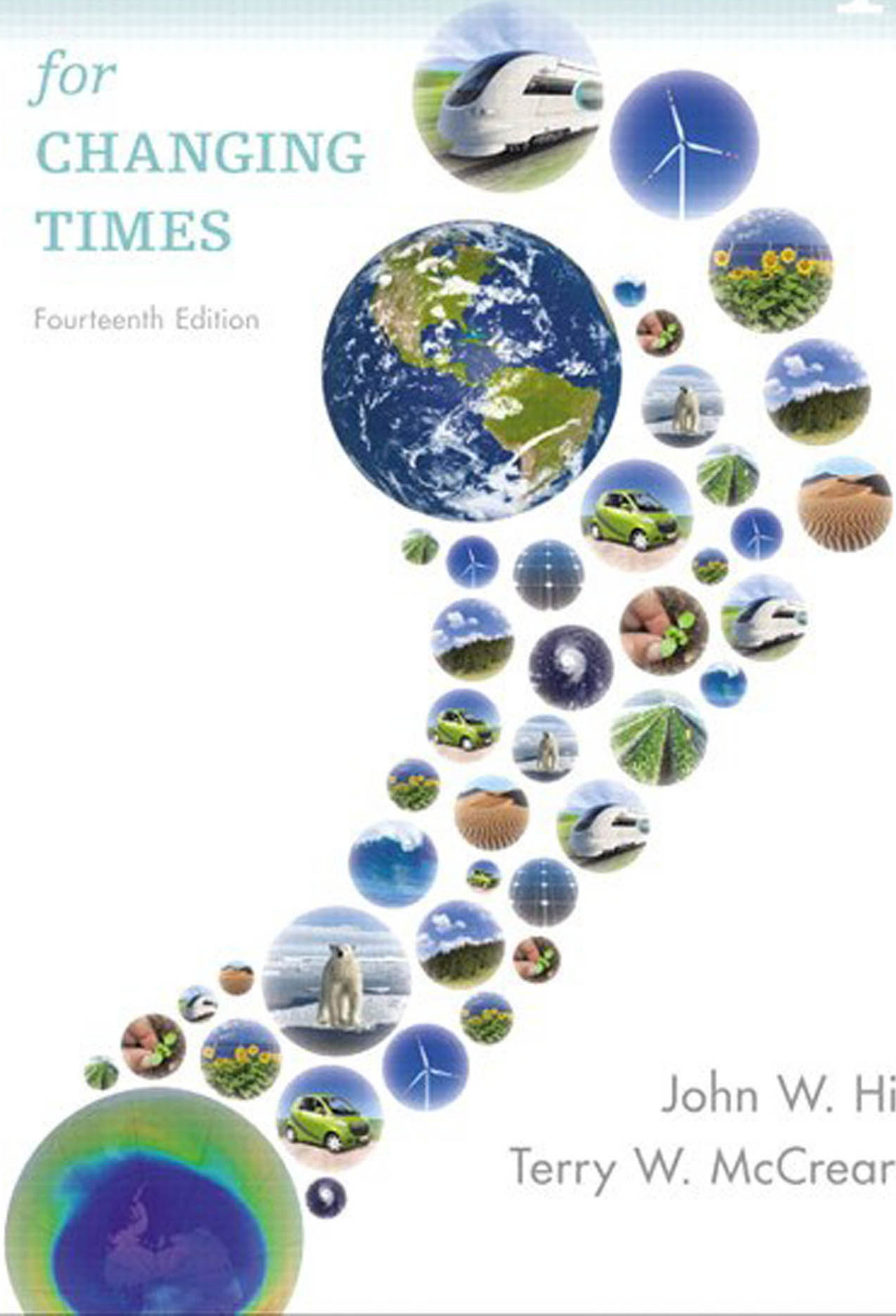
Chemistry for CHANGING TIMES

Fourteenth Edition



John W. Hill

Terry W. McCreary

PERIODIC TABLE OF THE ELEMENTS

Main groups — Transition metals — Main groups

⬜ Metals 🟦 Nonmetals 🟪 Noble gases

	1[a] 1A[b]	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B	10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
1	1 **H** Hydrogen 1.00794																	2 **He** Helium 4.002602
2	3 **Li** Lithium 6.941	4 **Be** Beryllium 9.012182											5 **B** Boron 10.811	6 **C** Carbon 12.0107	7 **N** Nitrogen 14.00674	8 **O** Oxygen 15.9994	9 **F** Fluorine 18.998403	10 **Ne** Neon 20.1797
3	11 **Na** Sodium 22.989770	12 **Mg** Magnesium 24.3050											13 **Al** Aluminum 26.981538	14 **Si** Silicon 28.0855	15 **P** Phosphorus 30.973762	16 **S** Sulfur 32.066	17 **Cl** Chlorine 35.4527	18 **Ar** Argon 39.948
4	19 **K** Potassium 39.0983	20 **Ca** Calcium 40.078	21 **Sc** Scandium 44.95591	22 **Ti** Titanium 47.867	23 **V** Vanadium 50.9415	24 **Cr** Chromium 51.9961	25 **Mn** Manganese 54.938049	26 **Fe** Iron 55.845	27 **Co** Cobalt 58.933200	28 **Ni** Nickel 58.6934	29 **Cu** Copper 63.546	30 **Zn** Zinc 65.39	31 **Ga** Gallium 69.723	32 **Ge** Germanium 72.61	33 **As** Arsenic 74.92160	34 **Se** Selenium 78.96	35 **Br** Bromine 79.904	36 **Kr** Krypton 83.80
5	37 **Rb** Rubidium 85.4678	38 **Sr** Strontium 87.62	39 **Y** Yttrium 88.90585	40 **Zr** Zirconium 91.224	41 **Nb** Niobium 92.90638	42 **Mo** Molybdenum 95.94	43 **Tc** Technetium [98]	44 **Ru** Ruthenium 101.07	45 **Rh** Rhodium 102.90550	46 **Pd** Palladium 106.42	47 **Ag** Silver 107.8682	48 **Cd** Cadmium 112.411	49 **In** Indium 114.818	50 **Sn** Tin 118.710	51 **Sb** Antimony 121.760	52 **Te** Tellurium 127.60	53 **I** Iodine 126.90447	54 **Xe** Xenon 131.29
6	55 **Cs** Cesium 132.90545	56 **Ba** Barium 137.327	57 ***La** Lanthanum 138.9055	72 **Hf** Hafnium 178.49	73 **Ta** Tantalum 180.9479	74 **W** Tungsten 183.84	75 **Re** Rhenium 186.207	76 **Os** Osmium 190.23	77 **Ir** Iridium 192.217	78 **Pt** Platinum 195.078	79 **Au** Gold 196.96655	80 **Hg** Mercury 200.59	81 **Tl** Thallium 204.3833	82 **Pb** Lead 207.2	83 **Bi** Bismuth 208.98038	84 **Po** Polonium [209]	85 **At** Astatine [210]	86 **Rn** Radon [222]
7	87 **Fr** Francium [223]	88 **Ra** Radium 226.025	89 **†Ac** Actinium 227.028	104 **Rf** Rutherfordium [261]	105 **Db** Dubnium [262]	106 **Sg** Seaborgium [266]	107 **Bh** Bohrium [267]	108 **Hs** Hassium [269]	109 **Mt** Meitnerium [268]	110 **Ds** Darmstadtium [281]	111 **Rg** Roentgenium [272]	112 **Cn** Copernicium [285]	113[c] [286]	114 **Fl** [289]	115 [288]	116 **Lv** [293]	117 [294]	118 [294]

*Lanthanide series	58 **Ce** Cerium 140.116	59 **Pr** Praseodymium 140.90765	60 **Nd** Neodymium 144.24	61 **Pm** Promethium [145]	62 **Sm** Samarium 150.36	63 **Eu** Europium 151.964	64 **Gd** Gadolinium 157.25	65 **Tb** Terbium 158.92534	66 **Dy** Dysprosium 162.50	67 **Ho** Holmium 164.93032	68 **Er** Erbium 167.26	69 **Tm** Thulium 168.93421	70 **Yb** Ytterbium 173.04	71 **Lu** Lutetium 174.967
†Actinide series	90 **Th** Thorium 232.0381	91 **Pa** Protactinium 231.03588	92 **U** Uranium 238.0289	93 **Np** Neptunium 237.048	94 **Pu** Plutonium [244]	95 **Am** Americium [243]	96 **Cm** Curium [247]	97 **Bk** Berkelium [247]	98 **Cf** Californium [251]	99 **Es** Einsteinium [252]	100 **Fm** Fermium [257]	101 **Md** Mendelevium [258]	102 **No** Nobelium [259]	103 **Lr** Lawrencium [262]

Atomic masses in brackets are the masses of the longest-lived or most important isotope of certain radioactive elements.

[a] The labels on top (1, 2, 3 ... 18) are the group numbers recommended by the International Union of Pure and Applied Chemistry.

[b] The labels on the bottom (1A, 2A, ... 8A) are the group numbers commonly used in the United States and the ones we use in this text.

[c] The names and symbols of elements 113, 115, 117, and 118 have not been assigned.

Further information is available at the Web site of WebElements™.

TABLE OF ATOMIC MASSES BASED ON CARBON-12

Name	Symbol	Atomic Number	Atomic Mass	Name	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	227.028	Manganese	Mn	25	54.9380
Aluminum	Al	13	26.9815	Meitnerium	Mt	109	(268)
Americium	Am	95	(243)	Mendelevium	Md	101	(258)
Antimony	Sb	51	121.760	Mercury	Hg	80	200.59
Argon	Ar	18	39.948	Molybdenum	Mo	42	95.94
Arsenic	As	33	74.9216	Neodymium	Nd	60	144.24
Astatine	At	85	(210)	Neon	Ne	10	20.1797
Barium	Ba	56	137.327	Neptunium	Np	93	237.048
Berkelium	Bk	97	(247)	Nickel	Ni	28	58.6934
Beryllium	Be	4	9.01218	Niobium	Nb	41	92.9064
Bismuth	Bi	83	208.980	Nitrogen	N	7	14.0067
Bohrium	Bh	107	(267)	Nobelium	No	102	(259)
Boron	B	5	10.811	Osmium	Os	76	190.23
Bromine	Br	35	79.904	Oxygen	O	8	15.9994
Cadmium	Cd	48	112.411	Palladium	Pd	46	106.42
Calcium	Ca	20	40.078	Phosphorus	P	15	30.9738
Californium	Cf	98	(251)	Platinum	Pt	78	195.078
Carbon	C	6	12.0107	Plutonium	Pu	94	(244)
Cerium	Ce	58	140.116	Polonium	Po	84	(209)
Cesium	Cs	55	132.905	Potassium	K	19	39.0983
Chlorine	Cl	17	35.4527	Praseodymium	Pr	59	140.908
Chromium	Cr	24	51.9961	Promethium	Pm	61	(145)
Cobalt	Co	27	58.9332	Protactinium	Pa	91	231.036
Copernicium	Cn	112	(285)	Radium	Ra	88	226.025
Copper	Cu	29	63.546	Radon	Rn	86	(222)
Curium	Cm	96	(247)	Rhenium	Re	75	186.207
Darmstadtium	Ds	110	(281)	Rhodium	Rh	45	102.906
Dubnium	Db	105	(262)	Roentgenium	Rg	111	(272)
Dysprosium	Dy	66	162.50	Rubidium	Rb	37	85.4678
Einsteinium	Es	99	(252)	Ruthenium	Ru	44	101.07
Erbium	Er	68	167.26	Rutherfordium	Rf	104	(261)
Europium	Eu	63	151.964	Samarium	Sm	62	150.36
Fermium	Fm	100	(257)	Scandium	Sc	21	44.9559
Flerovium	Fl	114	(289)	Seaborgium	Sg	106	(266)
Fluorine	F	9	18.9984	Selenium	Se	34	78.96
Francium	Fr	87	(223)	Silicon	Si	14	28.0855
Gadolinium	Gd	64	157.25	Silver	Ag	47	107.868
Gallium	Ga	31	69.723	Sodium	Na	11	22.9898
Germanium	Ge	32	72.61	Strontium	Sr	38	87.62
Gold	Au	79	196.967	Sulfur	S	16	32.066
Hafnium	Hf	72	178.49	Tantalum	Ta	73	180.948
Hassium	Hs	108	(269)	Technetium	Tc	43	(98)
Helium	He	2	4.00260	Tellurium	Te	52	127.60
Holmium	Ho	67	164.930	Terbium	Tb	65	158.925
Hydrogen	H	1	1.00794	Thallium	Tl	81	204.383
Indium	In	49	114.818	Thorium	Th	90	232.038
Iodine	I	53	126.904	Thulium	Tm	69	168.934
Iridium	Ir	77	192.217	Tin	Sn	50	118.710
Iron	Fe	26	55.845	Titanium	Ti	22	47.867
Krypton	Kr	36	83.80	Tungsten	W	74	183.84
Lanthanum	La	57	138.906	Uranium	U	92	238.029
Lawrencium	Lr	103	(262)	Vanadium	V	23	50.9415
Lead	Pb	82	207.2	Xenon	Xe	54	131.29
Lithium	Li	3	6.941	Ytterbium	Yb	70	173.04
Livermorium	Lv	116	(293)	Yttrium	Y	39	88.9059
Lutetium	Lu	71	174.967	Zinc	Zn	30	65.39
Magnesium	Mg	12	24.3050	Zirconium	Zr	40	91.224

Atomic masses in this table are relative to carbon-12 and limited to six significant figures, although some atomic masses are known more precisely. For certain radioactive elements the numbers listed (in parentheses) are the mass numbers of the most stable isotopes.

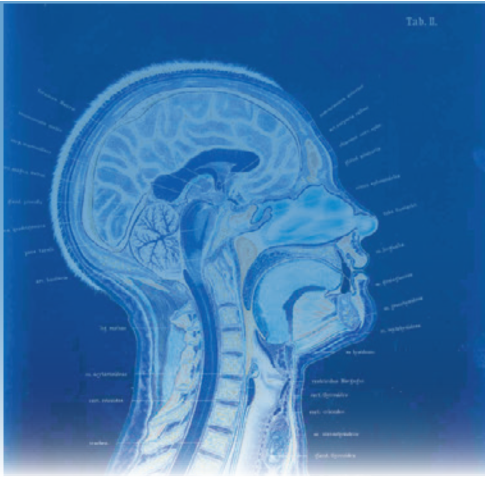
Twelve Principles of GREEN CHEMISTRY

1. **Prevention:** It is better to prevent waste than to treat or clean up waste after it has been created.
2. **Atom Economy:** Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
3. **Less Hazardous Chemical Syntheses:** Whenever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
4. **Design Safer Chemicals:** Chemical products should be designed to effect their desired function while minimizing toxicity.
5. **Safer Solvents and Auxiliaries:** The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
6. **Design for Energy Efficiency:** Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
7. **Use of Renewable Feedstocks:** A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
8. **Reduce Derivatives:** Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
9. **Catalysis:** Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
10. **Design for Degradation:** Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.
11. **Real-Time Analysis for Pollution Prevention:** Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
12. **Inherently Safer Chemistry for Accident Prevention:** Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

"Twelve Principles of Green Chemistry" from **Green Chemistry: Theory and Practice** by Paul Anastas and John Warner (1998), p. 30, Figure 4.1. By permission of Oxford University Press.

CHEMISTRY

FOR CHANGING TIMES



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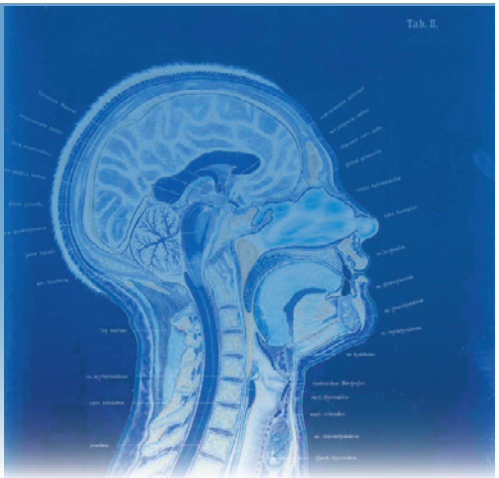
CHEMISTRY

FOR CHANGING TIMES



FOURTEENTH EDITION

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GREEN CHEMISTRY

The fourteenth 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.

Chapter 1	Green Chemistry: Reimagining Chemistry for a Sustainable World	Jennifer MacKellar and David Constable	*ACS Green Chemistry Institute®*
Chapter 2	It's Elemental	Lallie C. McKenzie	*Chem11 LLC*
Chapter 3	Clean Energy from Solar Fuels	Scott Cummings	*Kenyon College*
Chapter 4	Green Chemistry and Chemical Bonds	John C. Warner Amy S. Cannon	*Warner Babcock Institute for Green Chemistry* *Beyond Benign*
Chapter 5	Atom Economy	Margaret Kerr	*Worcester State University*
Chapter 6	Supercritical Fluids	Doug Raynie	*South Dakota State University*
Chapter 7	Acids and Bases–Greener Alternatives	Irvin J Levy	*Gordon College, Wenham, MA*
Chapter 8	Green Redox Catalysis	Roger A. Sheldon	*Delft University of Technology, Netherlands*
Chapter 9	The Art of Organic Synthesis: Green Chemists Find a Better Way	Thomas E. Goodwin	*Hendrix College*
Chapter 10	Life-Cycle Impact Assessment of New Products	Eric J. Beckman	*University of Pittsburgh*
Chapter 11	Can Nuclear Power Be Green?	Galen Suppes and Sudarshan Loyalka	*University of Missouri*
Chapter 12	Critical Supply of Key Elements	David Constable	
Chapter 13	It's Not Easy Being Green	Philip Jessop and Jeremy Durelle	*Queen's University*
Chapter 14	Fate of Chemicals in the Water Environment	Alex S. Mayer	*Michigan Technological University*
Chapter 15	Where Will We Get the Energy?	Michael Heben	*University of Toledo*
Chapter 16	Green Chemistry and Biochemistry	David A. Vosburg	*Harvey Mudd College*
Chapter 17	The Future of Food Waste–A Green Chemistry Perspective	Katie Privett	*Green Chemistry Centre of Excellence, York, United Kingdom*
Chapter 18	Green Pharmaceutical Production	Joseph M. Fortunak	
Chapter 19	Your Fitness Benefits the Planet	Doris Lewis	*Suffolk University*
Chapter 20	Safer Pesticides through Biomimicry and Green Chemistry	Amy S. Cannon	*Beyond Benign*
Chapter 21	Practicing Green Chemistry at Home	Marty Mulvihill	*University of California–Berkeley*
Chapter 22	Designing Safer Chemicals with Green Chemistry	Richard Williams	

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PREFACE

Chemistry for Changing Times is now in its fourteenth 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 thoroughly updated the text and further integrated green chemistry throughout. There is a new or revised green chemistry essay in each chapter. 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 thirteenth 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

- New! Chemistry@Home experiments have been added to the end of each chapter. These simple experiments give students the opportunity to apply the information learned in each chapter through experimentation that is easily done at home. Live demonstrations with assessment questions are also available in MasteringChemistry.
- We have placed greater focus on incorporating new data, statistics, and the latest scientific findings. Examples include:
    - In Chapter 2, we reworked the coverage of the laws of conservation of mass and of definite proportions.
    - Chapter 4 has been heavily revised to reflect new thinking on how to describe chemical bonding, stressing some important underlying concepts such as the octet rule and electronegativity.
    - Chapter 13 has been rewritten to incorporate the latest data captured during the constant monitoring of air quality and makeup of the atmosphere.
- Green chemistry coverage has been increased and further integrated into the text:
    - A greater emphasis is placed on sustainability—both in the green essays and within chapter application.
    - All essays have been carefully reviewed. Of the 22 essays, 11 are entirely new and the remaining have been rewritten extensively. Each essay identifies the principles of green chemistry that are applied in it.
    - In each chapter, there are two to five end-of-chapter problems that relate to the green chemistry essay. These have been vetted and renewed as necessary.
- Updated! Content has been streamlined throughout to expand coverage on topics where students struggle most. Some examples include:
    - In Chapter 1, we reduced historical content in favor of a greater emphasis on fundamental ideas, including the scientific method, green chemistry, and data assessment.
    - We developed a more intuitive feel for stoichiometry in Chapter 5, a concept that nonmajors often find to be the most challenging in this course.
    - Chapter 6 now includes coverage of Gay-Lussac's law.
    - We adjusted coverage of stability of isotopes in Chapter 11 (another topic that frequently provides a challenge) and the workings of catalytic converters in Chapter 13. We also added coverage of heat capacity and specific heat to Chapter 14.
- Learning objectives, located at the beginning of each chapter and at the start of each section, have been revised as needed for clarity. They are linked to end-of-chapter problems to assist students and professors when assessing mastery of concepts.
- Updated! At least 25% of the Critical Thinking Exercises have been revised or replaced in all chapters. These exercises require students to apply concepts learned in the chapter and stress that critical thinking is a regular part of the work of students and scientists.
- Self-Assessment Questions at the end of each section facilitate student interaction with topics just learned. These multiple-choice items provide immediate feedback to test students' understanding of the material and serve as quick checks during reading of the chapter.
- We have revised or replaced more than 25% of the end-of-chapter problems to highlight the constant changes taking place in chemistry. Between editions, we are constantly sketching out new and interesting problems, which then are incorporated into the following edition's problem sets.
- Many of the worked-out examples and their accompanying exercises in the chapters have also been modified or revised to reflect current thinking, applications, and even some novelty. This is especially the case in the first 12 chapters—the core of the course.

- Updated! Each chapter starts with compelling images and a set of questions called "Have You Ever Wondered?" These real-life questions engage students in the chapter's content. Many have been changed as we listen to students and the questions they bring up. We watch for new developments that interest the general public, too. Answers to the questions are found in the outer column within the chapter, near the related text content.
- Updated! Collaborative Group Projects, which follow the end-of-chapter problems, have been revised or replaced in many chapters. These projects can extend the students' learning of chemistry far beyond the textbook.

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:

- Review 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.

- Additional 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.

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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 fourteenth edition, we are especially grateful to the following reviewers:

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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.

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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, and Bradley University for all their help and support through the years. We are thankful to the contributors who revised all chapters for this new edition, Robert and Elzbieta Cook, Louisiana State University; Ricardo Delgado, Lindenwood University; Marilyn Duerst, University of Wisconsin-River Falls; Steven R. Gwaltney, Mississippi State University Andrew Jorgensen, The University of Toledo; Jeremy Mason, Texas Tech University; Rill Ann Reuter, Winona State University. Thank you to Amy Cannon and Kate Anderson who coordinated the Chemistry @ Home experiments. The Chemistry @ Home 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, program manager, 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. Director of Development Jennifer Hart and Development Editor Donald Gecewicz 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 Acquisitions Editor Chris Hess for his overall guidance and to Project Managers Francesca Monaco and Lisa Pierce for their diligence and patience in bringing all the parts together to yield a finished work. We are indebted to our copyeditor Betty Pessagno, whose expertise helped improve the consistency of the text; and to proofreaders 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, Carolyn Arcabascio, who vetted hundreds of images in the search for quality photos.

John W. Hill owes a very special kind of thanks to his wonderful spouse, Ina, who over the years has done typing, library research, and so many other things that allow him time to concentrate on writing. Most of all, he is grateful for her boundless patience, unflagging support, understanding, and enduring love. He is also grateful to his beloved daughter Cindy for her help with the house and the yard and so many other things. Terry W. McCreary would like to thank his wife, Geniece, and children, Corinne and Yvette, for their unflagging support, understanding, and love.

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."

ABOUT THE AUTHORS

John W. Hill

John Hill received his Ph.D. from the University of Arkansas. As an organic chemist, he has published more than 50 papers, most of which have an educational bent. He has authored or coauthored several introductory-level chemistry textbooks, all of which have been published in multiple editions. He has also presented over 60 papers at national conferences, many relating to chemical education. He has received several awards for outstanding teaching and has long been active in the American Chemical Society, both locally and nationally. Now professor emeritus at the University of Wisconsin–River Falls, he authored the first edition of *Chemistry for Changing Times* in 1972. Revising and updating this book has been a major focus of his life for four decades.

Terry W. McCreary

Terry McCreary received his B.S. from St. Francis University, his M.S. from the University of Georgia, and his Ph.D. from Virginia Tech. He has taught 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 American Chemical Society and the Kentucky Academy of Science and has served as technical editor for the *Journal of Pyrotechnics*. In his spare time, he designs, builds, and flies rockets with the Tripoli Rocketry Association; he was elected president of the association in 2010. McCreary is the author of several laboratory manuals: *General Chemistry* with John Hill, Ralph Petrucci, and Scott Perry; and *Experimental Composite Propellant*, a fundamental treatise on the preparation and properties of solid rocket propellant.

Without the help of several chapter contributors, the fourteenth edition would not exist. We are grateful to the following people who updated all 22 chapters of this new edition to make it more current.

Chapter Contributors of the Fourteenth Edition

Robert and Elzbieta Cook, Louisiana State University
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Jeremy Mason, Texas Tech University
Rill Ann Reuter, Winona State University

ABOUT OUR SUSTAINABILITY INITIATIVES

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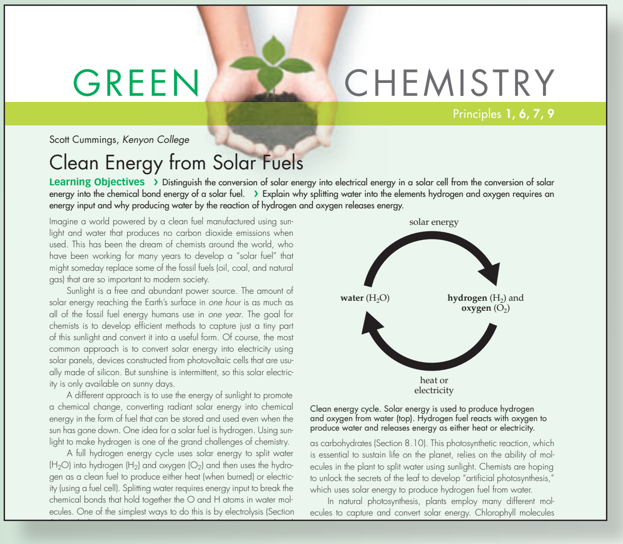
Green Chemistry Emphasis

The fourteenth edition emphasizes green chemistry through a framework of twelve principles. Each chapter contains a **Green Essay**, written by an expert in the field, which identifies the principles within the application. Chapter **Learning Objectives**, **End-of-Chapter Summaries**, and **Problems** now include green chemistry content to reinforce the principles for students.

Green Chemistry Essays

Green chemistry essays, written by experts in the field, introduce students to one or more of the twelve principles of green chemistry, while highlighting references to the chapter when applicable.



GREEN CHEMISTRY

Principles **1, 6, 7, 9**

Scott Cummings, *Kenyon College*

Clean Energy from Solar Fuels

Learning Objectives › Distinguish the conversion of solar energy into electrical energy in a solar cell from the conversion of solar energy into the chemical bond energy of a solar fuel. › Explain why splitting water into the elements hydrogen and oxygen requires an energy input and why producing water by the reaction of hydrogen and oxygen releases energy.

Imagine a world powered by a clean fuel manufactured using sunlight and water that produces no carbon dioxide emissions when used. This has been the dream of chemists around the world, who have been working for many years to develop a "solar fuel" that might someday replace some of the fossil fuels (oil, coal, and natural gas) that are so important to modern society.

Sunlight is a free and abundant power source. The amount of solar energy reaching the Earth's surface in *one hour* is as much as all of the fossil fuel energy humans use in *one year*. The goal for chemists is to develop efficient methods to capture just a tiny part of this sunlight and convert it into a useful form. Of course, the most common approach is to convert solar energy into electricity using solar panels, devices constructed from photovoltaic cells that are usually made of silicon. But sunshine is intermittent, so this solar electricity is only available on sunny days.

A different approach is to use the energy of sunlight to promote a chemical change, converting radiant solar energy into chemical energy in the form of fuel that can be stored and used even when the sun has gone down. One idea for a solar fuel is hydrogen. Using sunlight to make hydrogen is one of the grand challenges of chemistry.

A full hydrogen energy cycle uses solar energy to split water (H_2O) into hydrogen (H_2) and oxygen (O_2) and then uses the hydrogen as a clean fuel to produce either heat (when burned) or electricity (using a fuel cell). Splitting water requires energy input to break the chemical bonds that hold together the O and H atoms in water molecules. One of the simplest ways to do this is by electrolysis (Section

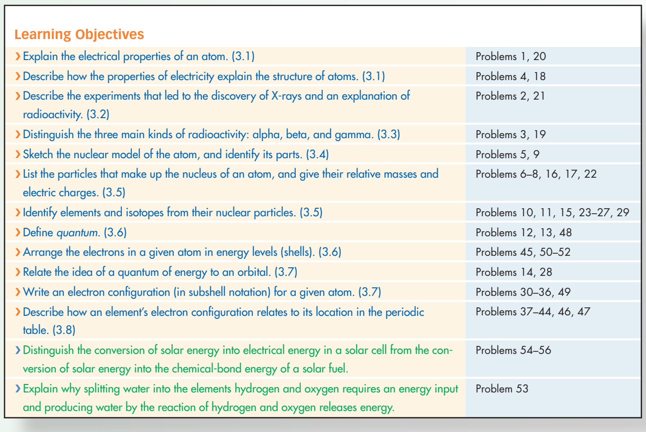
Clean energy cycle. Solar energy is used to produce hydrogen and oxygen from water (top). Hydrogen fuel reacts with oxygen to produce water and releases energy as either heat or electricity.

as carbohydrates (Section 8.10). This photosynthetic reaction, which is essential to sustain life on the planet, relies on the ability of molecules in the plant to split water using sunlight. Chemists are hoping to unlock the secrets of the leaf to develop "artificial photosynthesis," which uses solar energy to produce hydrogen fuel from water.

In natural photosynthesis, plants employ many different molecules to capture and convert solar energy. Chlorophyll molecules

Learning Objectives

Learning Objectives for each section in the text and related green chemistry have been added to every chapter and link to end-of-chapter problems in the textbook and in MasteringChemistry®.

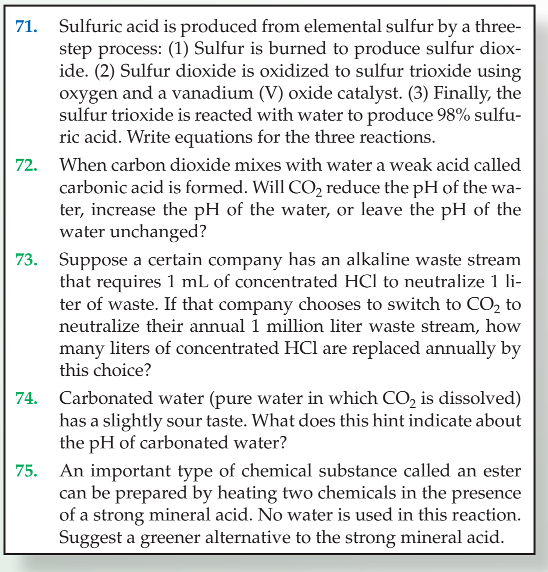


Learning Objectives

› Explain the electrical properties of an atom. (3.1)	Problems 1, 20
› Describe how the properties of electricity explain the structure of atoms. (3.1)	Problems 4, 18
› Describe the experiments that led to the discovery of X-rays and an explanation of radioactivity. (3.2)	Problems 2, 21
› Distinguish the three main kinds of radioactivity: alpha, beta, and gamma. (3.3)	Problems 3, 19
› Sketch the nuclear model of the atom, and identify its parts. (3.4)	Problems 5, 9
› List the particles that make up the nucleus of an atom, and give their relative masses and electric charges. (3.5)	Problems 6–8, 16, 17, 22
› Identify elements and isotopes from their nuclear particles. (3.5)	Problems 10, 11, 15, 23–27, 29
› Define *quantum*. (3.6)	Problems 12, 13, 48
› Arrange the electrons in a given atom in energy levels (shells). (3.6)	Problems 45, 50–52
› Relate the idea of a quantum of energy to an orbital. (3.7)	Problems 14, 28
› Write an electron configuration (in subshell notation) for a given atom. (3.7)	Problems 30–36, 49
› Describe how an element's electron configuration relates to its location in the periodic table. (3.8)	Problems 37–44, 46, 47
› Distinguish the conversion of solar energy into electrical energy in a solar cell from the conversion of solar energy into the chemical-bond energy of a solar fuel.	Problems 54–56
› Explain why splitting water into the elements hydrogen and oxygen requires an energy input and producing water by the reaction of hydrogen and oxygen releases energy.	Problem 53

End-of-Chapter Questions

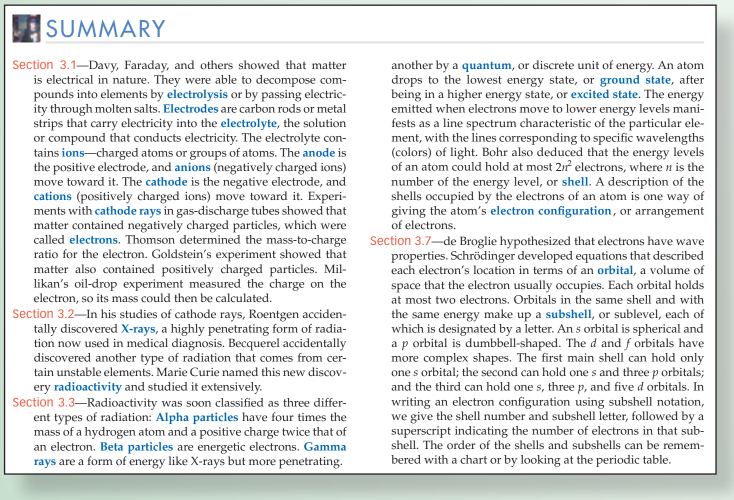
Each chapter includes two to five end-of-chapter problems that relate to the green chemistry in that chapter.



71. Sulfuric acid is produced from elemental sulfur by a three-step process: (1) Sulfur is burned to produce sulfur dioxide. (2) Sulfur dioxide is oxidized to sulfur trioxide using oxygen and a vanadium (V) oxide catalyst. (3) Finally, the sulfur trioxide is reacted with water to produce 98% sulfuric acid. Write equations for the three reactions.
72. When carbon dioxide mixes with water a weak acid called carbonic acid is formed. Will CO_2 reduce the pH of the water, increase the pH of the water, or leave the pH of the water unchanged?
73. Suppose a certain company has an alkaline waste stream that requires 1 mL of concentrated HCl to neutralize 1 liter of waste. If that company chooses to switch to CO_2 to neutralize their annual 1 million liter waste stream, how many liters of concentrated HCl are replaced annually by this choice?
74. Carbonated water (pure water in which CO_2 is dissolved) has a slightly sour taste. What does this hint indicate about the pH of carbonated water?
75. An important type of chemical substance called an ester can be prepared by heating two chemicals in the presence of a strong mineral acid. No water is used in this reaction. Suggest a greener alternative to the strong mineral acid.

End-of-Chapter Summaries

Each chapter includes end-of-chapter summaries, with key terms highlighted in blue, as well as a section summarizing the green chemistry highlighted within each chapter essay.



SUMMARY

Section 3.1—Davy, Faraday, and others showed that matter is electrical in nature. They were able to decompose compounds into elements by **electrolysis** or by passing electricity through molten salts. **Electrodes** are carbon rods or metal strips that carry electricity into the **electrolyte**, the solution or compound that conducts electricity. The electrolyte contains **ions**—charged atoms or groups of atoms. The **anode** is the positive electrode, and **anions** (negatively charged ions) move toward it. The **cathode** is the negative electrode, and **cations** (positively charged ions) move toward it. Experiments with **cathode rays** in gas-discharge tubes showed that matter contained negatively charged particles, which were called **electrons**. Thomson determined the mass-to-charge ratio for the electron. Goldstein's experiment showed that matter also contained positively charged particles. Millikan's oil-drop experiment measured the charge on the electron, so its mass could then be calculated.

Section 3.2—In his studies of cathode rays, Roentgen accidentally discovered **X-rays**, a highly penetrating form of radiation now used in medical diagnosis. Becquerel accidentally discovered another type of radiation that comes from certain unstable elements. Marie Curie named this new discovery **radioactivity** and studied it extensively.

Section 3.3—Radioactivity was soon classified as three different types of radiation: **Alpha particles** have four times the mass of a hydrogen atom and a positive charge twice that of an electron. **Beta particles** are energetic electrons. **Gamma rays** are a form of energy like X-rays but more penetrating.

another by a **quantum**, or discrete unit of energy. An atom drops to the lowest energy state, or **ground state**, after being in a higher energy state, or **excited state**. The energy emitted when electrons move to lower energy levels manifests as a line spectrum characteristic of the particular element, with the lines corresponding to specific wavelengths (colors) of light. Bohr also deduced that the energy levels of an atom could hold at most $2n^2$ electrons, where n is the number of the energy level, or **shell**. A description of the shells occupied by the electrons of an atom is one way of giving the atom's **electron configuration**, or arrangement of electrons.

Section 3.7—de Broglie hypothesized that electrons have wave properties. Schrödinger developed equations that described each electron's location in terms of an **orbital**, a volume of space that the electron usually occupies. Each orbital holds at most two electrons. Orbitals in the same shell and with the same energy make up a **subshell**, or sublevel, each of which is designated by a letter. An *s* orbital is spherical and a *p* orbital is dumbbell-shaped. The *d* and *f* orbitals have more complex shapes. The first main shell can hold only one *s* orbital; the second can hold one *s* and three *p* orbitals; and the third can hold one *s*, three *p*, and five *d* orbitals. In writing an electron configuration using subshell notation, we give the shell number and subshell letter, followed by a superscript indicating the number of electrons in that subshell. The order of the shells and subshells can be remembered with a chart or by looking at the periodic table.

Critical Thinking

In order to help students improve their critical thinking skills, Chapter One introduces the principles used to test a claim (falsifiability, logic, replicability, and sufficiency; identified by the acronym FLaReS). Each end-of-chapter section reinforces their importance by including a section of Critical Thinking questions, allowing students to use these principles to test each of the claims. Instructors can assign Critical Thinking questions in MasteringChemistry, which provide wrong answer feedback to help students learn from their mistakes and ultimately gain a stronger grasp of the process of science.

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.

3.1 Suppose you read in the newspaper that a chemist in South America claims to have discovered a new element with an atomic mass of 34. Extremely rare, it was found in a sample taken from the Andes Mountains. Unfortunately, the chemist has used all of the sample in his analyses.

3.2 Some aboriginal tribes have rain-making ceremonies in which they toss pebbles of gypsum up into the air. (Gypsum is the material used to make plaster of Paris by heating the rock to remove some of its water.) Sometimes it does rain several days after these rain-making ceremonies.

3.3 Some scientists think that life on other planets might be based on silicon rather than carbon. Evaluate this possibility.

3.4 You come across a website selling water made from only single isotopes of hydrogen and oxygen. A testimonial on the website claims that drinking only the isotopically pure water helps a person feel more refreshed throughout the day.

Worked Examples

Worked examples within each chapter guide students through the process of solvings particular types of problems. Examples are followed by one or more exercises allowing students to immediately check their problem-solving skills.

Example 3.1 Number of Neutrons

How many neutrons are there in the $^{235}_{92}\text{U}$ nucleus?

Solution

We simply subtract the atomic number Z (number of protons) from the mass number A (number of protons plus number of neutrons).

$$A - Z = \text{number of neutrons}$$
$$235 - 92 = 143$$

There are 143 neutrons in the $^{235}_{92}\text{U}$ nucleus.

■ EXERCISE 3.1A

How many neutrons are there in the $^{60}_{27}\text{Co}$ nucleus?

■ EXERCISE 3.1B

An iodine isotope has 78 neutrons in its nucleus. What are the mass number and the name of the isotope?

Exercise A allows students to apply the problem-solving method just explained to a similar situation.

Exercise B prompts the student to combine the specific problem-solving method just taught with concepts learned in previous sections.

Applications

Emulsions

When oil and water are vigorously shaken together, the oil is broken up into tiny, microscopic droplets and dispersed throughout the water, a mixture called an *emulsion*. Unless a third substance has been added, the emulsion usually breaks down rapidly, as the oil droplets recombine and float to the surface of the water.

Emulsions can be stabilized by adding a type of gum, a soap, or a protein that can form a protective coating around the oil droplets and prevent them from coming together. Lecithin in egg yolks keeps mayonnaise from separating, while casein in milk keeps fat droplets suspended. Compounds called *bile salts* keep tiny fat droplets suspended in aqueous media during human digestion. This greatly aids the digestive process. The tiny emulsified droplets provide a much greater surface area on which the water-soluble lipase enzymes can break down the triacylglycerides to glycerol and fatty acids.

▲ Many foods are emulsions. Milk is an emulsion of butterfat in water. The stabilizing agent is a protein called *casein*. Mayonnaise is an emulsion of vegetable oil in water, stabilized by egg yolk.

Current and Relevant Applications

Essays throughout the new edition focus on interesting, relevant applications to help students connect the chemistry covered in a particular chapter or section to the world around them.

It DOES Matter!

When light hits a photovoltaic "solar" cell, photons are absorbed, promoting electrons to excited states. Those excited state electrons are captured by the photovoltaic cell to produce an electrical current. Scientists are working to create new materials that will absorb more of the sun's photons and more efficiently convert those photons into electrical energy. Scientists are also working on creating new materials that will lower the cost to make solar cells. Depending on where you live and how much sunlight you get, solar electricity may already be cheaper than the electricity you buy from the power company.

It DOES Matter!

Marginal boxes briefly discuss a specific application or phenomenon and show students how the material being studied relates to their world.

NEW! Chemistry@Home

The Chemistry@Home experiments located at the end of each chapter give students the opportunity to apply the information learned in each chapter through experimentation they can easily do at home.

CHEMISTRY@HOME How Sweet It Is to Be Fermented by You!

Materials required

- Yeast (jar)
- Large measuring cup: 2 cup or larger capacity
- Measuring spoons (teaspoon and tablespoon)
- 6 resealable plastic bags
- 1 tablespoon of sugar
- 1 tablespoon of sweetener (Equal®, Sweet'N Low®)
- 1 tablespoon of flour
- 2 breakfast cereal samples (each with sugar listed as ingredient)
- Lukewarm water
- Paper towels (for clean-up)

What does yeast need to survive and thrive? Can yeast also digest artificial sweeteners and flour?

Yeast is most commonly used in the kitchen to make dough rise. Have you ever watched pizza crust or a loaf of bread swell in the oven? Yeast makes the dough expand. But what is yeast exactly and how does it work? Yeast strains are made up of living eukaryotic microbes, meaning that they contain cells with nuclei and are classified as fungi. In this experiment, we will watch yeast come to life as it breaks down sugar, also known as sucrose, through a process called fermentation.

To begin, create a data table for your experiment results. The data table should include columns for 6 bags, their contents, and your observations. Label bags 1 through 6.

Bag 1 will be your control.

–To bag 2, add 1 tablespoon of sugar.

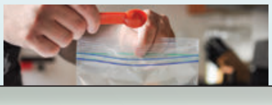
–To bag 3, add 1 tablespoon of sweetener (Sweet'N Low® or Equal®).

–To bag 4, add 1 tablespoon of flour.

–To bag 5, add 1 tablespoon of breakfast cereal A, crushed.

–To bag 6, add 1 tablespoon of breakfast cereal B, crushed.

Next add $\frac{1}{4}$ cup of lukewarm water and 2 teaspoons of yeast to each bag.



▶ **Figure 2**

Carefully, without spilling any of the contents, squeeze out as much air as possible and seal each bag. Put the bags in a warm place for 20 minutes. (Either a window or a large bowl with warm water works well.) Observe the bags periodically. After 20 minutes, remove the bags from the warm place and observe them.

▶ **Figure 3**

What changes have occurred? Which bag has grown in size the most?

To measure the volume of the bags, fill the large measuring cup with 1 cup water and lower the bag into the large measuring cup. To find the estimated volume, you will use displacement measurement. Record the volume of the water with the bag in it and subtract the initial starting volume of 1 cup of water to obtain your volume. (Don't forget to account for any volume change of your control bag.)

Resources

Resource	Available in Print	Available Online	Instructor or Student Resource	Description
Study Guide and Selected Solutions Manual ISBN: 0133889041	✓		Resource for Students	The Study Guide and Selected Solutions Manual assists students with the text material. It contains learning objectives, chapter outlines, key terms, additional problems with self-tests and answers, and answers to odd-numbered problems in the text.
Chemical Investigations for Changing Times ISBN: 0133891852	✓		Resource for Students	This resource contains over 60 laboratory experiments that correspond to topics covered in *Chemistry for Changing Times, 14th edition*.
Online Instructor Resource Center ISBN: 013388922X		✓	Resource for Instructor	This resource contains the following: • All illustrations, tables, and photos from the text in JPEG format • Four pre-built PowerPoint Presentations (lecture, worked examples, images, CRS/ clicker questions) • TestGen computerized software with the TestGen version of the Testbank • Word files of the Test Item File
Instructor's Manual (Download Only) ISBN: 0133889025		✓	Resource for Instructor	Organized by chapter, this useful guide includes objectives, lecture outlines, references to figures and solved problems, as well as teaching demonstrations.
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Test Bank ISBN: 0133888991		✓	Resource for Instructor	The Test Bank contains more than 2500 multiple choice, true/false, and matching questions.

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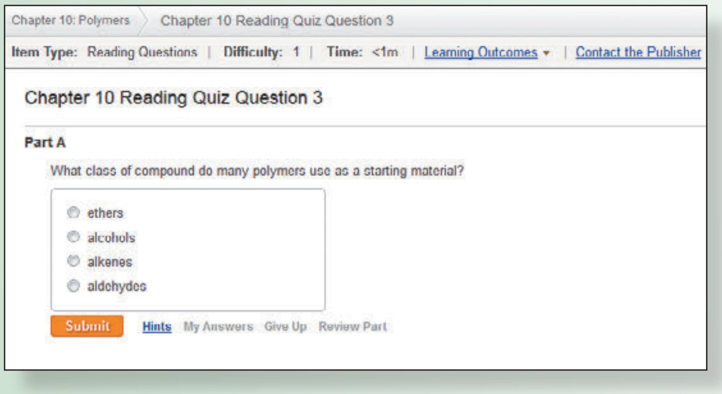
MasteringChemistry® from Pearson is the leading online teaching and learning system designed to improve results by engaging students before, during, and after class with powerful content. Ensure that students arrive ready to learn by assigning educationally effective content before class, and encourage critical thinking and retention with in-class resources such as Learning Catalytics. Students can further master concepts after class through traditional homework assignments that provide hints and answer-specific feedback. The Mastering gradebook records scores for all automatically graded assignments while diagnostic tools give instructors access to rich data that helps assess student understanding and identifies class-wide misconceptions. Mastering brings learning full circle by continuously adapting to each student and making learning more personal than ever—before, during, and after class.

BEFORE CLASS

Reading Quizzes

Reading Quizzes give you the opportunity to assign reading and test students on their comprehension of chapter content before they come to class, empowering you to assume a certain baseline level of knowledge and helping you to spend more time on the toughest topics that require your expertise.



Chapter 10: Polymers › Chapter 10 Reading Quiz Question 3

Item Type: Reading Questions | **Difficulty:** 1 | **Time:** <1m | Learning Outcomes ▾ | Contact the Publisher

Chapter 10 Reading Quiz Question 3

Part A

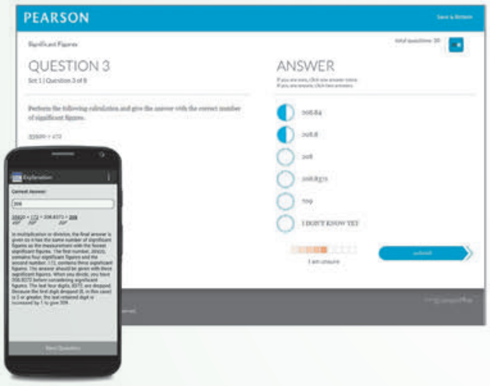
What class of compound do many polymers use as a starting material?

○ ethers
○ alcohols
○ alkenes
○ aldehydes

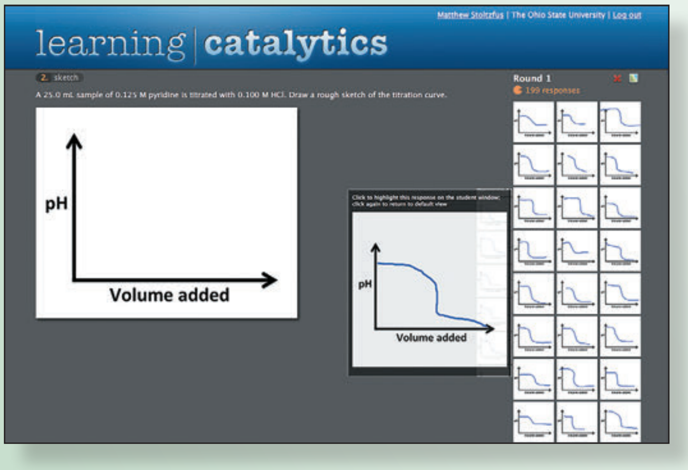
Dynamic Study Modules

Help students quickly learn chemistry!

Now assignable, Dynamic Study Modules (DSMs) enable your students to study on their own and be better prepared to achieve higher scores on their tests. When your students use DSMs outside of class, you can take knowledge transfer out of the classroom, allowing class time to be spent on higher-order learning. The mobile app is available for iOS and Android devices for study on the go.



DURING CLASS



Matthew Stoltzfus | The Ohio State University | Log out

learning | catalytics

2. sketch

A 25.0 mL sample of 0.125 M pyridine is titrated with 0.100 M HCl. Draw a rough sketch of the titration curve.

Round 1

199 responses

Click to highlight this response on the student window; click again to return to default view

Learning Catalytics

Learning Catalytics "is a "bring your own device" student engagement, assessment, and classroom intelligence system. With Learning Catalytics you can:

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students' critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics fit your course exactly.
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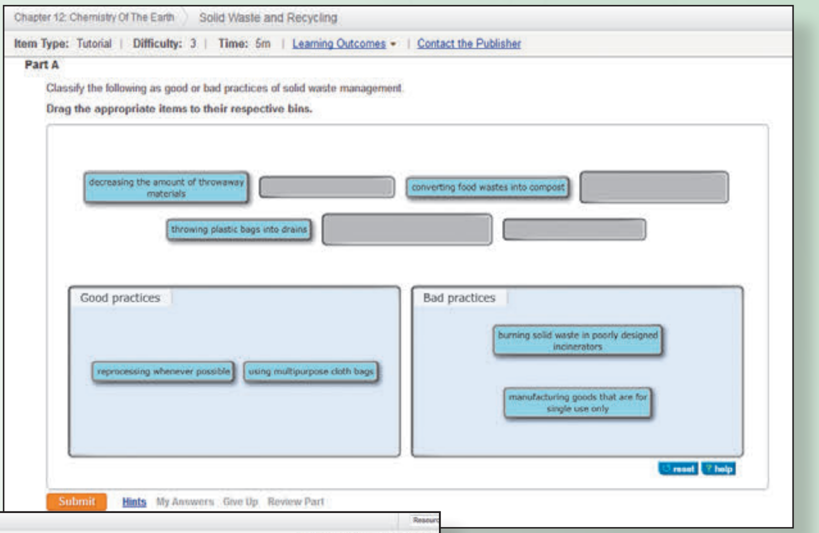
AFTER CLASS

Student Tutorials

Tutorials, featuring specific wrong-answer feedback, hints, and a wide variety of educationally effective content, guide your students through the toughest topics in chemistry. The hallmark Hints and Feedback offer scaffolded instruction similar to what students would experience in an office hour, allowing them to learn from their mistakes without being given the answer.



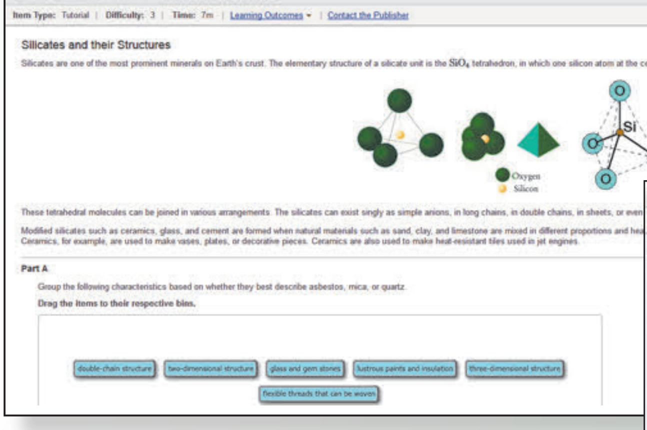
Chapter 12: Chemistry Of The Earth › Solid Waste and Recycling

Item Type: Tutorial | **Difficulty:** 3 | **Time:** 5m | Learning Outcomes ▾ | Contact the Publisher

Part A

Classify the following as good or bad practices of solid waste management.

Drag the appropriate items to their respective bins.



Chapter 12: Chemistry Of The Earth › Silicates and their Structures

Item Type: Tutorial | **Difficulty:** 3 | **Time:** 7m | Learning Outcomes ▾ | Contact the Publisher

Manage this Item: Standard View

Silicates and their Structures

Silicates are one of the most prominent minerals on Earth's crust. The elementary structure of a silicate unit is the SiO_4 tetrahedron, in which one silicon atom at the center is surrounded by oxygen atoms at the four vertices of the tetrahedron.

These tetrahedral molecules can be joined in various arrangements. The silicates can exist singly as simple anions, in long chains, in double chains, in sheets, or even

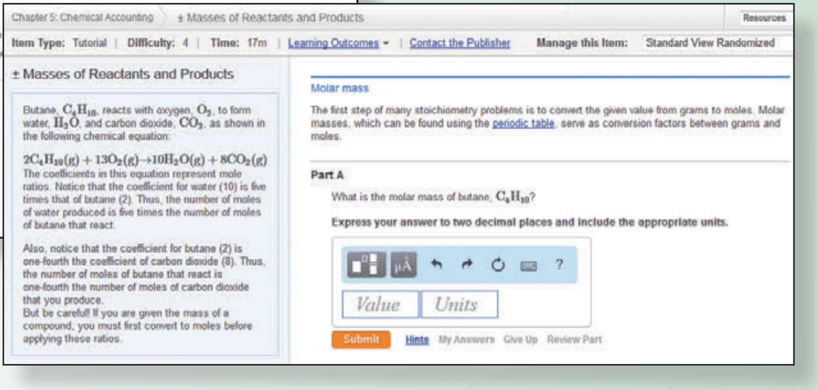
Modified silicates such as ceramics, glass, and cement are formed when natural materials such as sand, clay, and limestone are mixed in different proportions and hea

Ceramics, for example, are used to make vases, plates, or decorative pieces. Ceramics are also used to make heat-resistant tiles used in jet engines.

Part A

Group the following characteristics based on whether they best describe asbestos, mica, or quartz.

Drag the items to their respective bins.



Chapter 5: Chemical Accounting › ± Masses of Reactants and Products

Item Type: Tutorial | **Difficulty:** 4 | **Time:** 17m | Learning Outcomes ▾ | Contact the Publisher **Manage this Item:** Standard View Randomized

± Masses of Reactants and Products

Butane, C_4H_{10}, reacts with oxygen, O_2, to form water, H_2O, and carbon dioxide, CO_2, as shown in the following chemical equation:

$$2C_4H_{10}(g) + 13O_2(g) \rightarrow 10H_2O(g) + 8CO_2(g)$$

The coefficients in this equation represent mole ratios. Notice that the coefficient for water (10) is five times that of butane (2). Thus, the number of moles of water produced is five times the number of moles of butane that react.

Also, notice that the coefficient for butane (2) is one-fourth the coefficient of carbon dioxide (8). Thus, the number of moles of butane that react is one-fourth the number of moles of carbon dioxide that you produce.

But be careful! If you are given the mass of a compound, you must first convert to moles before applying these ratios.

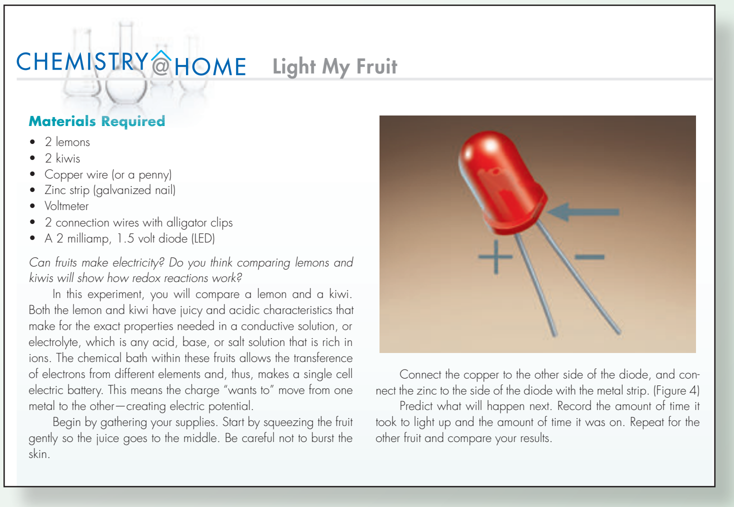
Molar mass

The first step of many stoichiometry problems is to convert the given value from grams to moles. Molar masses, which can be found using the periodic table, serve as conversion factors between grams and moles.

Part A

What is the molar mass of butane, C_4H_{10}?

Express your answer to two decimal places and include the appropriate units.



CHEMISTRY@HOME Light My Fruit

Materials Required

- 2 lemons
- 2 kiwis
- Copper wire (or a penny)
- Zinc strip (galvanized nail)
- Voltmeter
- 2 connection wires with alligator clips
- A 2 milliamp, 1.5 volt diode (LED)

Can fruits make electricity? Do you think comparing lemons and kiwis will show how redox reactions work?

In this experiment, you will compare a lemon and a kiwi. Both the lemon and kiwi have juicy and acidic characteristics that make for the exact properties needed in a conductive solution, or electrolyte, which is any acid, base, or salt solution that is rich in ions. The chemical bath within these fruits allows the transference of electrons from different elements and, thus, makes a single cell electric battery. This means the charge "wants to" move from one metal to the other—creating electric potential.

Begin by gathering your supplies. Start by squeezing the fruit gently so the juice goes to the middle. Be careful not to burst the skin.

Connect the copper to the other side of the diode, and connect the zinc to the side of the diode with the metal strip. (Figure 4)

Predict what will happen next. Record the amount of time it took to light up and the amount of time it was on. Repeat for the other fruit and compare your results.

The interactive Chemistry@Home demonstrations bring the subject matter to life and are assignable with follow-up assessments in MasteringChemistry.

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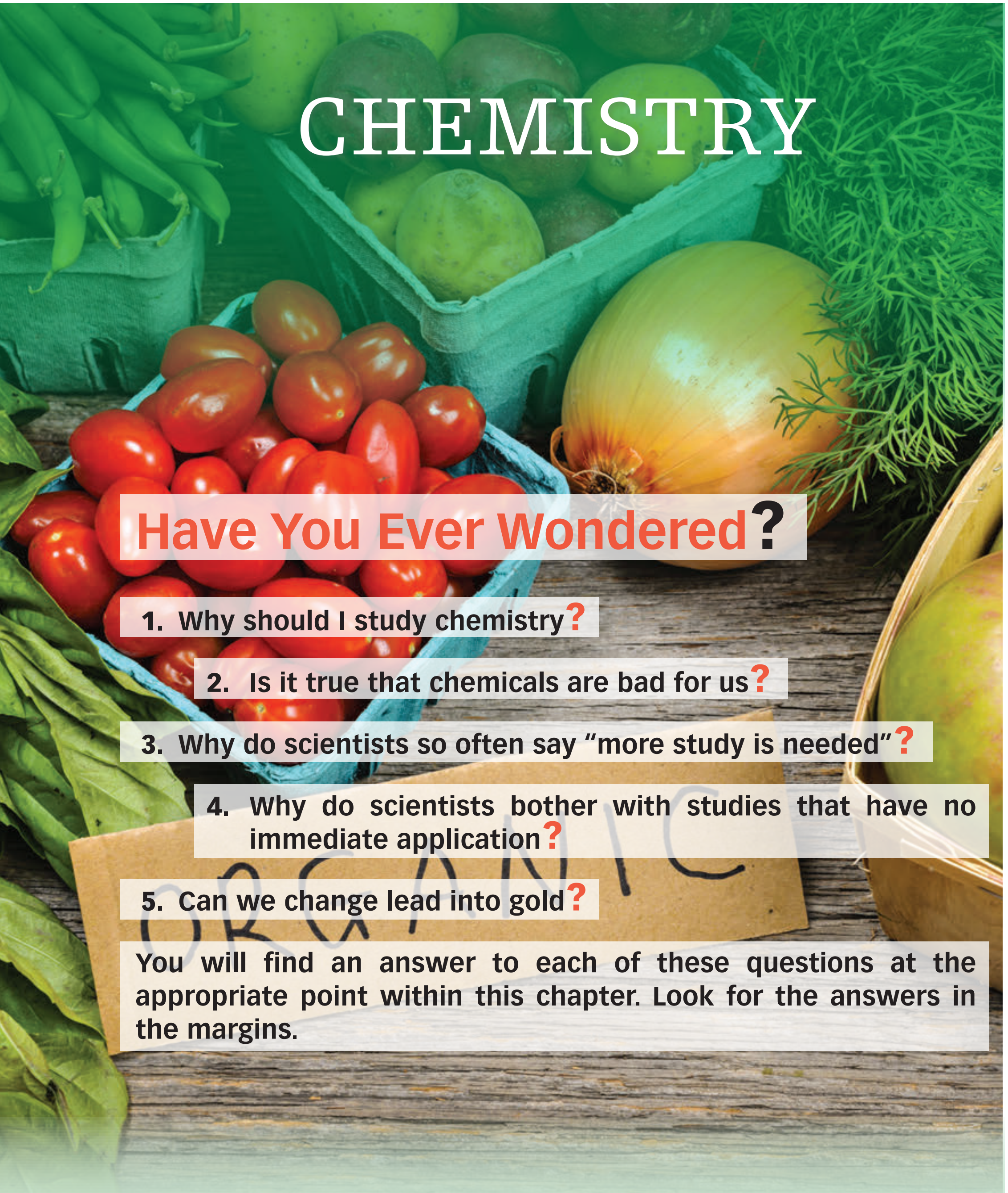


CHEMISTRY

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 We invite you to join us on a journey toward a horizon of infinite possibilities. We will be exploring 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 is everywhere, not just in laboratories. Chemistry occurs in soil and rocks, in waters, in clouds, and in us. Knowledge of chemistry enhances our understanding of climate change, helps to provide food for Earth's increasing population, and is crucial to the development and production of sustainable fuels.

Learning Objectives

- Define science, chemistry, technology, and alchemy. (1.1)
- Describe the importance of green chemistry and sustainable chemistry. (1.1)
- Define *hypothesis, scientific law, scientific theory*, and *scientific model*, and explain their relationships in science. (1.2)
- Define *risk* and *benefit*, and give an example of each. (1.3)
- Estimate a desirability quotient from benefit and risk data. (1.3)
- Distinguish basic research from applied research. (1.4)
- Differentiate: mass and weight; physical and chemical change; and physical and chemical properties. (1.5)
- Classify matter according to state and as mixture, substance, compound, and/or element. (1.6)
- Assign proper units of measurement to observations, and manipulate units in conversions. (1.7)
- Calculate the density, mass, or volume of an object given the other two quantities. (1.8)
- Distinguish between heat and temperature. (1.9)
- Explain how the temperature scales are related. (1.9)
- Use critical thinking to evaluate claims and statements. (1.10)
- Define green chemistry.
- Describe how *green chemistry* reduces risk and prevents environmental problems.

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

Chemistry also affects society as a whole. Developments in health and medicine involve a lot of chemistry. The astounding advances in biotechnology—such as genetic engineering, new drugs, 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 climate change and ozone depletion involve chemistry.

So what 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 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 the primary means by which we obtain new knowledge. It is an accumulation of knowledge about nature and our physical world and of theories that we use to explain that knowledge. **Chemistry** is that area of knowledge that deals with the behavior of matter.

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, 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. Those 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.

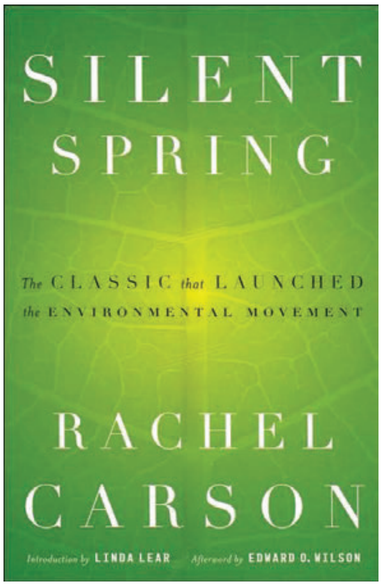
The experimental roots of chemistry lie in **alchemy**, a primitive form of chemistry that flourished in Europe from about 500 to 1500 C.E. Alchemists searched for a "philosopher's stone" that would turn cheaper metals into gold and for an elixir that would bring eternal life. Although they never achieved 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 by 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, giving little thought to the consequences. Rachel Carson, 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 roundly 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 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 in themselves. 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 beginnings 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 would 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 best exemplifies sustainable chemistry?
   - **a.** Toluene, extracted from coal, is used to make TNT, an explosive.
   - **b.** Paper is made from hardwood trees.
   - **c.** Minerals mined in South America are used in China to make LCD screens.
   - **d.** Plastic bottles are made from both petroleum and recycled plastic.

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

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

Learning Objectives › 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 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, but it is not especially good at establishing truths. 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 to 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 undergone *peer review* and has been verified by other scientists.

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

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.

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.

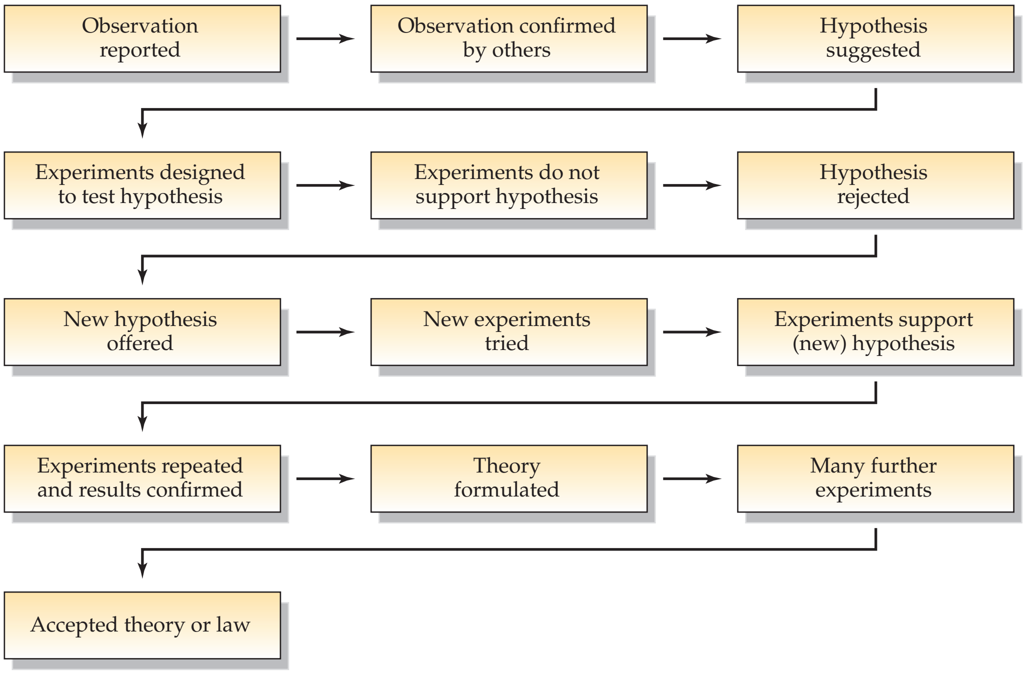
Large amounts of scientific data are often summarized in brief verbal or mathematical statements called **scientific laws**. For example, Robert Boyle (1627–1691), an Irishman, conducted many experiments on gases. In each experiment, he founded *Boyle's law*, which said that the volume of the gas decreased 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.

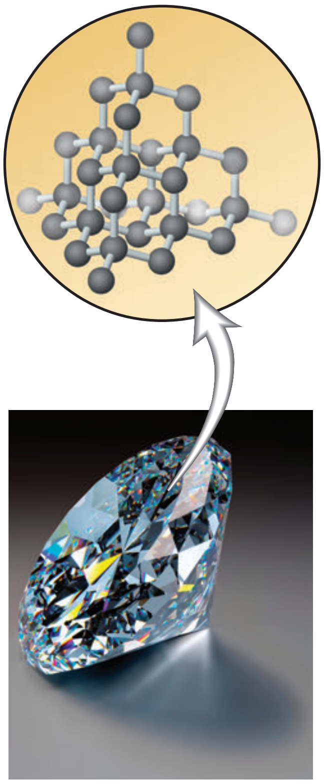
Scientific Theories Are Tentative and Predictive

Scientists organize the knowledge they accumulate on a framework of detailed explanations called theories. A **theory** represents the best current explanation for a phenomenon, but it is always *tentative*. In the future, a theory may have to be modified or even discarded as a result of new observations, for the body of knowledge that is 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. 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 Possible Scientific Process

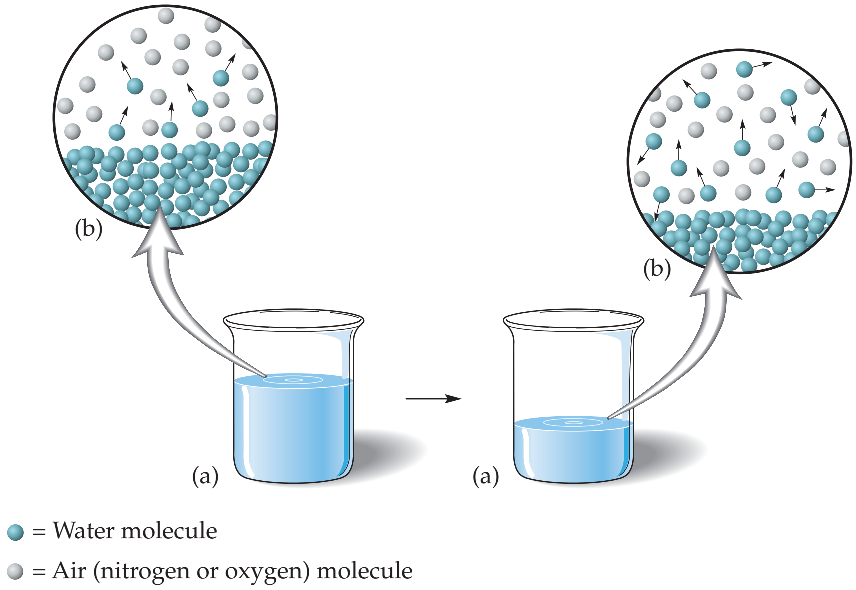




▲ A molecular model of diamond shows the tightly linked, rigid structure that explains why diamonds are so hard.

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 billiard 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 1.1).



▶ **Figure 1.1** 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 in terms of the motion of molecules.

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 billiard balls on a playing table. Sometimes, a "hard break" of billiard balls causes one ball to fly off the 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 doing 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.

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 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.

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.

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?

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 such factors 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 that 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.** UFOs frequent the Bermuda Triangle, which accounts for all of the oddities in the region.
   - **b.** Ice floats on water because of the air bubbles that get trapped during the freezing process.
   - **c.** Oxygen reacts with silver to form rust.
   - **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 leads 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. 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. Thus, milk is not always suitable for use in programs to relieve malnutrition.

It DOES Matter!

For most people of northern European ancestry, 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.

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 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 of the technological advancements will help you make a more accurate risk–benefit analysis for you, your family, your community, and the world.

CONCEPTUAL Example 1.1 Risk–Benefit Analysis

Heroin is thought by some to be more effective than other drugs for the relief of severe pain. For example, heroin is a legal prescription drug in the United Kingdom. People can become addicted to heroin with continued use in as little as three days, and recreational use often renders addicts unable to function in society. Do a risk–benefit analysis of the use of heroin in treating the pain of **(a)** a young athlete with a broken leg and **(b)** a terminally ill cancer patient.

Solution

a. The heroin would provide the benefit of pain relief, but its use for such purposes has been judged to be too risky by the U.S. Food and Drug Administration. The DQ is low.

b. The heroin would provide the benefit of pain relief. The risk of addiction in a dying person is irrelevant. Heroin is banned for any purpose in the United States. The DQ is uncertain. (Both answers involve judgments that are not clearly scientific; people can differ in their assessments of each.)

▪ 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 a risk–benefit analysis of administering chloramphenicol to **(a)** sick farm animals, whose milk or meat 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 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 in Europe 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 suffered by AIDS patients). Do a risk–benefit analysis of prescribing thalidomide to **(a)** all women and **(b)** women with AIDS.

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]	Approximate Lifetime Odds	Details/Assumptions
All causes	1	1 in 1	We all die of something.
Cigarettes	0.25	1 in 4	Cigarette smoking, 1 pack/day
Heart disease	0.20	1 in 5	Heart attacks, congestive heart failure
All cancers	0.14	1 in 7	All cancers
Motor vehicles	0.01	1 in 100	Death in motor vehicle accident
Home accidents	0.010	1 in 100	Home accident death
Natural forces	0.0003	1 in 3360	Heat, cold, storm, quakes, etc.
Peanut butter (aflatoxin)	0.00060	1 in 1700	4 tablespoons peanut butter a day
Airplane accidents	0.00005	1 in 20,000	Death in aircraft crashes
Terrorist attack[b]	0.00077	1 in 1300	One 9/11-level attack per year
Terrorist attack[c]	0.000077	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. Lifetime odds of dying of a specific cause are calculated by dividing the one-year odds by the life expectancy of a person born in that year.

[b] Unlikely scenario

[c] More reasonable 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 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 psychology. 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.