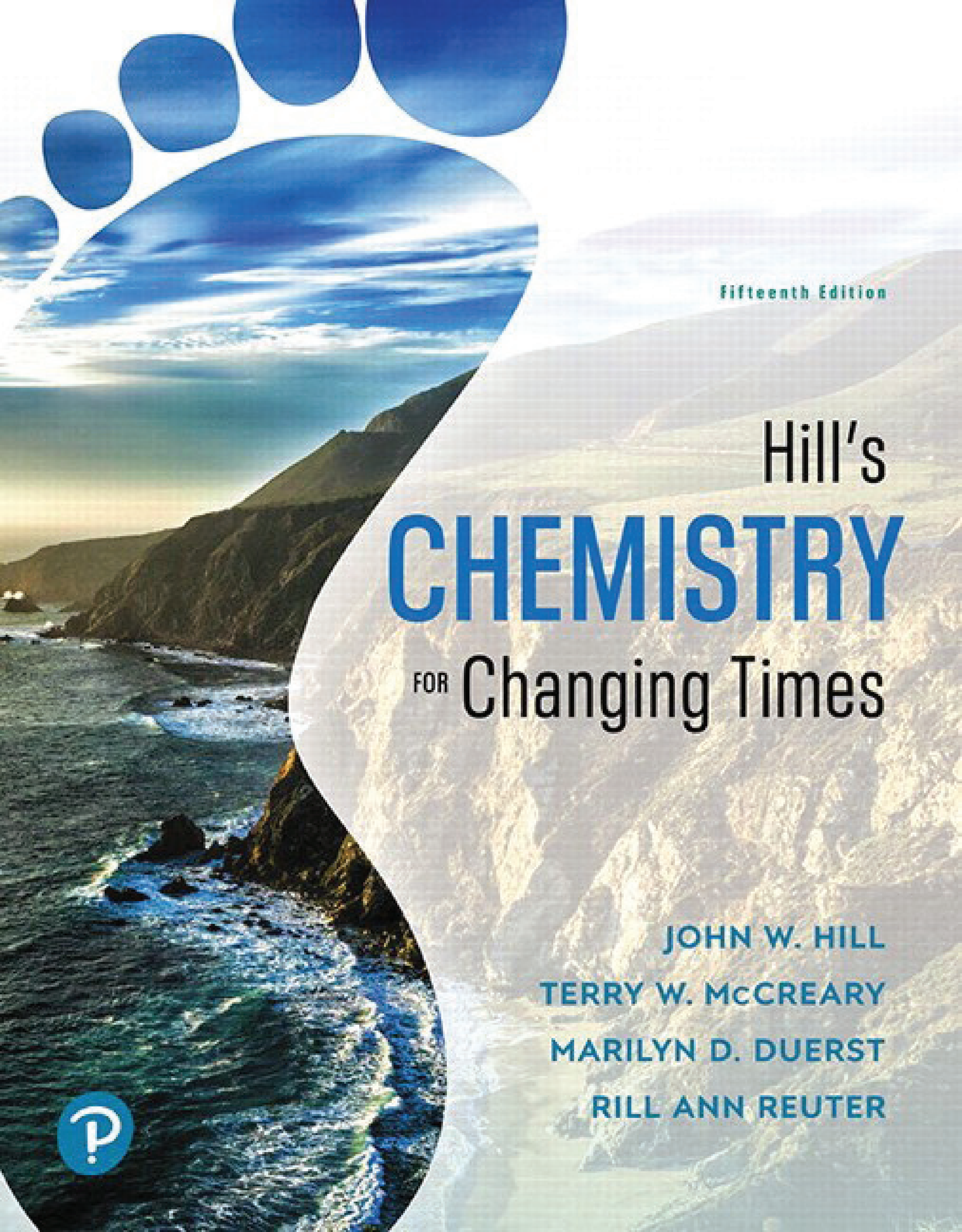

Fifteenth Edition

Hill's CHEMISTRY FOR Changing Times

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

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CHEMISTRY
for Changing Times

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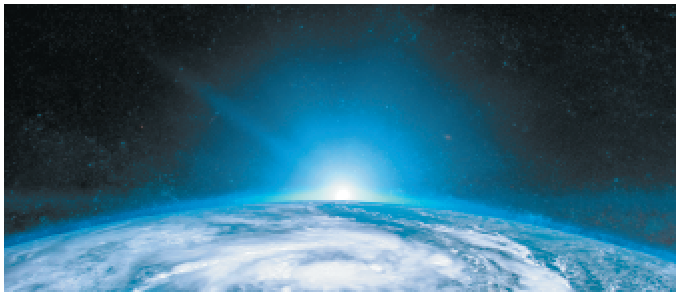
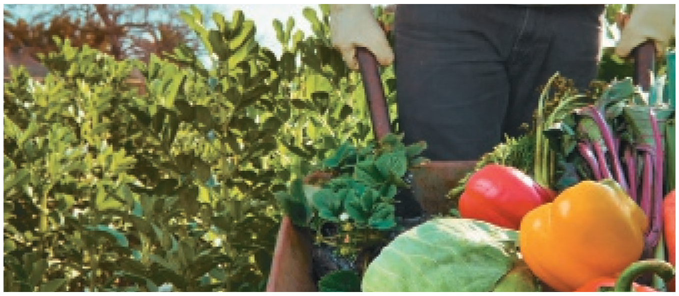
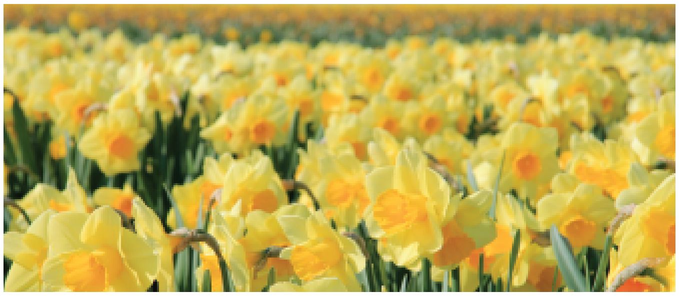
Brief Contents

Contents







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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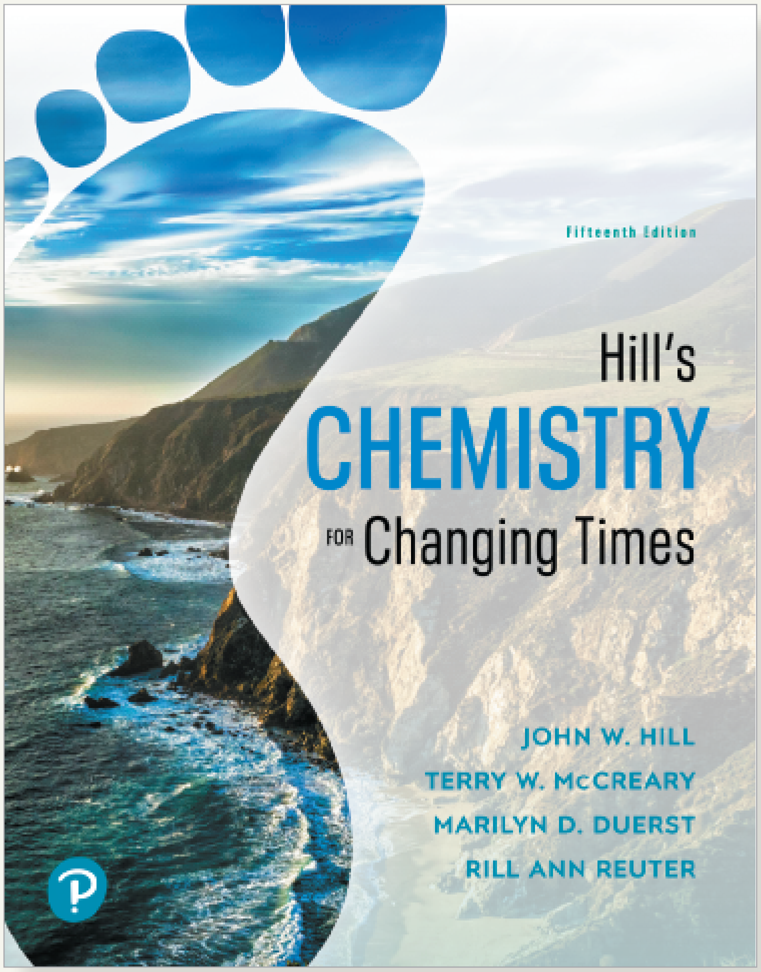
Engage students with contemporary and relevant applications of chemistry

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.**



Pearson

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 $\frac{1}{2}$ 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

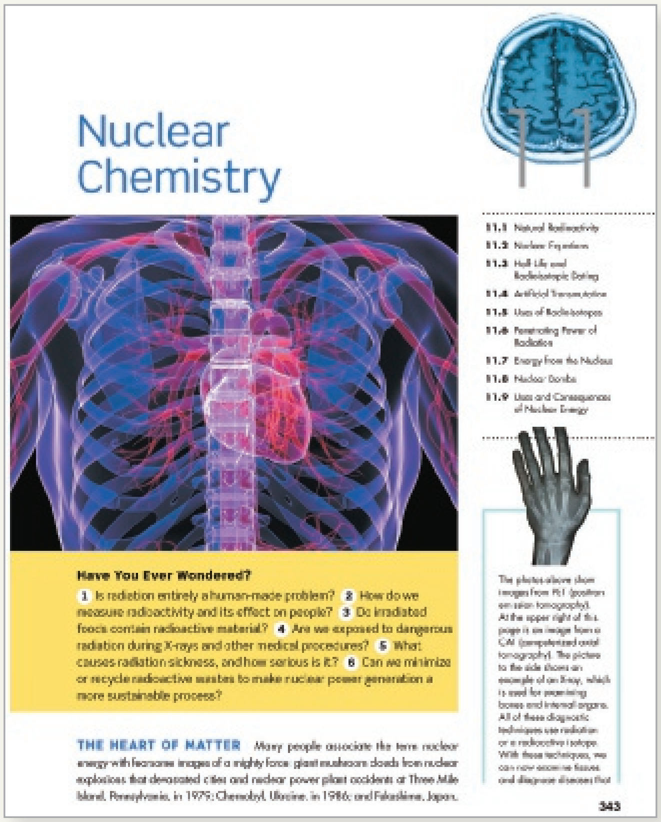
The incandescent light bulb is very inefficient with respect to the energy it uses; as much as 95% of the electric energy it uses is changed to heat, not light. Though compact fluorescent bulbs, containing mercury, were popular for about a decade, now LED bulbs are taking over the light bulb market. 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.



Nuclear Chemistry

11.1 Natural Radioactivity
11.2 Nuclear Equations
11.3 Half-Life and Radioisotopic Dating
11.4 Artificial Transmutation
11.5 Uses of Radioisotopes
11.6 Penetrating Power of Radiation
11.7 Energy from the Nucleus
11.8 Nuclear Bombs
11.9 Uses and Consequences of Nuclear Energy

Have You Ever Wondered?

1 Is radiation entirely a human-made problem? 2 How do we measure radioactivity and its effect on people? 3 Do irradiated foods contain radioactive material? 4 Are we exposed to dangerous radiation during X-rays and other medical procedures? 5 What causes radiation sickness, and how serious is it? 6 Can we minimize or recycle radioactive wastes to make nuclear power generation a more sustainable process?

THE HEART OF MATTER Many people associate the term nuclear energy with fearsome images of a mighty force: giant mushroom clouds from nuclear explosions that devastated cities and nuclear power plant accidents at Three Mile Island, Pennsylvania, in 1979; Chernobyl, Ukraine, in 1986; and Fukushima, Japan,

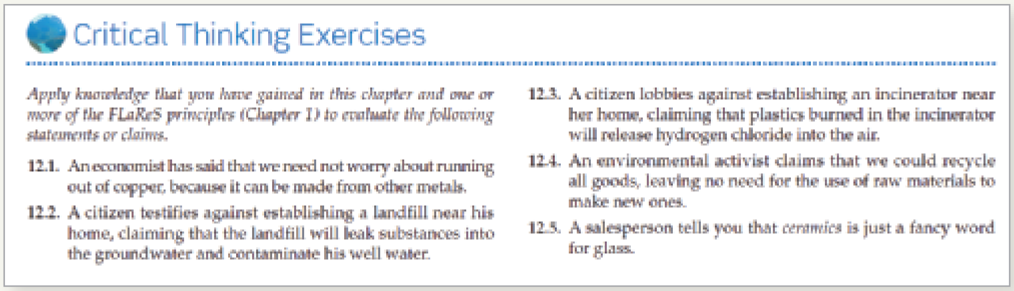
The photos above show images from PET (positron emission tomography). At the upper right of this page is an image from a CAT (computerized axial tomography). The picture to the side shows an example of an X-ray, which is used for examining bones and internal organs. All of these diagnostic techniques use radiation or a radioactive isotope. With these techniques, we can now examine tissues and diagnose diseases that

343

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.

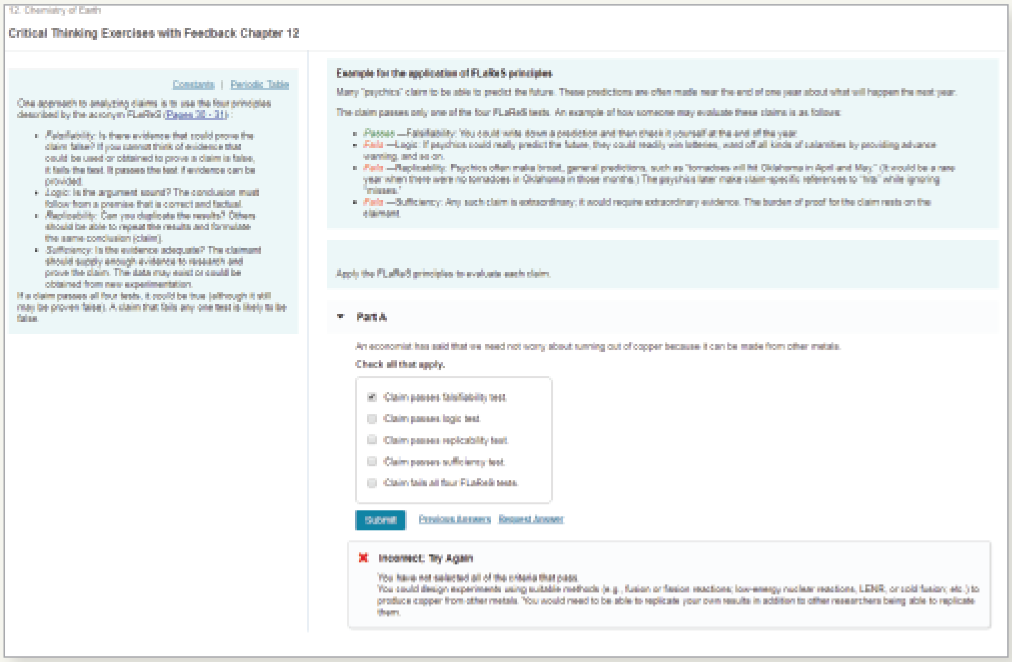
12.4. An environmental activist claims that we could recycle all goods, leaving no need for the use of raw materials to make new ones.

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

pg. 396

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?

pg. 175

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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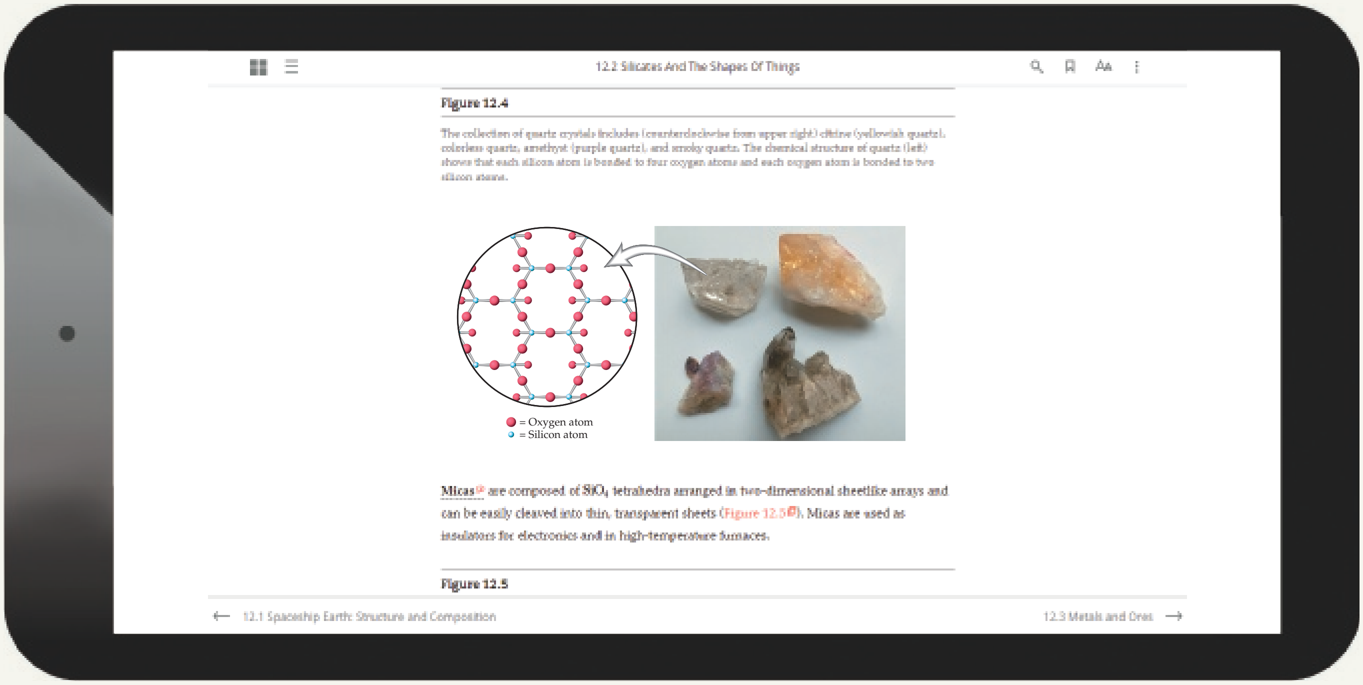
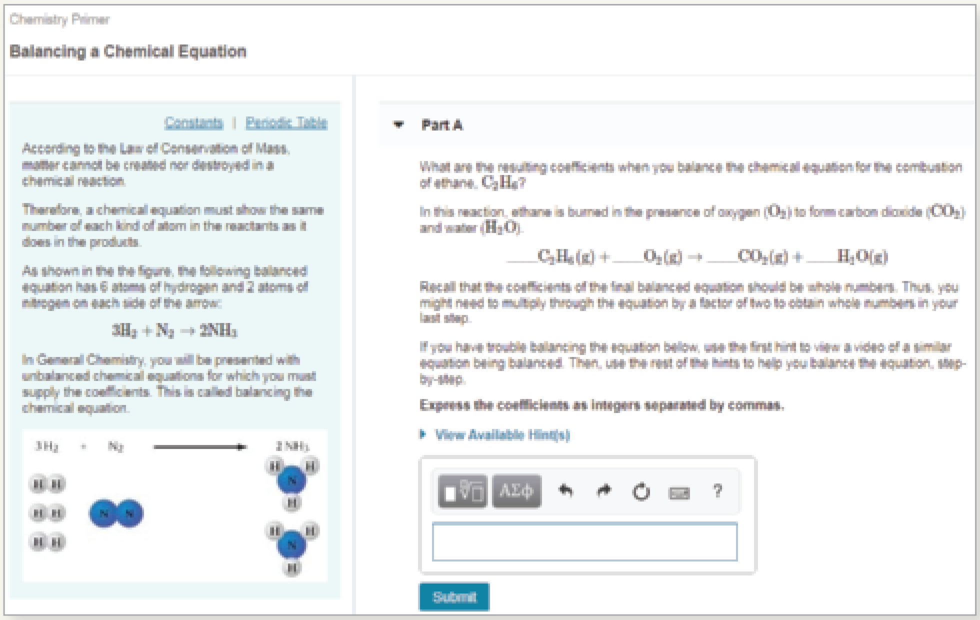
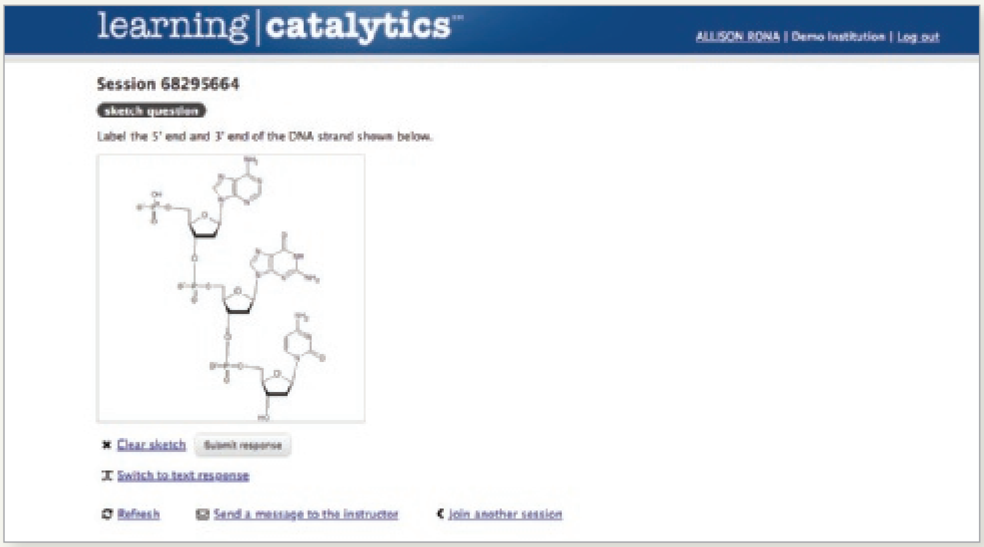


Reach every student with Mastering Chemistry



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.**

Download instructor resources from the links below.

PowerPoint Presentation Tools

Chapter 7 Image PowerPoint	pptx, 25.9 MB
Chapter 7 Lecture Outline PowerPoint	zip, 16.4 MB
Chapter 7 Reading Quiz Clicker PowerPoint	pptx, 3.4 MB
Chapter 7 Review Clicker PowerPoint	pptx, 3.3 MB

JPEG Images

Appendices Labeled JPEG Images Labeled images from appendices in the text.	zip, 11.5 MB
Chapter 7 Labeled JPEG Images Labeled images from the text.	zip, 24.7 MB
Chapter 7 Unlabeled JPEG Images Unlabeled images from the text.	zip, 6.2 MB

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.

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

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.

▲ 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.

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

▲ 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.

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.

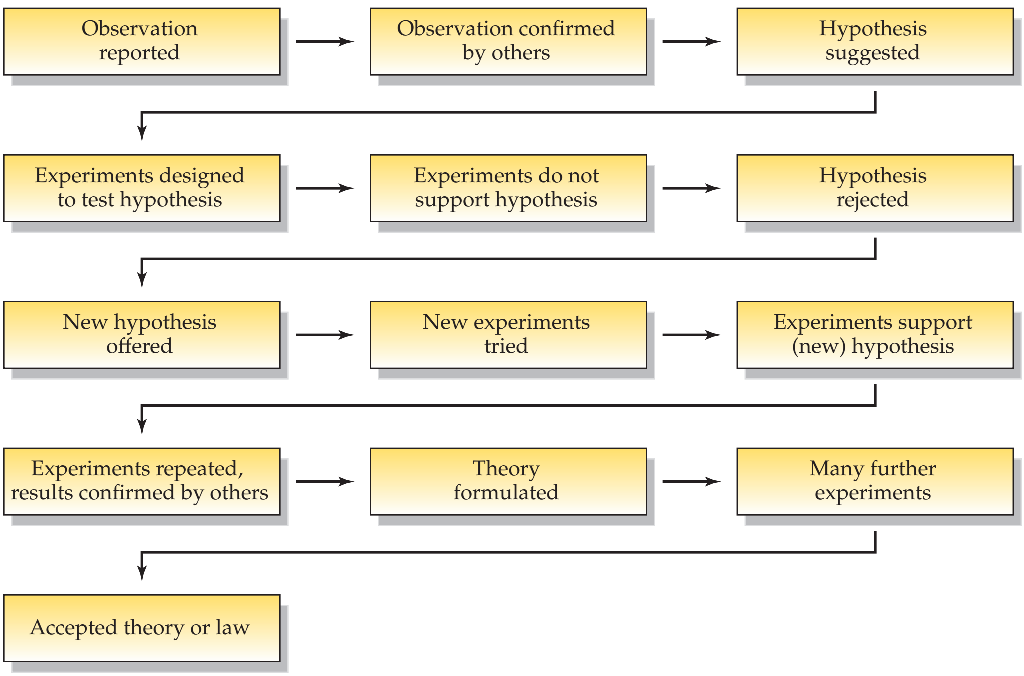
We have defined science, but science has certain characteristics that distinguish it from other studies.

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"?

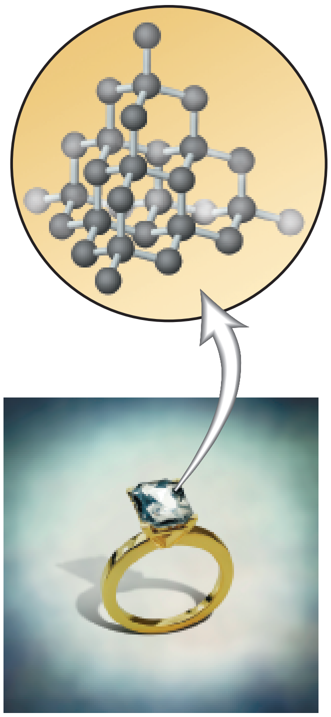
More data help scientists refine a hypothesis so that it is better defined, clearer, or more applicable.

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.

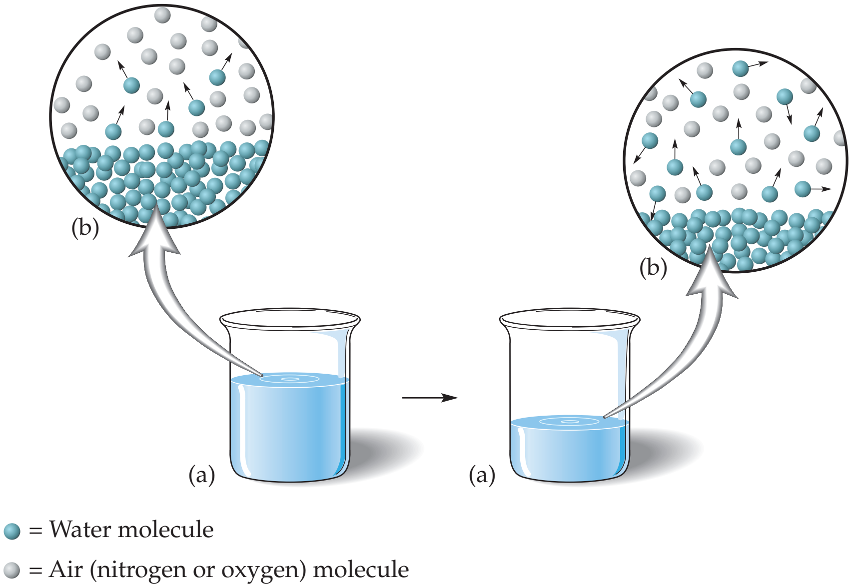


▲ A molecular model of diamond shows the tightly linked, rigid structure that explains why diamonds are so hard.

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.

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).

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

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.