth as he does (180 pounds each), he finds it fairly easy to move, because lunar gravity pulls him and his suit only one-sixth as much as gravity does on Earth.

Q *Based on the information in the caption, how much do Schmitt and his moon suit weigh, in pounds, on the moon? What would be the mass in kilograms of him in his suit on Earth?*

CONCEPTUAL EXAMPLE 1.2 Mass and Weight

Gravity on the planet Mercury is three-eighths that on Earth. **(a)** What would be the mass on Mercury of a person who had a mass of 80 kilograms (kg) on Earth? **(b)** What would be the weight in pounds on Mercury of a person who weighed 160 pounds (lb.) on Earth?

Solution

- **a.** The person's mass would be the same as on Earth (80 kg). The quantity of matter has not changed.
- **b.** The force of attraction between Mercury and the person is only three-eighths, or 0.375 times, that between Earth and the person, so the person would weigh only 0.375×160 lb. $= 60$ lb.

› Exercise 1.2A

At the surface of Venus, the force of gravity is 0.903 times that at Earth's surface. **(a)** What would be the mass of a 1.00 kg object on Venus? **(b)** How much (in pounds) would a man who weighed 198 lb. on Earth weigh on the surface of Venus?

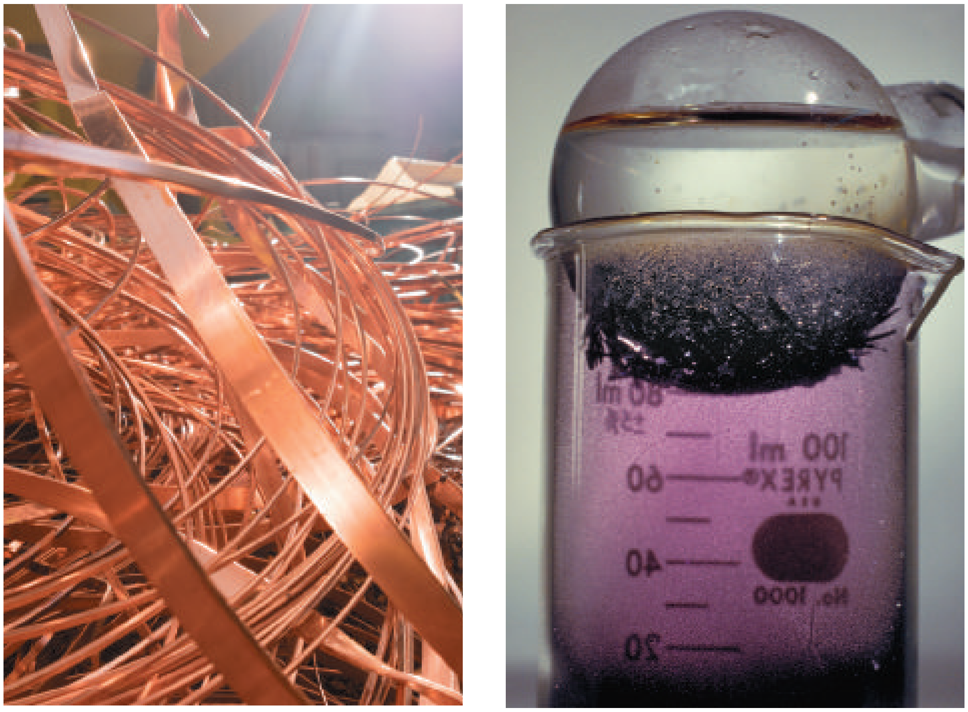
› Exercise 1.2B

A man who weighs 198 pounds on Earth would weigh 475 pounds on the surface of Jupiter. How many times greater than Earth's gravity is Jupiter's gravity?

Physical and Chemical Properties

We can use our knowledge of chemistry to change matter to make it more useful. Chemists can change crude oil into gasoline, plastics, pesticides, drugs, detergents, and thousands of other products. Changes in matter are accompanied by changes in energy. Often, we change matter to extract part of its energy. For example, we burn gasoline to get energy to propel our automobiles.

To distinguish between samples of matter, we can compare their properties (Figure 1.5). A **physical property** of a substance is a characteristic or behavior that can be observed or measured without forming new types of matter. Color, odor,



▶ **Figure 1.5** A comparison of the physical properties of two elements. Copper (left) can be hammered into thin foil or drawn into wire. Iodine (right) consists of brittle gray crystals that crumble into a powder when struck.

Q *What additional physical properties of copper and iodine are apparent from the photographs?*

TABLE 1.2 **Some Examples of Physical Properties**

Property	Examples
Temperature	Water freezes at 0 °C and boils at 100 °C.
Mass	A nickel has a mass of 5 g. A penny has a mass of 2.5 g.
Color	Sulfur is yellow. Bromine is reddish-brown.
Taste	Acids are sour. Bases are bitter.
Odor	Benzyl acetate smells like jasmine. Hydrogen sulfide smells like rotten eggs.
Boiling point	Water boils at 100 °C. Ethyl alcohol boils at 78.5 °C.
Hardness	Diamond is exceptionally hard. Sodium metal is soft.
Density	1.00 g/mL for water, 19.3 g/cm^3 for gold.

TABLE 1.3 **Some Examples of Chemical Properties**

Substance	Typical Chemical Property
Iron	Rusts (combines with oxygen to form iron oxide)
Carbon	Burns (combines with oxygen to form carbon dioxide)
Silver	Tarnishes (combines with sulfur to form silver sulfide)
Nitroglycerin	Explodes (decomposes to produce a mixture of gases)
Carbon monoxide	Is toxic (combines with hemoglobin, causing anoxia)
Neon	Is inert (does not react with anything)

and hardness are physical properties (Table 1.2). When a **chemical property** is observed, new types of matter with different compositions are formed. Burning wood is a chemical change because new substances such as carbon dioxide, water vapor, and ash (mostly potassium oxide) are formed (Table 1.3).

When a **physical change** occurs, there is a change in the physical appearance of matter without changing its chemical identity or composition. An ice cube can melt to form a liquid, but it is still water. Melting is a physical change, and the temperature at which it occurs—the melting point—is a physical property.

A **chemical change** or chemical reaction involves a change in the chemical identity of matter into other substances that are chemically different. In exhibiting a chemical property, matter undergoes a chemical change. At least one substance in the original matter is replaced by one or more new substances. Iron metal reacts with oxygen from the air to form rust (iron oxide). When sulfur burns in air, sulfur—a yellow solid made up of one type of atom—and odorless oxygen gas (from air), which is made up of another type of atom, combine to form sulfur dioxide, a smelly, choking gas made up of molecules, each containing one sulfur atom and two oxygen atoms. A *molecule* is a group of atoms bound together as a single unit. (You'll learn more about atoms and molecules in the next section.)

It is difficult at times to determine whether a change is physical or chemical. We can decide, though, on the basis of what happens to the composition or structure of the matter involved as well as the reversibility of the change. Physical changes are often reversible while chemical changes are not. *Composition* refers to the types of atoms that are present and their relative proportions, and *structure* refers to the arrangement of those atoms with respect to one another or in space. A chemical change results in a change in composition or structure, whereas a physical change does not. To answer the question "Is this a chemical change?" simply consider whether new substances with new properties have been formed. If new substances are formed, the change is a chemical change.

CONCEPTUAL EXAMPLE 1.3 Chemical Change and Physical Change

Identify each of the following as a physical change or chemical change.

a. A piece of wood is sanded to make it smooth, forming sawdust.
b. Lemon juice is added to warmed milk to make cottage cheese.
c. Molten aluminum is poured into a mold, where it solidifies.
d. Sodium chloride (table salt) is broken down into sodium metal and chlorine gas.

Solution

We examine each change and determine whether there has been a change in composition or structure. In other words, we ask, "Have new substances that are chemically different been created?" If so, the change is chemical; if not, it is physical.

a. Physical change: Both the smoothed wood and the sawdust are still wood, chemically the same as the wood before sanding.
b. Chemical change: Cottage cheese and milk have very different compositions.
c. Physical change: Whether it is solid or liquid, aluminum is the same substance with the same composition.
d. Chemical change: New substances, sodium and chlorine, are formed.

› Exercise 1.3A

Identify each of the following as a physical change or chemical change.

a. A steel wrench left out in the rain becomes rusty.
b. A stick of butter melts.
c. Charcoal briquettes are burned.

› Exercise 1.3B

Identify each of the following as a physical change or chemical change.

a. A food processor changes a beef roast into ground beef.
b. Pancake batter is cooked on a griddle.
c. The plastic filament in a 3D printer is used to make a small figure.

SELF-ASSESSMENT Questions

Select the best answer or response.

1. Which of the following is *not* an example of matter?
a. methane gas **b.** steam
c. silver **d.** a rainbow

2. Which of the following is an example of matter?
a. sunlight
b. air pollution
c. magnetic field
d. ultraviolet light from a tanning lamp

3. Two identical items are taken from Earth to Mars, where they have
a. both the same mass and the same weight as on Earth
b. neither the same mass nor the same weight as on Earth
c. the same mass but not the same weight as on Earth
d. the same weight but not the same mass as on Earth

4. What kind of change alters the identity of a material?
a. lowering the temperature **b.** physical
c. hammering the material **d.** chemical

5. Bending glass tubing in a hot flame involves
a. applied research **b.** a chemical change
c. an experiment **d.** a physical change

6. Creating solid ice from liquid water involves
a. adding energy to the water
b. a physical change
c. a chemical change
d. creating a new substance

7. Which of the following is a chemical property?
a. Iodine vapor is purple.
b. Copper tarnishes.
c. Salt dissolves in water.
d. Balsa wood is easily carved.

8. Which of the following is an example of a physical change?
a. A cake is baked from flour, baking powder, sugar, eggs, shortening, and milk.
b. Cream left outside a refrigerator overnight turns sour.
c. Sheep are sheared, and the wool is spun into yarn.
d. Spiders eat flies and make spider silk.

9. Which of the following is an example of a chemical change?
a. An egg is broken and poured into an eggnog mix.
b. A tree is pruned, shortening some branches.
c. A tree grows larger from being watered and fertilized.
d. Frost forms on a cold windowpane.

Answers: 1, d; 2, b; 3, c; 4, d; 5, d; 6, b; 7, b; 8, c; 9, c

1.6 Classification of Matter

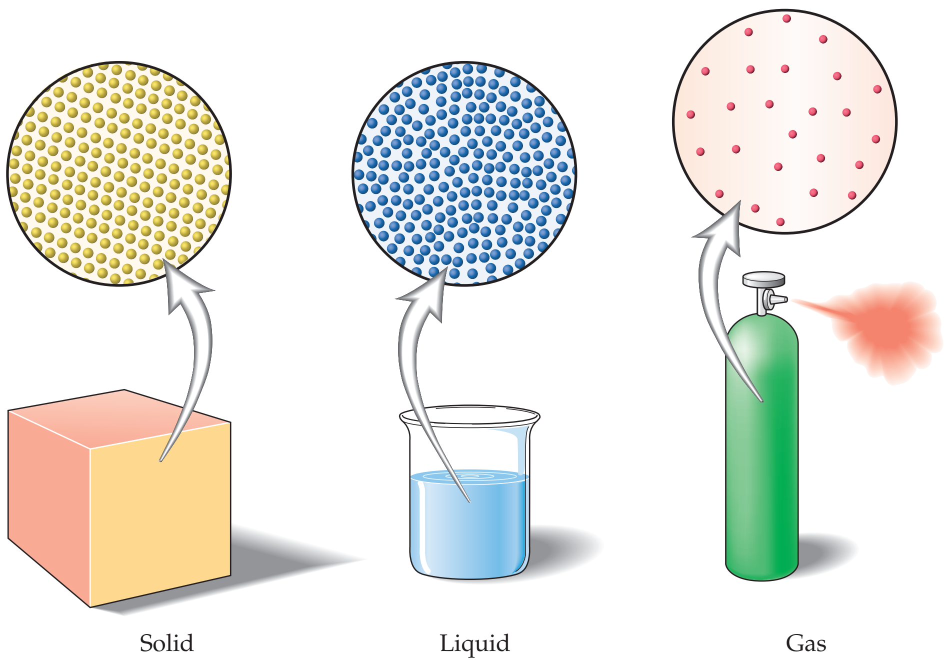
Learning Objective • Classify matter according to state and as mixture, substance, compound, and/or element.

In this section, we examine three of the many ways of classifying matter. First, we look at the physical forms or *states of matter*.

The States of Matter

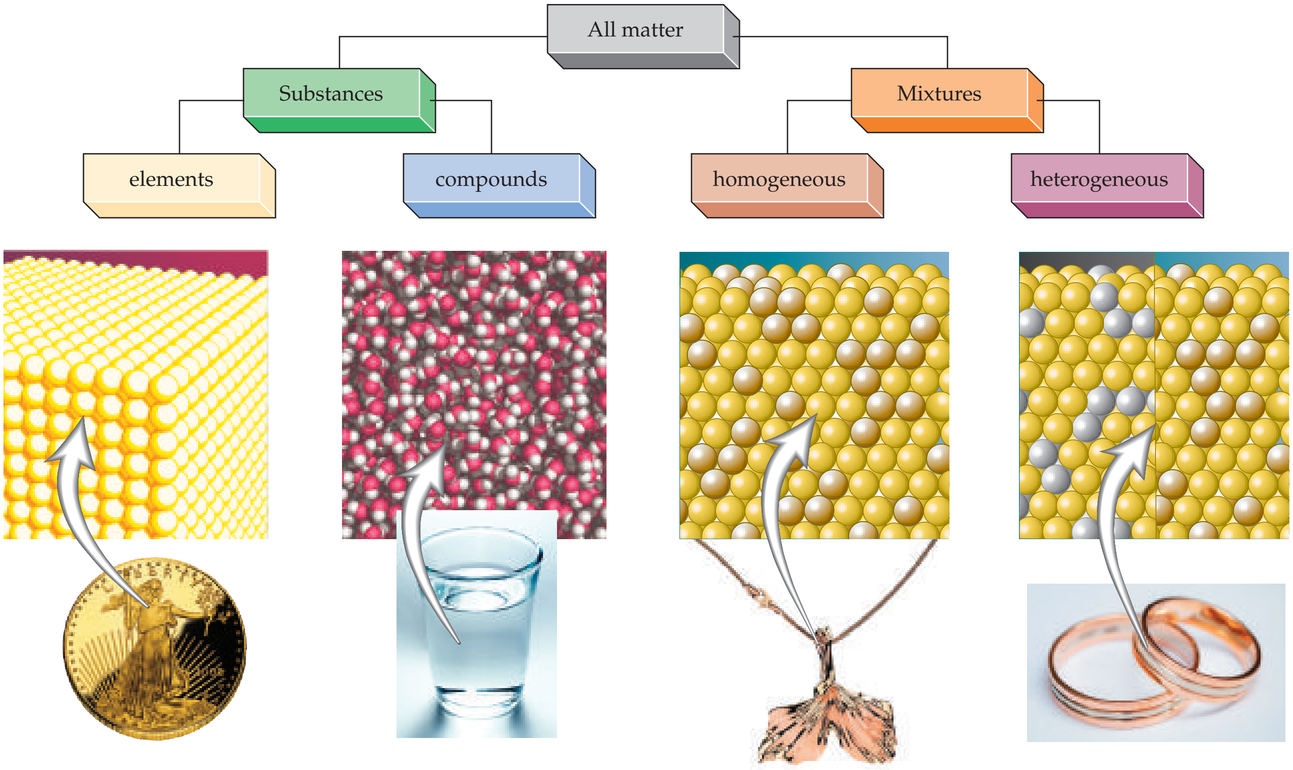
There are three familiar states of matter: solid, liquid, and gas (Figure 1.6). They can be classified by bulk properties (a *macro* view) or by arrangement of the particles that compose them (a *molecular*, or *micro*, view). A **solid** object maintains its shape and volume regardless of its location. A **liquid** occupies a definite volume but assumes the shape of the portion of a container that it occupies. If you have 355 milliliters (mL) of a soft drink, you have 355 mL regardless of whether the soft drink is in a can, in a bottle, or, through a mishap, on the floor—which demonstrates another property of liquids. Unlike solids, liquids flow readily. A **gas** maintains neither shape nor volume. It expands to fill completely whatever container it occupies. Like liquids, gases flow; unlike liquids and solids, gases are easily compressed. For example, enough air for many minutes of breathing can be compressed into a steel tank for SCUBA diving.

Bulk properties of solids, liquids, and gases are explained using the kinetic-molecular theory (Chapter 5). In solids, the particles are close together and in fixed positions. In liquids, the particles are close together, but they are free to move about. In gases, the particles are far apart and are in rapid random motion.



▲ **Figure 1.6** The kinetic-molecular theory can be used to interpret (or explain) the bulk properties of *solids, liquids*, and *gases*. In solids, the particles are close together and in fixed positions. In liquids, the particles are close together, but they are free to move about. In gases, the particles are far apart and are in rapid random motion.

Q *Based on this figure, why does a quart of water vapor weigh so much less than a quart of liquid water?*



▲ **Figure 1.7** A scheme for classifying matter according to its composition. From left to right: The coin is pure gold, an *element*. Water is a *compound*. The pendant is made of rose gold, a *homogeneous mixture* of gold and copper; all parts of the pendant have the same composition. The ring at the far right is a *heterogeneous mixture* of rose gold and white gold (which contains gold and silver). Rose gold and white gold have different compositions.

Substances and Mixtures

Matter can be either pure or mixed (Figure 1.7). A **substance** is a pure form of matter which has a definite, or fixed, composition that does not vary from one sample to another. Pure gold (24-karat gold) consists entirely of gold atoms, so it is a substance. All samples of pure water are composed of molecules consisting of two hydrogen atoms and one oxygen atom, so water is also a substance.

A **mixture** is a variable composition of two or more substances. The substances retain their identities. They do not change chemically; they simply mix. Mixtures can be separated by physical changes. Mixtures can be either *homogeneous* or *heterogeneous*. All parts of a **homogeneous mixture** have the same composition (Section 6.4) and the same appearance. A solution of salt in water is a homogeneous mixture. The proportions of salt and water can vary from one solution to another, but the water is still water and the salt remains salt. The two substances can be separated by physical means. For example, the water can be boiled away, leaving the salt behind.

Different parts of a **heterogeneous mixture** have different compositions. Peanut brittle is a heterogeneous mixture. The appearance is not the same throughout. The peanuts are obviously different from the candy holding them together. Most things we deal with each day are heterogeneous mixtures. All you have to do is look at a computer, a book, a pen, or a person to see that different parts of those mixtures have different compositions. (Your hair is quite different from your skin, for example.)

5 Can we change lead into gold?

One element cannot be changed into another element by chemical reactions. An element cannot be created or destroyed, although an element can be extracted from a mixture or compound containing the element.

Elements and Compounds

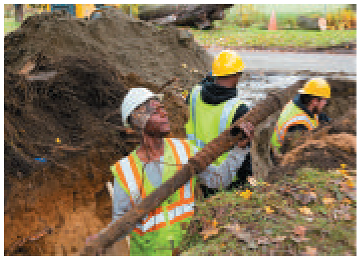
A *substance* is either an element or a compound. An **element** is one of the fundamental substances from which all material things are constructed. Elements cannot be broken down into simpler substances by any chemical process. There are 118 known elements, of which this book deals with only about a third. A list of all elements appears near the front of this book. Oxygen, carbon, sulfur, aluminum, and iron are familiar elements.

A **compound** is a substance made up of two or more elements chemically combined in a fixed ratio. For example, water is a compound because it has fixed proportions of hydrogen (H) and oxygen (O). Aluminum oxide (the "sand" on sandpaper), carbon dioxide, and iron disulfide (FeS_2, "fool's gold") are other compounds. Just as a whole dictionary of words can be constructed from 26 letters, tens of millions of compounds have been made from the 118 elements. A distinguishing property of a compound is that it can only be separated into its elements by a chemical change.

Because elements are so fundamental to our study of chemistry, we find it useful to refer to them in a shorthand form. Each element can be represented by a **chemical symbol** made up of one or two letters derived from the name of the element. Symbols for the elements are listed in the Table of Atomic Masses near the front cover. The first letter of a symbol is always capitalized. The second (if there are two) is always lowercase. It makes a difference. For example, Co is the symbol for cobalt, a metallic element, but CO is the formula for carbon monoxide, a poisonous compound.

A chemical symbol in a formula stands for one atom of the element. If more than one atom is included in a formula, a subscript number is used after the symbol. For example, the formula H_2 represents two atoms of hydrogen, and the formula CH_4 represents a compound with molecules each of which contains one atom of carbon and four atoms of hydrogen. Mixtures do not have such formulas, because a mixture does not have a fixed composition.

The elements' symbols are the alphabet of chemistry. Most are based on the English names of the elements, but a few are based on Latin and Greek names. For example, the symbol for gold is Au, from the Latin word *aurum*, and lead's symbol is Pb, from the Latin word *plumbum*. (The latter is also the origin of the word *plumbing*, because lead was used for plumbing pipes and fittings until the 1960s.)



▲ Lead plumbing pipes such as this one were used in home and commercial construction up to the 1960s, and lead-based solder was used to join copper pipes until the Safe Drinking Water Act of 1986. Lead is soft and easy to work, but even tiny traces of lead in drinking water can lead to impaired cognition, as was seen in Flint, Michigan, starting in 2015.

CONCEPTUAL EXAMPLE 1.4 Elements and Compounds

Which of the following represent elements and which represent compounds?

C Cu HI BN In HBr

Solution

The periodic table shows that C, Cu, and In represent elements. (Each is a single symbol.) HI, BN, and HBr are each composed of symbols of two elements, and represent compounds.

› Exercise 1.4A

Which of the following represent elements, and which represent compounds?

Hf No CuO NO HF Fm

› Exercise 1.4B

How many *different* elements are represented in the list in Exercise 1.4A?

Atoms and Molecules

An **atom** is the smallest characteristic part of an element. Each element is composed of atoms of a particular kind. For example, the element copper is made up of copper atoms, and gold is made up of gold atoms. All copper atoms are alike in a fundamental way and are different from gold atoms.

The smallest characteristic part of most compounds is a molecule. A **molecule** is a group of atoms bound together as a unit. All the molecules of a given compound have the same atoms in the same proportions. For example, all water molecules have two hydrogen atoms and one oxygen atom, as indicated by the formula, H_2O. We will discuss atoms in some detail in Chapter 2, and much of the focus of many later chapters is on molecules.

SELF-ASSESSMENT Questions

1. Which state of matter has a definite volume but not a definite shape?
   a. gas **b.** compound **c.** liquid **d.** solid
2. Which of the following is a mixture?
   a. carbon **b.** copper **c.** silver **d.** soda water
3. Which of the following is *not* an element?
   a. aluminum **b.** brass **c.** lead **d.** sulfur
4. A compound can be separated into its elements
   a. by chemical means **b.** by mechanical means
   c. by physical means **d.** using a magnet
5. The smallest part of an element is a(n)
   a. atom **b.** corpuscle **c.** mass **d.** molecule
6. The symbol for sodium is
   a. S **b.** Na **c.** Sd **d.** So
7. Ar is the symbol for
   a. air **b.** argon **c.** aluminum **d.** arsenic

Answers: 1, c; 2, d; 3, b; 4, a; 5, a; 6, b; 7, b

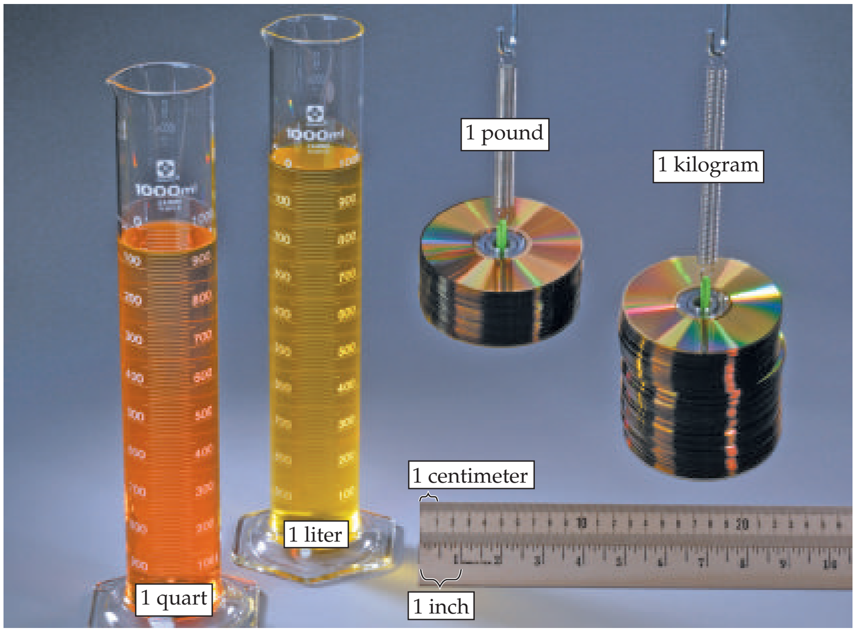
1.7 The Measurement of Matter

Learning Objective • Assign proper units of measurement to observations, and manipulate units in conversions.

Accurate measurements of such properties as mass, volume, time, and temperature are essential to the compilation of dependable scientific data. Such data are of critical importance in all science-related fields. Measurements of temperature and blood pressure are routinely made in medicine, and modern medical diagnosis depends on a whole battery of other measurements, including careful chemical analyses of blood and urine.

Some form of standardization of units is critical. For example, if we did not agree on the meaning of "one pound," trade would be impossible. The measurement system agreed upon by scientists since 1960 is the *International System of Units*, or **SI units** (from the French *Système International*), a modernized version of the metric system established in France in 1791. Most countries use metric measures in everyday life. In the United States, these units are used mainly in science laboratories, although they are increasingly being used in commerce, especially in businesses with an international component. One-liter and two-liter bottled beverages are found everywhere, and sporting events often use metric measurements, such as the 100-meter dash. Figure 1.8 compares some metric and customary units.

Because SI units are based on the decimal system, it is easy to convert from one unit to another. All measured quantities can be expressed in terms of the seven base units listed in Table 1.4. We use the first six in this text.



▶ **Figure 1.8** Comparisons of metric and customary units of measure. The meter stick is 100 centimeters long and is slightly longer than the yardstick below it (1 m = 1.09 yd.).

Q *From this figure, approximately how many pounds are in a kilogram? Which two units are closer in size, the inch and centimeter or the quart and the liter?*

TABLE 1.4 The Seven SI Base Units

Physical Quantity	Name of Unit	Symbol of Unit
Length	meter [a]	m
Mass	kilogram	kg
Time	second	s
Temperature	kelvin	K
Amount of substance	mole	mol
Electric current	ampere	A
Luminous intensity	candela	Cd

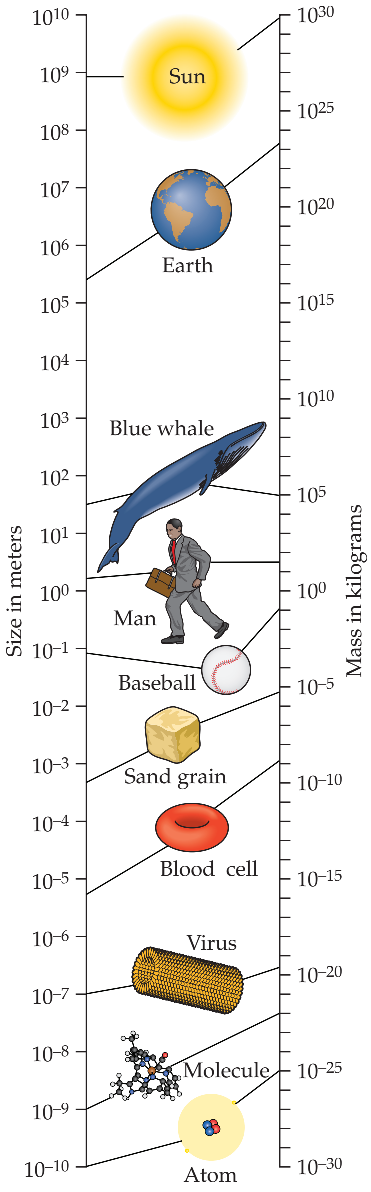
[a]Spelled *metre* in most countries.

Exponential Numbers: Powers of 10

Scientists deal with objects smaller than atoms and as large as the universe. We usually use exponential notation to describe the sizes of such objects. A number is in **exponential notation** when it is written as the product of a coefficient and a power of 10, such as 1.6×10^{-19} or 35×10^6. A number is said to be expressed in **scientific notation** when the coefficient has a value between 1 and 10 or −1 and −10.

An electron has a diameter of about 10^{-15} meter (m) and a mass of about 10^{-30} kilogram (kg). At the other extreme, a galaxy typically measures about 10^{23} m across and has a mass of about 10^{41} kg. It is difficult even to imagine numbers so small or so large. The accompanying figure offers some perspectives on size. Appendix A.2 provides a more detailed discussion of scientific notation.

Because measurements using the basic SI units can be of awkward magnitude, we often use exponential numbers. However, it is sometimes more convenient to use prefixes (Table 1.5) to indicate units larger or smaller than the base unit. The following examples show how prefixes and powers of 10 are interconverted.



▲ Comparison of very large and very small objects is much easier with exponential notation.

EXAMPLE 1.5 Prefixes and Powers of 10

Convert each of the following measurements to a unit that replaces the power of 10 by a prefix.

a. 2.89×10^{-6} g **b.** 4.30×10^3 m

Solution

Our goal is to replace each power of 10 with the appropriate prefix from Table 1.5. For example, $10^{-3} = 0.001$, which corresponds to milli (unit). (It doesn't matter what the unit is; here we are dealing only with the prefixes.)

a. 10^{-6} corresponds to the prefix *micro-*; that is, $10^{-6} \times$ (unit) = micro (unit). So we have 2.89 micrograms (μg).

b. 10^3 corresponds to the prefix *kilo-*; that is, $10^3 \times$ (unit) = kilo (unit). So we have 4.30 km.

› Exercise 1.5A

Convert each of the following measurements to a unit that replaces the power of 10 by a prefix.

a. 7.24×10^3 g **b.** 4.29×10^{-6} m **c.** 7.91×10^{-3} s

› Exercise 1.5B

Convert each of the following measurements to a measurement that uses the base unit and a power of 10.

a. 3.8 ns **b.** 7.54 mm **c.** 2.9 kA

TABLE 1.5 Approved Numerical Prefixes[a]

Exponential Expression	Decimal Equivalent	Prefix	Pronounced	Symbol
10^{12}	1,000,000,000,000	*tera-*	TER-uh	T
10^{9}	1,000,000,000	*giga-*	GIG-uh	G
10^{6}	1,000,000	*mega-*	MEG-uh	M
10^{3}	1,000	*kilo-*	KIL-oh	k
10^{2}	100	*hecto-*	HEK-toe	h
10^{1}	10	*deka-*	DEK-uh	da
10^{-1}	0.1	*deci-*	DES-ee	d
10^{-2}	0.01	*centi-*	SEN-tee	c
10^{-3}	0.001	*milli-*	MIL-ee	m
10^{-6}	0.000001	*micro-*	MY-kro	μ
10^{-9}	0.000000001	*nano-*	NAN-oh	n
10^{-12}	0.000000000001	*pico-*	PEE-koh	p
10^{-15}	0.000000000000001	*femto-*	FEM-toe	F

[a]The most commonly used prefixes are shown in color.

EXAMPLE 1.6 Prefixes and Powers of 10

Express each of the following measurements in terms of an SI base unit in both decimal and exponential form.

a. 4.12 cm
b. 947 ms
c. 3.17 nm

Solution

a. Our goal is to find the power of 10 that relates the given unit to the SI base unit. That is, centi (base unit) $= 10^{-2} \times$ (base unit):

$$4.12\text{ cm} = 4.12\text{ centimeter} = 4.12 \times 10^{-2}\text{ m} = 0.0412\text{ m}$$

b. To change millisecond (ms) to the base unit second, we replace the prefix *milli-* with 10^{-3}; as a shortcut, you can move the decimal place to the left for each negative power or to the right for each positive power:

$$947\text{ ms} = 0.947\text{ s}$$

c. To change nanometer (nm) to the base unit meter, we replace the prefix *nano-* with 10^{-9}. The answer in exponential form is 3.17×10^{-9} m, and in decimal notation, it is 0.00000000317.

› Exercise 1.6A

Convert the following measurements to an SI base unit.

a. 7.45 nm **b.** 5.25 μs **c.** 1.415 km
d. 2.06 mm **e.** 6.19×10^{6} mm

› Exercise 1.6B

Convert the following measurements to an SI base unit.

a. 57 km
b. 11 mA

Mass

The SI base unit for mass is the **kilogram (kg)**, about 2.2 pounds (lb.), or about the mass of a 1 L soft drink. This base unit is unusual in that it already has a prefix. A more convenient mass unit for most laboratory work is the gram (g), about the mass of a large paperclip.

$$1 \text{ kg} = 1000 \text{ g} = 10^3 \text{ g}$$

The milligram (mg) is a suitable unit for small quantities of materials, such as some drug dosages or spices added while cooking food. Other drugs or vitamins that we take require a very small amount, such as a microgram (μg), which is commonly abbreviated as mcg on the label.

$$1 \text{ mg} = 10^{-3} \text{ g} = 0.001 \text{ g} \qquad 1\ \mu\text{g} = 10^{-6} \text{ g} = 0.000001 \text{ g}$$

Chemists can now detect masses in the nanogram (ng), picogram (pg), and even femtogram (fg) ranges.

Length, Area, and Volume

The SI base unit of length is the **meter (m)**, a unit slightly longer than 1 yard (yd.). The kilometer (km) is used to measure distances along highways.

$$1 \text{ km} = 1000 \text{ m}$$

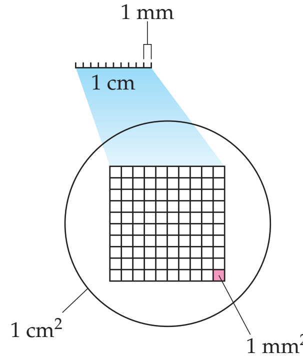
In the laboratory, we usually find lengths smaller than the meter to be more convenient. For example, we use the centimeter (cm), which is about the width of a typical calculator button, or the millimeter (mm), which is about the thickness of the cardboard backing in a notepad.

$$1 \text{ cm} = 0.01 \text{ m} \quad 1 \text{ mm} = 0.001 \text{ m}$$

For measurements at the atomic and molecular levels, we use the micrometer (μm), the nanometer (nm), and the picometer (pm). For example, a hemoglobin molecule, which is nearly spherical, has a diameter of 5.5 nm or 5500 pm, and the diameter of a sodium atom is 372 pm.

The units for area and volume are derived from the base unit of length. The SI unit of area is the square meter (m^2), but we often find square centimeters (cm^2) or square millimeters (mm^2) to be more convenient for laboratory work. Notice that although 1 cm $= 10^{-2}$ m, 1 cm^2 is *not* equal to 10^{-2} m^2.

$$1 \text{ cm}^2 = (10^{-2} \text{ m})^2 = 10^{-4} \text{ m}^2 \qquad 1 \text{ mm}^2 = (10^{-3} \text{ m})^2 = 10^{-6} \text{ m}^2$$



▲ Units of area such as mm^2 and cm^2 are derived from units of length.

Q *How many mm are in 1 cm? How many mm^2 are in 1 mm^2?*

Similarly, the SI unit of volume is the cubic meter (m^3), but two units more likely to be used in the laboratory are the cubic centimeter (cm^3 or cc) and the cubic decimeter (dm^3). A cubic centimeter is about the volume of a sugar cube, and a cubic decimeter is slightly larger than 1 quart (qt). As with area, 1 cm^3 is *not* equal to 10^{-2} m^3.

$$1 \text{ cm}^3 = (10^{-2} \text{ m})^3 = 10^{-6} \text{ m}^3 \qquad 1 \text{ dm}^3 = (10^{-1} \text{ m})^3 = 10^{-3} \text{ m}^3$$

The cubic decimeter is commonly called a liter. A **liter (L)** is 1 cubic decimeter, or 1000 cubic centimeters.

$$1 \text{ L} = 1 \text{ dm}^3 = 1000 \text{ cm}^3$$

The milliliter (mL), or cubic centimeter, is frequently used in laboratories. A milliliter is about one "squirt" from a medicine dropper.

$$1 \text{ mL} = 1 \text{ cm}^3$$

Time

The SI base unit for measuring intervals of time is the **second (s)**. Extremely short time periods are expressed using SI prefixes: millisecond (ms), microsecond (μs), nanosecond (ns), and picosecond (ps).

$$1\ \text{ms} = 10^{-3}\ \text{s} \qquad 1\ \mu\text{s} = 10^{-6}\ \text{s} \qquad 1\ \text{ns} = 10^{-9}\ \text{s} \qquad 1\ \text{ps} = 10^{-12}\ \text{s}$$

Long time intervals, in contrast, are usually expressed in traditional, non-SI units: minute (min), hour (h), day (d), and year (y).

$$1\ \text{min} = 60\ \text{s} \qquad 1\ \text{h} = 60\ \text{min} \qquad 1\ \text{d} = 24\ \text{h} \qquad 1\ \text{y} = 365\ \text{d}$$

Problem Solving: Estimation

Many chemistry problems require calculations that yield numerical answers. When you use a calculator, it will always give you an answer—but the answer may not be correct. You may have punched a wrong number or used the wrong function. You can learn to estimate answers so you can tell whether your calculated answers are reasonable. At times an estimated answer is good enough, as the following example and exercises illustrate. This ability to estimate answers can be important in everyday life as well as in a chemistry course. Note that estimation does *not* require a detailed calculation. Only a rough calculation—or none at all—is required.

EXAMPLE 1.7 Mass, Length, Area, Volume

Without doing detailed calculations, determine which of the following are a reasonable **(a)** mass (weight) and **(b)** height for a typical two-year-old child.

Mass:	10 mg	10 g	10 kg	100 g
Height:	85 mm	85 cm	850 cm	8.5 m

Solution

a. In customary units, a two-year-old child should weigh about 20–25 lb. Since 1 kg is a little more than 2 lb., the only reasonable answer is 10 kg.

b. In customary units, a two-year-old child should be about 30–36 in. tall. Since 1 cm is a little less than 0.5 in., the answer must be a little more than twice that range, or a bit more than 60–72 cm. Thus the only reasonable answer is 85 cm.

› Exercise 1.7A

Without doing a detailed calculation, determine which of the following is a reasonable area for the front cover of your textbook.

$500\ \text{mm}^2 \quad 50\ \text{cm}^2 \quad 500\ \text{cm}^2 \quad 50\ \text{m}^2$

› Exercise 1.7B

Without doing a detailed calculation, determine which of the following is a reasonable volume for your textbook.

$1600\ \text{mm}^3 \quad 16\ \text{cm}^3 \quad 1600\ \text{cm}^3 \quad 1.6\ \text{m}^3$

Problem Solving: Unit Conversions

It is easy to convert from one metric unit to another using the *unit conversion* method of problem solving. If you are not familiar with this method, you should study it now in Appendix A.3, which also discusses the conversion of common units to metric units.

You can find a discussion of **significant figures**, a way of indicating the precision of measurements, in Appendix A.4. In the following problems and throughout the text, we will simply carry three digits in most calculations.

EXAMPLE 1.8 Unit Conversions

Convert

(a) 1.83 kg to grams and

(b) 729 microliters to milliliters.

Solution

a. We start with the given quantity, 1.83 kg. The prefix *kilo-* means 1000, which gives us the equivalence 1 kg = 1000 g. From this we can form a conversion factor (see Appendix A.3) that allows us to cancel the unit kg and end with the unit g.

$$1.83\ \cancel{\text{kg}} \times \frac{1000\ \text{g}}{1\ \cancel{\text{kg}}} = 1830\ \text{g}$$

b. Here we start with the given quantity, 729 μL, which we want to be in mL. We do not have a single factor to change from μL to mL, so one way to approach the problem is to use two conversion factors. According to Table 1.5, *micro-* is 10^{-6} and *milli-* is 10^{-3}. That is, 1 μL = 10^{-6} L and 1 mL = 10^{-3} L. Set up the first conversion factor with μL (starting unit) on the bottom and L on top. The second factor will have L on the bottom and mL (desired unit) on top. Both μL and L cancel, leaving us with an answer in the correct unit.

$$729\ \cancel{\mu\text{L}} \times \frac{10^{-6}\ \cancel{\text{L}}}{1\ \cancel{\mu\text{L}}} \times \frac{1\ \text{mL}}{10^{-3}\ \cancel{\text{L}}} = 0.729\ \text{mL}$$

› Exercise 1.8A

Convert

a. 0.755 m to millimeters

b. 205.6 mL to liters

c. 0.206 g to micrograms

d. 7.38 microamperes to amperes

› Exercise 1.8B

Convert

a. 0.409 kg to mg

b. 245 ms to nanoseconds

SELF-ASSESSMENT Questions

1. The SI unit of length is the
a. foot **b.** kilometer
c. pascal **d.** meter

2. The SI unit of mass is the
a. dram **b.** gram
c. grain **d.** kilogram

3. The prefix that means 10^{-2} is
a. centi- **b.** deci-
c. micro- **d.** milli-

4. An inch is about 250% longer than a
a. meter **b.** centimeter
c. millimeter **d.** decimeter

5. One cubic centimeter is equal to one
a. deciliter **b.** dram
c. liter **d.** milliliter

6. One quart is slightly less than one
a. deciliter **b.** kiloliter
c. liter **d.** milliliter

7. A rope is 5.775 cm long. What is its length in millimeters?
a. 0.05775 mm **b.** 0.5775 mm
c. 5.775 mm **d.** 57.75 mm

8. Which of the following has a mass of roughly 1 g?
a. an ant **b.** an orange
c. a peanut **d.** a watermelon

9. Your doctor recommends that you take 1000 μg of vitamin B_{12}. That is the same as
a. 1 centigram **b.** 1 decigram
c. 1 gram **d.** 1 milligram

10. Which of the following has a thickness of roughly 1 cm?
a. a brick **b.** a cell phone
c. a knife blade **d.** this textbook

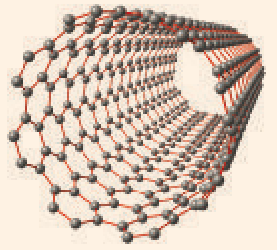
11. Which of the following has a volume of roughly 250 mL (0.250 L)?
a. 1 cup **b.** 1 gallon
c. 1 pint **d.** 1 tablespoon

Answers: 1, d; 2, d; 3, a; 4, b; 5, d; 6, c; 7, d; 8, c; 9, d; 10, b; 11, a

Nanoworld

For over two centuries, chemists have been able to rearrange atoms to make molecules, which have dimensions in the *picometer* (10^{-12} m) range. This ability has led to revolutions in the design of drugs, plastics, and many other materials. Over the last several decades, scientists have made vast strides in handling materials with dimensions in the *micrometer* (10^{-6} m) range. The revolution in electronic devices—computers, cell phones, and so on—was spurred by the ability of scientists to produce computer chips by photolithography on a micrometer scale.

Now many scientists focus on *nanotechnology*. The prefix *nano-* means one-billionth (10^{-9}). Nanotechnology bridges the gap between picometer-sized molecules and micrometer-sized electronics. A nanometer-sized object contains just a few hundred to a few thousand atoms or molecules, and such objects often have different properties than large objects of the same substance. For example, bulk gold is yellow, but a ring made up of nanometer-sized gold particles appears red. Carbon in the form of graphite (pencil lead) is quite weak and soft, but carbon nanotubes can be 100 times stronger than steel. Nanotubes, so called because of their size (only one 10,000th the thickness of a human hair) and their shape (hollow tube), have thousands of potential uses but are extremely expensive to make. Scientists can now manipulate matter on every scale, from nanometers to meters, greatly increasing the scope of materials design. We will examine some of the many practical applications of nanotechnology in subsequent chapters.



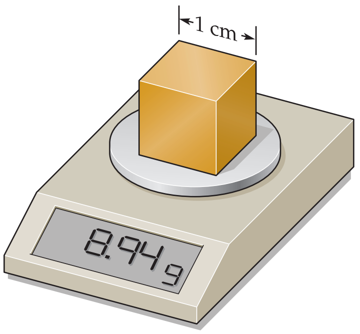
▲ Molecular view of a carbon nanotube—stronger than steel and more expensive than gold.

1.8 Density

Learning Objective • Calculate the density, mass, or volume of an object given the other two quantities.

In everyday life, we might speak of lead as "heavy" or aluminum as "light," but such descriptions are imprecise at best. What we really mean is that lead is heavy (or aluminum is light) for its "size" or for the space it takes up. Scientists use the term *density* to describe this important property. The **density**, *d*, of a substance is the quantity of mass, *m*, per unit of volume, *V*.

$$d = \frac{m}{V}$$



▲ One cubic centimeter of copper weighs 8.94 g, so the density of copper is 8.94 g/cm^3.

Q *What is the mass of 2 cm^3 of copper? What is the density of 2 cm^3 of copper?*

For substances that don't mix, such as oil and water, the concept of density allows us to predict which will float on the other. It isn't the mass of each material but the *mass per unit volume*—the density—that determines the result. Density is the property that explains why oil (lower density) floats on water (higher density) in a bottle of Italian salad dressing. Figure 1.9 shows other examples.

We can rearrange the equation for density to give

$$m = d \times V \quad \text{and} \quad V = \frac{m}{d}$$

These equations are useful for calculations. Densities of some common substances are listed in Table 1.6. They are customarily reported in grams per milliliter (g/mL) for liquids and grams per cubic centimeter (g/cm^3) for solids. Values listed in the table are used in some of the following examples and exercises and in some of the end-of-chapter problems.

TABLE 1.6 Densities of Some Common Substances at Specified Temperatures

Substance*	Density	Temperature
Solids		
Copper (Cu)	8.94 g/cm^3	25 °C
Gold (Au)	19.3 g/cm^3	25 °C
Magnesium (Mg)	1.738 g/cm^3	20 °C
Water (ice) (H_2O)	0.917 g/cm^3	0 °C
Liquids		
Ethanol (CH_3CH_2OH)	0.789 g/mL	20 °C
Hexane ($CH_3CH_2CH_2CH_2CH_2CH_3$)	0.660 g/mL	20 °C
Mercury (Hg)	13.534 g/mL	25 °C
Urine (a mixture)	1.003–1.030 g/mL	25 °C
Water (H_2O)	0.9998 g/mL	0 °C
Water	1.000 g/mL	4 °C
Water	0.998 g/mL	20 °C

*Formulas are provided for possible future reference.

▲ **Figure 1.9** At room temperature, the density of water is approximately 1.00 g/mL. A coin sinks in water, but a cork floats on water.

Q *Is the density of these coins less than, equal to, or greater than 1.00 g/mL? Is the density of the corks less than, equal to, or greater than 1.00 g/mL?*

As with problems involving mass, length, area, and volume (Example 1.7 on page 23), it is often sufficient to estimate answers to problems involving densities—for example, in determining relative volumes of materials or whether a material will float or sink in water. Such estimation is illustrated in the following example and exercises. Note again that estimation does *not* require a detailed calculation.

EXAMPLE 1.9 Mass, Volume, and Density

Density can provide a wealth of information without even doing a detailed calculation. This example and the accompanying exercises can be worked without using a calculator.

During the gold rush, prospectors would often find *fool's gold* (iron pyrite), which looks almost exactly like gold. However, iron pyrite has a density of approximately 3.3 g/cm^3. Using Table 1.6, find the density of gold. If a miner found a nugget of fool's gold that fit in the palm of his hand, **(a)** would there be a significant difference in mass compared with a similar-sized nugget of pure gold? **(b)** If the fool's gold weighed the same as the gold nugget, would you see a difference in size?

Solution

a. From Table 1.6, we can see that the density of gold is 19.3 g/ml. That means gold is nearly 6 times heavier than a similarly sized piece of iron pyrite. This allowed prospectors to easily identify which ore they had found.

b. As seen above, the density of gold is roughly 6 times that of iron pyrite. Because gold is denser, it can pack in tighter and take up less space. Comparing two ore samples of equal mass, we find that the gold would be one-sixth as large as the pyrite.

› Exercise 1.9A

Lead has a density of 11.34 g/cm^3. Will lead float or sink in hexane? In mercury?

› Exercise 1.9B

Based on what you know about crude oil, which is most likely to be its density: 0.88 g/mL, 1.25 g/mL, or 1.83 g/mL? (Hint: See Table 1.6 for useful information.)

EXAMPLE 1.10 Density, Mass, or Volume

Mass and volume give density. What is the density of iron if 156 g of iron occupies a volume of 20.0 cm^3?

Solution

The given quantities are

$$m = 156 \text{ g} \quad \text{and} \quad V = 20.0 \text{ cm}^3$$

We use the equation that defines density.

mass (m)

$$d = \frac{m}{V} = \frac{156 \text{ g}}{20.0 \text{ cm}^3} = 7.80 \text{ g/cm}^3$$

volume (V)

density (d)

Likewise, density and mass give you volume; volume and density give you mass, according to the following rearrangements of our original density equation.

$$V = \frac{m}{d} \quad \text{or} \quad m = dV$$

› Exercise 1.10A

Find the density of a salt solution if 210 mL of solution has a mass of 234 g.

› Exercise 1.10B

What metal do you most likely have if a 10 cm^3 piece weighs 17.38 g? (See Table 1.6.)

You can do your own demonstration of a density difference. Make a classic French vinaigrette salad dressing by adding 10 mL of red wine vinegar to 30–40 mL of extra virgin olive oil. Add seasonings such as salt, pepper, oregano, thyme, Dijon mustard, and garlic. Which material—oil or vinegar—forms the top layer? Enjoy!

SELF-ASSESSMENT Questions

1. The density of a wood plank floating on a lake is
a. less than that of air
b. less than that of water
c. more than that of water
d. the same as that of water

2. A pebble and a lead sinker both sink when dropped into a pond. This shows that the two objects
a. are both less dense than water
b. are both denser than water
c. have different densities
d. have the same density

3. Ice floats on liquid water. A reasonable value for the density of ice is
a. 0.92 g/cm^3
b. 1.08 g/cm^3
c. 1.98 g/cm^3
d. 4.90 g/cm^3

4. A prospector panning for gold swirls a mixture of mud, gravel, and water in a pan. He looks for gold at the bottom because gold
a. dissolves in water and sinks
b. has a high density and sinks
c. is less dense than rocks
d. is repelled by the other minerals

5. Which of the following metals will sink in a pool of mercury (d = 13.534 g/cm^3)?
a. aluminum (d = 2.6 g/cm^3)
b. iron (d = 7.9 g/cm^3)
c. lead (d = 11.34 g/cm^3)
d. uranium (d = 19.5 g/cm^3)

6. If the volume of a rock is 80.0 cm^3 and its mass is 160.0 g, its density is
a. 0.05 g/cm^3 **b.** 0.50 g/cm^3
c. 2.0 g/cm^3 **d.** 20 g/cm^3

Answers: 1, b; 2, b; 3, a; 4, b; 5, d; 6, c