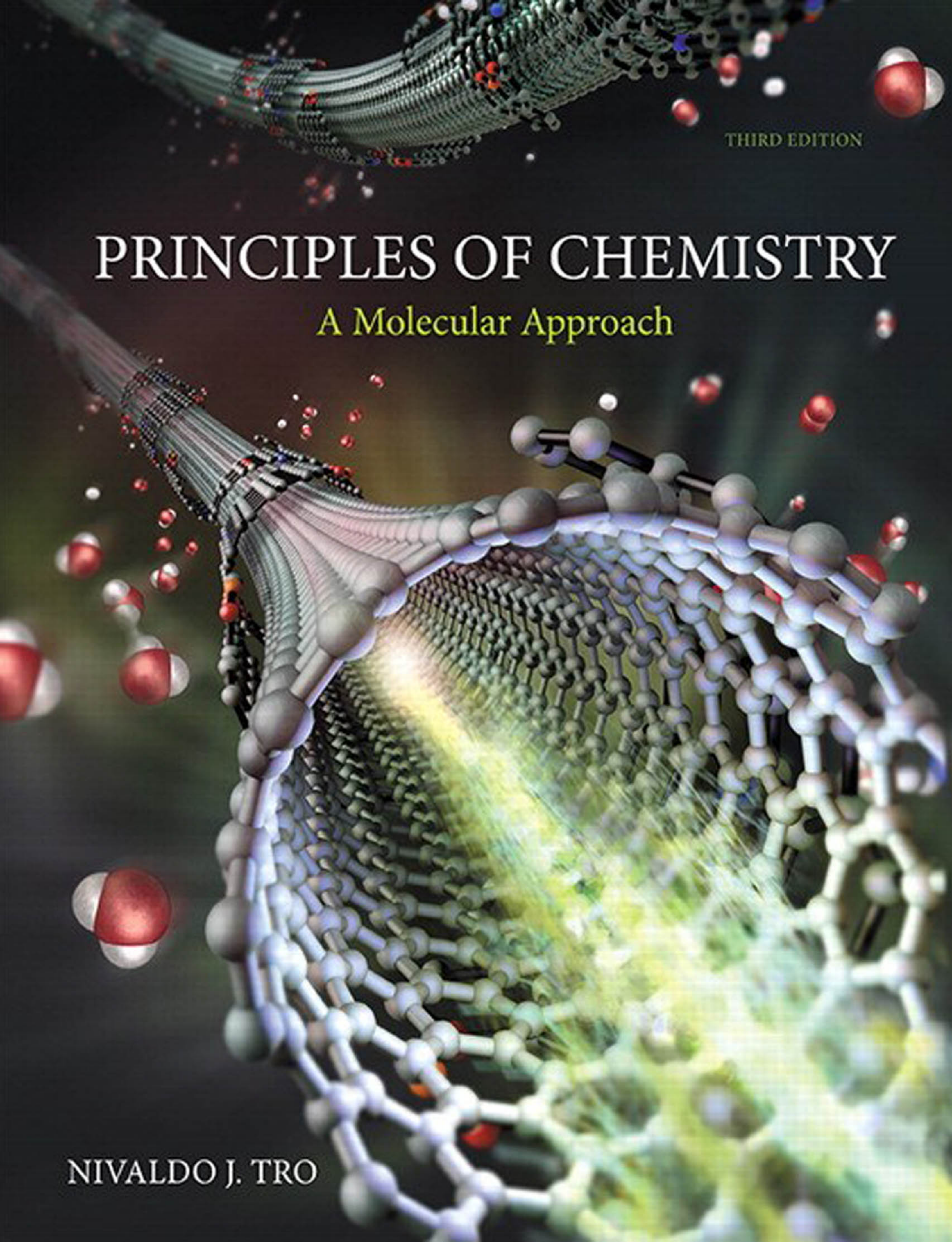

THIRD EDITION

PRINCIPLES OF CHEMISTRY

A Molecular Approach

NIVALDO J. TRO

Main groups | Transition metals | Main groups

Metals | Metalloids | Nonmetals

Period	1A[a] 1	2A 2	3B 3	4B 4	5B 5	6B 6	7B 7	8B 8	8B 9	8B 10	1B 11	2B 12	3A 13	4A 14	5A 15	6A 16	7A 17	8A 18
1	1 **H** 1.008																	2 **He** 4.003
2	3 **Li** 6.94	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
3	11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.06	17 **Cl** 35.45	18 **Ar** 39.95
4	19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.87	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.38	31 **Ga** 69.72	32 **Ge** 72.63	33 **As** 74.92	34 **Se** 78.97	35 **Br** 79.90	36 **Kr** 83.80
5	37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.95	43 **Tc** [98]	44 **Ru** 101.07	45 **Rh** 102.91	46 **Pd** 106.42	47 **Ag** 107.87	48 **Cd** 112.41	49 **In** 114.82	50 **Sn** 118.71	51 **Sb** 121.76	52 **Te** 127.60	53 **I** 126.90	54 **Xe** 131.29
6	55 **Cs** 132.91	56 **Ba** 137.33	57 **La** 138.91	72 **Hf** 178.49	73 **Ta** 180.95	74 **W** 183.84	75 **Re** 186.21	76 **Os** 190.23	77 **Ir** 192.22	78 **Pt** 195.08	79 **Au** 196.97	80 **Hg** 200.59	81 **Tl** 204.38	82 **Pb** 207.2	83 **Bi** 208.98	84 **Po** [208.98]	85 **At** [209.99]	86 **Rn** [222.02]
7	87 **Fr** [223.02]	88 **Ra** [226.03]	89 **Ac** [227.03]	104 **Rf** [261.11]	105 **Db** [262.11]	106 **Sg** [266.12]	107 **Bh** [264.12]	108 **Hs** [269.13]	109 **Mt** [268.14]	110 **Ds** [271]	111 **Rg** [272]	112 **Cn** [285]	113	114 **Fl** [289]	115	116 **Lv** [292]	117*	118

Lanthanide series	58 **Ce** 140.12	59 **Pr** 140.91	60 **Nd** 144.24	61 **Pm** [145]	62 **Sm** 150.36	63 **Eu** 151.96	64 **Gd** 157.25	65 **Tb** 158.93	66 **Dy** 162.50	67 **Ho** 164.93	68 **Er** 167.26	69 **Tm** 168.93	70 **Yb** 173.05	71 **Lu** 174.97
Actinide series	90 **Th** 232.04	91 **Pa** 231.04	92 **U** 238.03	93 **Np** [237.05]	94 **Pu** [244.06]	95 **Am** [243.06]	96 **Cm** [247.07]	97 **Bk** [247.07]	98 **Cf** [251.08]	99 **Es** [252.08]	100 **Fm** [257.10]	101 **Md** [258.10]	102 **No** [259.10]	103 **Lr** [262.11]

[a] The labels on top (1A, 2A, etc.) are common American usage. The labels below these (1, 2, etc.) are those recommended by the International Union of Pure and Applied Chemistry.

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

*Element 117 is currently under review by IUPAC.

List of Elements with Their Symbols and Atomic Masses

Element	Symbol	Atomic Number	Atomic Mass
Actinium	Ac	89	227.03[a]
Aluminum	Al	13	26.98
Americium	Am	95	243.06[a]
Antimony	Sb	51	121.76
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	209.99[a]
Barium	Ba	56	137.33
Berkelium	Bk	97	247.07[a]
Beryllium	Be	4	9.012
Bismuth	Bi	83	208.98
Bohrium	Bh	107	264.12[a]
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.41
Calcium	Ca	20	40.08
Californium	Cf	98	251.08[a]
Carbon	C	6	12.01
Cerium	Ce	58	140.12
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Copernicium	Cn	112	285[a]
Copper	Cu	29	63.55
Curium	Cm	96	247.07[a]
Darmstadtium	Ds	110	271[a]
Dubnium	Db	105	262.11[a]
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	252.08[a]
Erbium	Er	68	167.26
Europium	Eu	63	151.96
Fermium	Fm	100	257.10[a]
Flerovium	Fl	114	289[a]
Fluorine	F	9	19.00
Francium	Fr	87	223.02[a]
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.63
Gold	Au	79	196.97
Hafnium	Hf	72	178.49
Hassium	Hs	108	269.13[a]
Helium	He	2	4.003
Holmium	Ho	67	164.93
Hydrogen	H	1	1.008
Indium	In	49	114.82
Iodine	I	53	126.90
Iridium	Ir	77	192.22
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrencium	Lr	103	262.11[a]
Lead	Pb	82	207.2
Lithium	Li	3	6.94
Livermorium	Lv	116	292[a]
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94

[a] Mass of longest-lived or most important isotope.

[b] The names of these elements have not yet been decided.

Element	Symbol	Atomic Number	Atomic Mass
Meitnerium	Mt	109	268.14[a]
Mendelevium	Md	101	258.10[a]
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.95
Neodymium	Nd	60	144.24
Neon	Ne	10	20.18
Neptunium	Np	93	237.05[a]
Nickel	Ni	28	58.69
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	259.10[a]
Osmium	Os	76	190.23
Oxygen	O	8	16.00
Palladium	Pd	46	106.42
Phosphorus	P	15	30.97
Platinum	Pt	78	195.08
Plutonium	Pu	94	244.06[a]
Polonium	Po	84	208.98[a]
Potassium	K	19	39.10
Praseodymium	Pr	59	140.91
Promethium	Pm	61	145[a]
Protactinium	Pa	91	231.04
Radium	Ra	88	226.03[a]
Radon	Rn	86	222.02[a]
Rhenium	Re	75	186.21
Rhodium	Rh	45	102.91
Roentgenium	Rg	111	272[a]
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Rutherfordium	Rf	104	261.11[a]
Samarium	Sm	62	150.36
Scandium	Sc	21	44.96
Seaborgium	Sg	106	266.12[a]
Selenium	Se	34	78.97
Silicon	Si	14	28.09
Silver	Ag	47	107.87
Sodium	Na	11	22.99
Strontium	Sr	38	87.62
Sulfur	S	16	32.06
Tantalum	Ta	73	180.95
Technetium	Tc	43	98[a]
Tellurium	Te	52	127.60
Terbium	Tb	65	158.93
Thallium	Tl	81	204.38
Thorium	Th	90	232.04
Thulium	Tm	69	168.93
Tin	Sn	50	118.71
Titanium	Ti	22	47.87
Tungsten	W	74	183.84
Uranium	U	92	238.03
Vanadium	V	23	50.94
Xenon	Xe	54	131.293
Ytterbium	Yb	70	173.05
Yttrium	Y	39	88.91
Zinc	Zn	30	65.38
Zirconium	Zr	40	91.22
*[b]		113	284[a]
*[b]		115	288[a]

Principles of Chemistry

A Molecular Approach

THIRD EDITION

NIVALDO J. TRO
Westmont College

PEARSON

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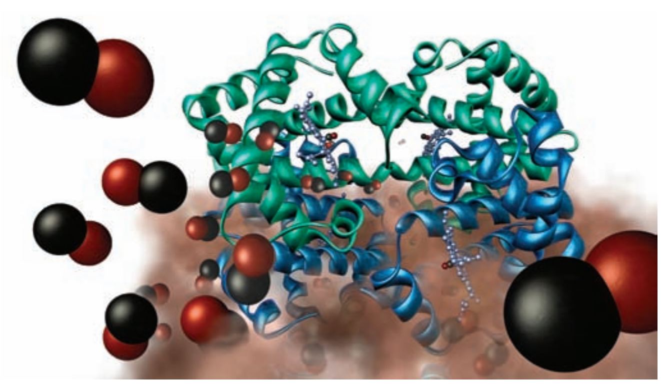
To Michael, Ali, Kyle, and Kaden

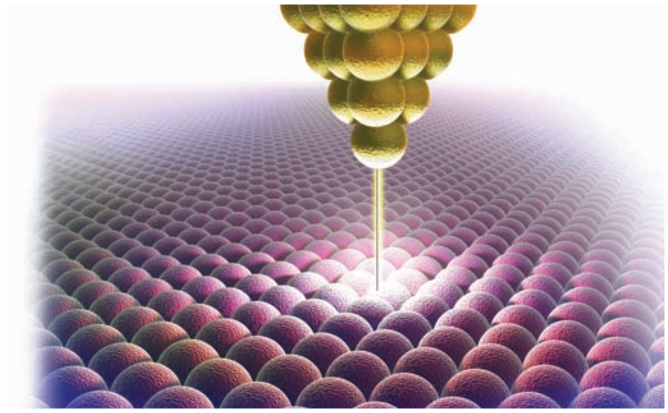
About the Author

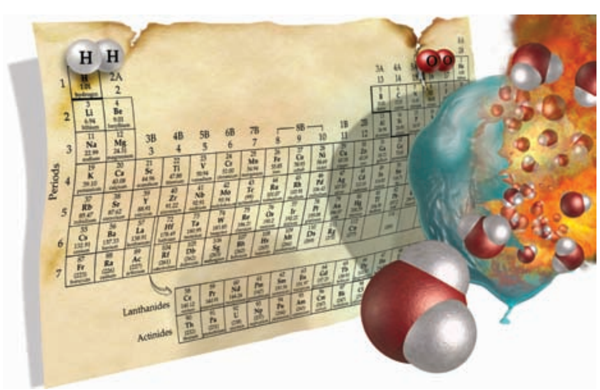
Nivaldo Tro is a professor of chemistry at Westmont College in Santa Barbara, California, where he has been a faculty member since 1990. He received his Ph.D. in chemistry from Stanford University for work on developing and using optical techniques to study the adsorption and desorption of molecules to and from surfaces in ultrahigh vacuum. He then went on to the University of California at Berkeley, where he did postdoctoral research on ultrafast reaction dynamics in solution. Since coming to Westmont, Professor Tro has been awarded grants from the American Chemical Society Petroleum Research Fund, from the Research Corporation, and from the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. He has been honored as Westmont's outstanding teacher of the year three times and has also received the college's outstanding researcher of the year award. Professor Tro lives in Santa Barbara with his wife, Ann, and their four children, Michael, Ali, Kyle, and Kaden. In his leisure time, Professor Tro enjoys mountain biking, surfing, reading to his children, and being outdoors with his family.

Brief Contents

Contents



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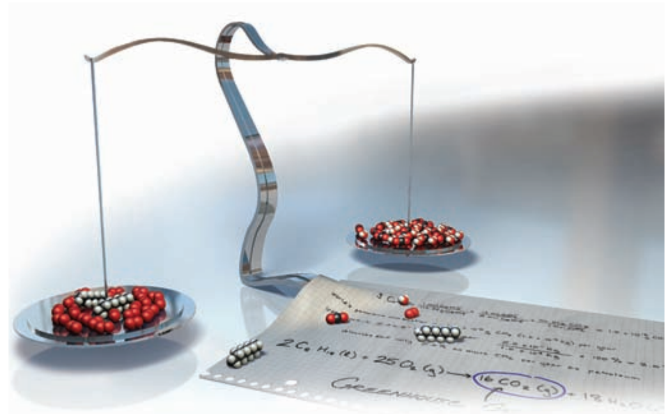
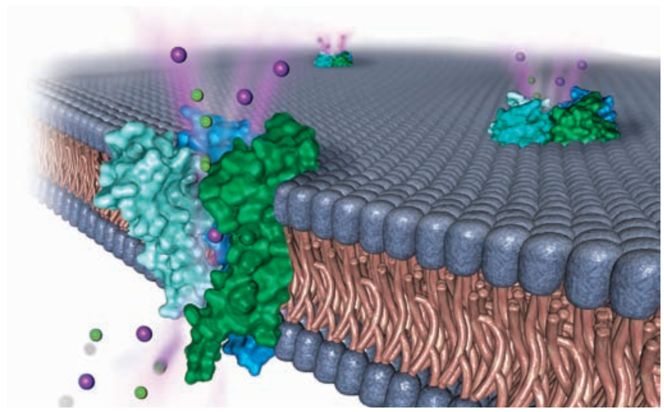
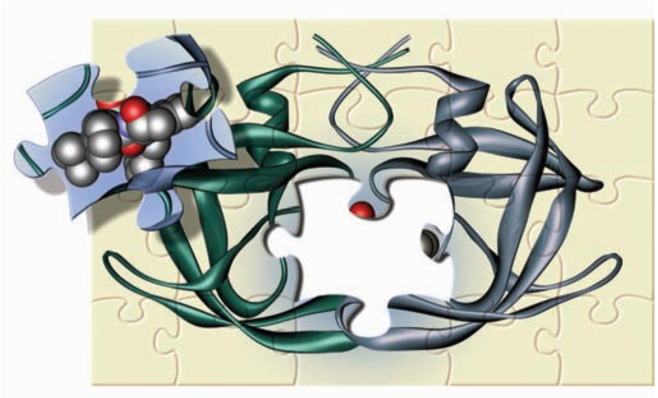
Lanthanides
Actinides

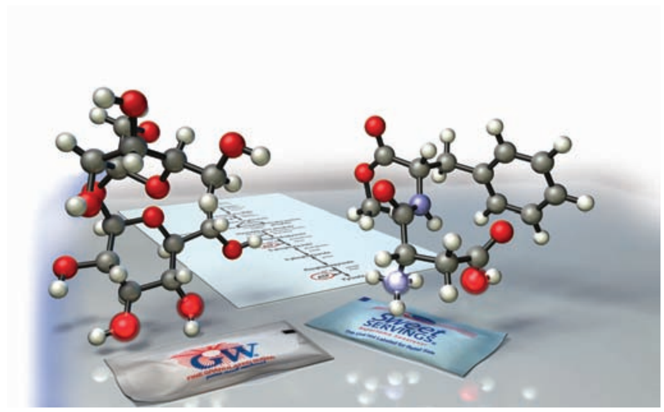


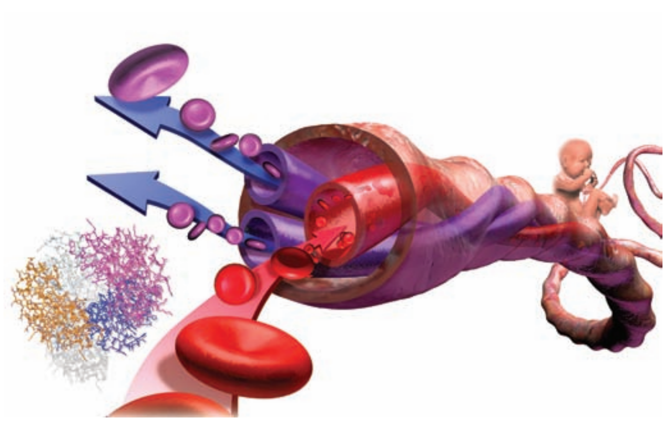

PV=nRT

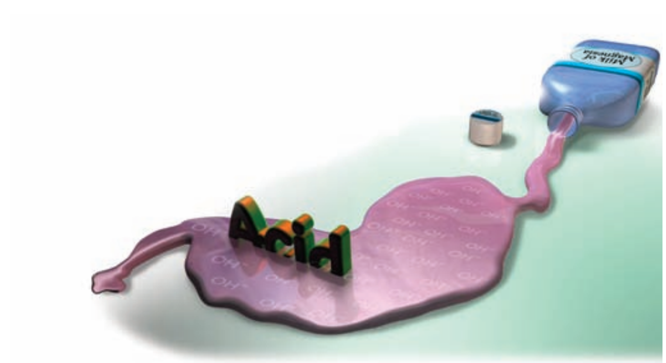

Fe(s) + 3O2(g) → 2 Fe2O3(s)

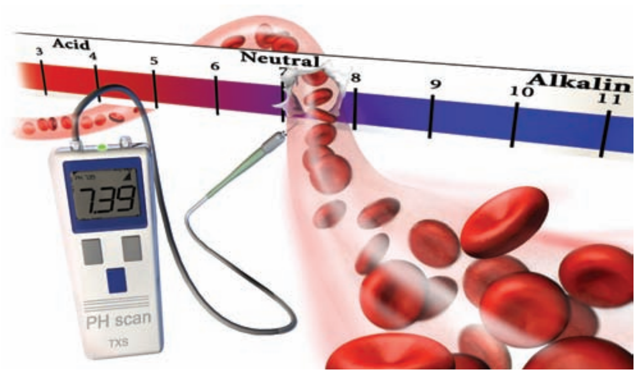




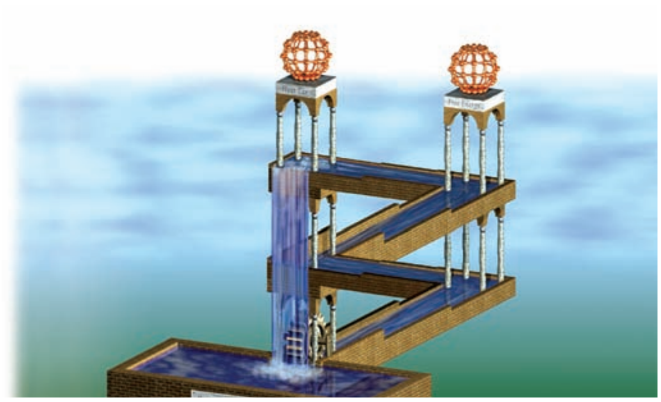




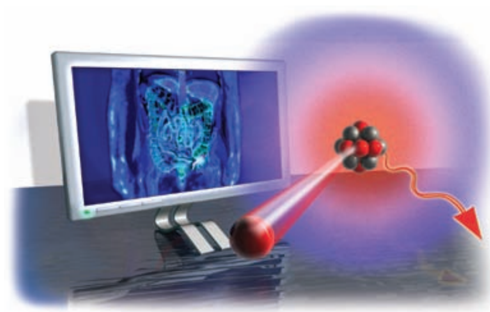

Acid



Acid
Neutral
Alkalin
7.39
PH scan




Cathode reaction:
Overall reaction:
Fuel Cell



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Preface

To the Student

As you begin this course, I invite you to think about your reasons for enrolling in it. Why are you taking general chemistry? More generally, why are you pursuing a college education? If you are like most college students taking general chemistry, part of your answer is probably that this course is required for your major and that you are pursuing a college education so you can get a good job someday. While these are good reasons, I suggest a better one. I think the primary reason for your education is to prepare you to *live a good life*. You should understand chemistry—not for what it can *get* you—but for what it can *do* for you. Understanding chemistry, I believe, is an important source of happiness and fulfillment. Let me explain.

Understanding chemistry helps you to live life to its fullest for two basic reasons. The first is *intrinsic*: Through an understanding of chemistry, you gain a powerful appreciation for just how rich and extraordinary the world really is. The second reason is *extrinsic*: Understanding chemistry makes you a more informed citizen—it allows you to engage with many of the issues of our day. In other words, understanding chemistry makes *you* a deeper and richer person and makes your country and the world a better place to live. These reasons have been the foundation of education from the very beginnings of civilization.

How does chemistry help prepare you for a rich life and conscientious citizenship? Let me explain with two examples. My first one comes from the very first page of Chapter 1 of this book. There, I ask the following question: What is the most important idea in all of scientific knowledge? My answer to that question is this: **The properties of matter are determined by the properties of molecules and atoms**. That simple statement is the reason I love chemistry. We humans have been able to study the substances that compose the world around us and explain their behavior by reference to particles so small that they can hardly be imagined. If you have never realized the remarkable sensitivity of the world we *can* see to the world we *cannot*, you have missed out on a fundamental truth about our universe. To have never encountered this truth is like never having read a play by Shakespeare or seen a sculpture by Michelangelo—or, for that matter, like never having discovered that the world is round. It robs you of an amazing and unforgettable experience of the world and the human ability to understand it.

My second example demonstrates how science literacy helps you to be a better citizen. Although I am largely sympathetic to the environmental movement, a lack of science literacy within some sectors of that movement, and the resulting anti-environmental backlash, creates confusion that impedes real progress and opens the door to what could be misinformed policies. For example, I have heard conservative pundits say that volcanoes emit more carbon dioxide—the most significant greenhouse gas—than does petroleum combustion. I have also heard a liberal environmentalist say that we have to stop using hairspray because it is causing holes in the ozone layer that will lead to global warming. Well, the claim about volcanoes emitting more carbon dioxide than petroleum combustion can be refuted by the basic tools you will learn to use in Chapter 4 of this book. We can easily show that volcanoes emit only 1/50th as much carbon dioxide as petroleum combustion. As for hairspray depleting the ozone layer and thereby leading to global warming: The chlorofluorocarbons that deplete ozone have been banned from hairspray since 1978, and ozone depletion has nothing to do with global warming anyway. People with special interests or axes to grind can conveniently distort the truth before an ill-informed public, which is why we all need to be knowledgeable.

So this is why I think you should take this course. Not just to satisfy the requirement for your major, and not just to get a good job someday, but also to help you to lead a fuller life and to make the world a little better for everyone. I wish you the best as you embark on the journey to understand the world around you at the molecular level. The rewards are well worth the effort.

To the Professor

First and foremost, thanks to all of you who adopted this book in its first and second editions. You helped to make this book successful and I am grateful beyond words. Second, I have listened carefully to your feedback on the previous edition. The changes you see in this edition are a direct result of your input, as well as my own experience in using the book in my general chemistry courses. If you have acted as a reviewer or have contacted me directly, you are likely to see your suggestions reflected in the changes I have made. The goal of this edition remains the same: *to present a rigorous and accessible treatment of general chemistry in the context of relevance.*

Teaching general chemistry would be much easier if all of our students had exactly the same level of preparation and ability. But alas, that is not the case. Even though I teach at a relatively selective institution, my courses are populated with students with a range of backgrounds and abilities in chemistry. The challenge of successful teaching, in my opinion, is therefore figuring out how to instruct and challenge the best students while not losing those with lesser backgrounds and abilities. My strategy has always been to set the bar relatively high, while at the same time providing the motivation and support necessary to reach the high bar. That is exactly the philosophy of this book. We do not have to compromise away rigor in order to make chemistry accessible to our students. In this book, I have worked hard to combine rigor with accessibility—to create a book that does not dilute the content, yet can be used and understood by any student willing to put in the necessary effort.

Principles of Chemistry: A Molecular Approach is first a *student-oriented* book. My main goal is to motivate students and get them to achieve at the highest possible level. As we all know, many students take general chemistry because it is a requirement; they do not see the connection between chemistry and their lives or their intended careers. *Principles of Chemistry: A Molecular Approach* strives to make those connections consistently and effectively. Unlike other books, which often teach chemistry as something that happens only in the laboratory or in industry, this book teaches chemistry in the context of relevance. It shows students *why* chemistry is important to them, to their future careers, and to their world.

Second, *Principles of Chemistry: A Molecular Approach* is a *pedagogically-driven* book. In seeking to develop problem-solving skills, a consistent approach (Sort, Strategize, Solve, and Check) is applied, usually in a two- or three-column format. In the two-column format, the left column shows the student how to analyze the problem and devise a solution strategy. It also lists the steps of the solution, explaining the rationale for each one, while the right column shows the implementation of each step. In the three-column format, the left column outlines a general procedure for solving an important category of problems that is then applied to two side-by-side examples. This strategy allows students to see both the general pattern and the slightly different ways in which the procedure may be applied in differing contexts. The aim is to help students understand both the *concept of the problem* (through the formulation of an explicit conceptual plan for each problem) and the *solution to the problem.*

Third, *Principles of Chemistry: A Molecular Approach* is a *visual* book. Wherever possible, images are used to deepen the student's insight into chemistry. In developing chemical principles, multipart images help to show the connection between everyday processes visible to the unaided eye and what atoms and molecules are actually doing. Many of these images have three parts: macroscopic, molecular, and symbolic. This combination helps students to see the relationships between the formulas they write down on paper (symbolic), the world they see around them (macroscopic), and the atoms and molecules that compose that world (molecular). In addition, most figures are designed to teach rather than just to illustrate. They are rich with annotations and labels intended to help the student grasp the most important processes and the principles that underlie them. The resulting images contain significant amounts of information but are also uncommonly clear and quickly understood.

Fourth, *Principles of Chemistry: A Molecular Approach* is a *"big picture"* book. At the beginning of each chapter, a short introduction helps students to see the key relationships between the different topics they are learning. Through focused and concise narrative, I strive to make the basic ideas of every chapter clear to the student. Interim summaries are provided at selected spots in the narrative, making it easier to grasp (and review) the main points of important discussions. And to make sure that students never lose sight of the forest for the trees, each chapter includes several *Conceptual Connections*, which ask them to think about concepts and solve problems without doing any math. I want students to learn the concepts, not just plug numbers into equations to churn out the right answer.

Principles of Chemistry: A Molecular Approach is, lastly, a book that delivers the core of the standard chemistry curriculum, without sacrificing depth of coverage. Through our research, we have determined the topics that most faculty do not teach and we have eliminated them. When writing a brief book, the temptation is great to cut out the sections that show the excitement and relevance of chemistry; *we have not done that here.* Instead, we have cut out pet topics that are often included in books simply to satisfy a small minority of the market. We have also eliminated extraneous material that does not seem central to the discussion. The result is a lean book that covers core topics in depth, while still demonstrating the relevance and excitement of these topics.

I hope that this book supports you in your vocation of teaching students chemistry. I am increasingly convinced of the importance of our task. Please feel free to email me with any questions or comments about the book.

Nivaldo J. Tro
tro@westmont.edu

What's New in This Edition?

The third edition has been extensively revised and contains many more small changes than I can detail here. Below is a list of the most significant changes from the previous edition.

- More robust media components have been added, including 80 Interactive Worked Examples, 39 Key Concept Videos, 14 additional Pause & Predict videos, 33 PHET simulations, and 5 new Mastering simulations with tutorials.
- Each chapter now has a 10–15 question multiple-choice end-of-chapter Self-Assessment Quiz. Since many colleges and universities use multiple-choice exams, and because standardized final exams are often multiple choice, students can use these quizzes to both assess their knowledge of the material in the chapter and to prepare for exams. These quizzes are also available on mobile devices.
- Approximately 100 new end-of-chapter group work questions have been added to encourage small group work in or out of the classroom.
- Approximately 45 new end-of-chapter problems have been added.
- New conceptual connections have been added and many from the previous edition have been modified. In addition, to support active, in class, learning, these questions are now available in Learning Catalytics.
- All data have been updated to the most recent available. See for example:

  Section 1.7 *The Reliability of a Measurement* in which the data in the table of carbon monoxide concentrations in Los Angeles County (Long Beach) have been updated.

  Figure 4.2 *Carbon Dioxide Concentrations in the Atmosphere* is updated to include information through 2013.

  Figure 4.3 *Global Temperature* is updated to include information through 2013.

  Figure 4.19 *U.S. Energy Consumption* is updated to include the most recent available information.

- Many figures and tables have been revised for clarity. See, for example:

  Figure 3.6 *Metals Whose Charge Is Invariant* in Section 3.5. This replaces Table 3.2 *Metals Whose Charge Is Invariant from One Compound to Another*.

  The weather map in Section 5.2 has been replaced, and the caption for the weather map has been simplified and linked more directly to the text discussion.

  Figure 7.3 *Components of White Light* has been replaced with a corrected image of light passing through a prism.

  Figure 7.4 *The Color of an Object* and Figure 7.17 *The Quantum-Mechanical Strike Zone* both have updated photos.

  The orbital diagram figure in Section 7.5 *Quantum Mechanics and the Atom* that details the various principal levels and sublevels has been replaced with an updated version that is more student-friendly and easier to navigate.

  Figure 8.2 *Shielding and Penetration* is modified so that there is a clear distinction between parts a and b.

  Figure 10.15 *Molecular Orbital Energy Diagrams for Second-Row Homonuclear Diatomic Molecules* now has magnetic properties and valence electron configuration information.

  Figure 12.10 *Solubility and Temperature*. Data for Na_2SO_4 have been deleted from the graph, and data $Ce_2(SO_4)_3$ have been added to the graph.

  Figure 13.11 *Thermal Energy Distribution* is modified. It is now noted in the caption that E_a is a constant and does not depend on temperature; new notations have also been added to the figure.

  Table 15.5 *Acid Ionization Constants for Some Monoprotic Weak Acids at 25 °C* has been modified to include pK_a values.

  The unnumbered photo of a fuel cell car in Section 18.1 *Pulling the Plug on the Power Grid* has been replaced with an updated image of a newer fuel cell car.
- In Section 10.5 and throughout Chapter 11, the use of electrostatic potential maps has been expanded. See, for example, Figures 11.6, 11.7, 11.9, and 11.10.
- In Section 10.8 *Molecular Orbital Theory: Electron Delocalization* in the subsection on *Linear Combination of Atomic Orbitals (LCAO)*, a discussion of molecular orbital electron configuration has been added.
- New chapter-opening art, briefer introductory material, and a new first section (11.1 *Water, No Gravity*) replace Section 11.1.
- In Section 13.4 *The Integrated Rate Law: The Dependence of Concentration on Time*, the derivation to integrate the differential rate law to obtain the first-order integrated rate law is now shown in a margin note.
- The format for all the ICE tables is new in Chapters 14, 15, and 16; the format has been modified to make them easier to read.
- A new section entitled *The Titration of a Polyprotic Acid* has been added to Section 16.4 *Titrations and Curves*. Content includes new Figure 16.8 *Titration Curve: Diprotic Acid with Strong Base*.
- Some new in-chapter examples have been added, including Example 4.14 *Writing Equations for Acid–Base Reactions Involving a Weak Acid* and Example 9.9 *Drawing Resonance Structures and Assigning Formal Charge for Organic Compounds*.

Acknowledgments

The book you hold in your hands bears my name on the cover, but I am really only one member of a large team that carefully crafted this book. Most importantly, I thank my editor, Terry Haugen, who has become a friend and colleague. Terry is a skilled and competent editor. He has given me direction, inspiration, and most importantly, loads of support. I am just as grateful for my program manager, Jessica Moro, and project manager, Beth Sweeten, who have worked tirelessly behind the scenes to bring this project to completion. I continue to be grateful for Jennifer Hart in her new role overseeing development. Jennifer, your guidance and wisdom are central to the success of my projects, and I am eternally grateful. I am also grateful to Caitlin Falco who helped with organizing reviews, as well as numerous other tasks associated with keeping the team running smoothly. I also thank Erin Mulligan, who has now worked with me on many projects. Erin is an outstanding developmental editor who not only worked with me on crafting and thinking through every word but is now also a friend and fellow foodie. I am also grateful to Adam Jaworski. Adam has become a fantastic leader at Pearson and a friend to me. Thanks also to Dave Theisen, who has been selling my books for 15 years and has become a great friend. Dave, I appreciate your tireless efforts, your professionalism, and your in-depth knowledge of my work. And of course, I am continually grateful for Paul Corey, with whom I have now worked for over 14 years and a dozen books. Paul is a man of incredible energy and vision, and it is my great privilege to work with him. Paul told me many years ago (when he first signed me on to the Pearson team) to dream big, and then he provided the resources I needed to make those dreams come true. *Thanks, Paul.* I would also like to thank my first editor at Pearson, Kent Porter-Hamann. Kent and I spent many good years together writing books, and I continue to miss her presence in my work.

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11 Liquids, Solids, and Intermolecular Forces

It's a wild dance floor there at the molecular level.
—Roald Hoffmann (1937–)

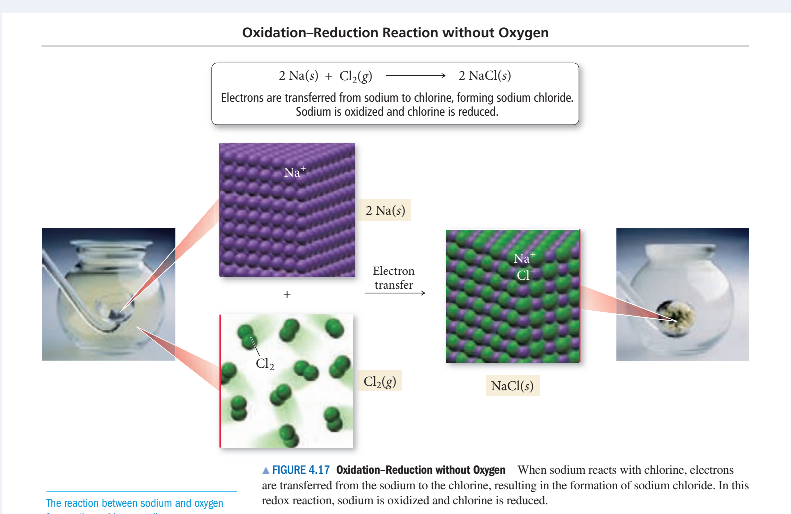
In the absence of gravity (such as in a space station), a sample of water sticks together to form a perfect sphere. This behavior is a direct result of intermolecular forces—attractive forces that exist among the particles that compose matter.

WE LEARNED IN CHAPTER 1 THAT matter exists primarily in three states: solid, liquid, and gas. In Chapter 5, we examined the gas state. In this chapter we turn to the solid and liquid states, known collectively as the condensed states (or condensed phases). The solid and liquid states are more similar to each other than they are to the gas state. In the gas state, the constituent particles—atoms or molecules—are separated by large distances and do not interact with each other very much. In the condensed states, the constituent particles are close together and exert moderate to strong attractive forces on one another. Whether a substance is a solid, liquid, or gas at room temperature depends on the magnitude of the attractive forces among the constituent particles. In this chapter, we will see how the properties of a particular atom or molecule determine the magnitude of those attractive forces.

11.1 Water, No Gravity

In the space station there are no spills. When an astronaut squeezes a full water bottle, the water squirts out like it does on Earth, but instead of falling to the floor and forming a puddle, the water sticks together to form a floating, oscillating, blob of water. Over time, the blob stops oscillating and forms a nearly perfect sphere. Why?

429



▲ FIGURE 4.17 **Oxidation–Reduction without Oxygen** When sodium reacts with chlorine, electrons are transferred from the sodium to the chlorine, resulting in the formation of sodium chloride. In this redox reaction, sodium is oxidized and chlorine is reduced.

Visualizing Chemistry

Student-friendly, multipart images include macroscopic, molecular, and symbolic perspectives with the goal of connecting you to what you see and experience (macroscopic) with the molecules responsible for that world (molecular) and with the way chemists represent those molecules (symbolic). Illustrations include extensive labels and annotations to highlight key elements and to help differentiate the most critical information (white box) to secondary information (beige box).

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A unique yet consistent step-by-step format encourages logical thinking throughout the problem-solving process rather than simply memorizing formulas.

Icons appear next to examples indicating a digital version is available in the etext and on mobile devices via a QR code located here, and on the back cover of your textbook.

EXAMPLE 4.1 Stoichiometry

During photosynthesis, plants convert carbon dioxide and water into glucose ($C_6H_{12}O_6$) according to the reaction:

$$6\ CO_2(g) + 6\ H_2O(l) \xrightarrow{\text{sunlight}} 6\ O_2(g) + C_6H_{12}O_6(aq)$$

Suppose a particular plant consumes 37.8 g CO_2 in one week. Assuming that there is more than enough water present to react with all of the CO_2, what mass of glucose (in grams) can the plant synthesize from the CO_2?

SORT The problem gives the mass of carbon dioxide and asks you to find the mass of glucose that can be produced.

GIVEN 37.8 g CO_2
FIND g $C_6H_{12}O_6$

STRATEGIZE The conceptual plan follows the general pattern of mass A → amount A (in moles) → amount B (in moles) → mass B. From the chemical equation, you can deduce the relationship between moles of carbon dioxide and moles of glucose. Use the molar masses to convert between grams and moles.

CONCEPTUAL PLAN

$$\text{g } CO_2 \xrightarrow{\frac{1\text{ mol } CO_2}{44.01\text{ g } CO_2}} \text{mol } CO_2 \xrightarrow{\frac{1\text{ mol } C_6H_{12}O_6}{6\text{ mol } CO_2}} \text{mol } C_6H_{12}O_6 \xrightarrow{\frac{180.16\text{ g } C_6H_{12}O_6}{1\text{ mol } C_6H_{12}O_6}} \text{g } C_6H_{12}O_6$$

RELATIONSHIPS USED
molar mass $CO_2 = 44.01$ g/mol
6 mol CO_2 : 1 mol $C_6H_{12}O_6$
molar mass $C_6H_{12}O_6 = 180.16$ g/mol

SOLVE Follow the conceptual plan to solve the problem. Begin with g CO_2 and use the conversion factors to arrive at g $C_6H_{12}O_6$.

SOLUTION

$$37.8\text{ g } CO_2 \times \frac{1\text{ mol } CO_2}{44.01\text{ g } CO_2} \times \frac{1\text{ mol } C_6H_{12}O_6}{6\text{ mol } CO_2} \times \frac{180.16\text{ g } C_6H_{12}O_6}{1\text{ mol } C_6H_{12}O_6} = 25.8\text{ g } C_6H_{12}O_6$$

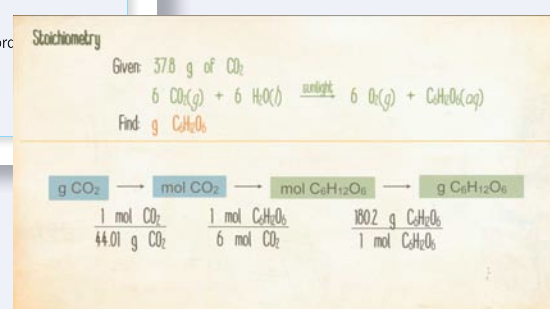
CHECK The units of the answer are correct. The magnitude of the answer (25.8 g) is less than the initial mass of CO_2 (37.8 g). This is reasonable because each carbon in CO_2 has two oxygen atoms associated with it, while in $C_6H_{12}O_6$ each carbon has only one oxygen atom associated with it and two hydrogen atoms, which are much lighter than oxygen. Therefore the mass of glucose produced should be less than the mass of carbon dioxide for this reaction.

FOR PRACTICE 4.1

Magnesium hydroxide, the active ingredient in milk of magnesia, neutralizes stomach acid, primarily HCl, accord reaction:

$$Mg(OH)_2(aq) + 2\ HCl(aq) \rightarrow 2\ H_2O(l) + MgCl_2(aq)$$

What mass of HCl, in grams, is neutralized by a dose of milk of magnesia containing 3.26 g $Mg(OH)_2$?



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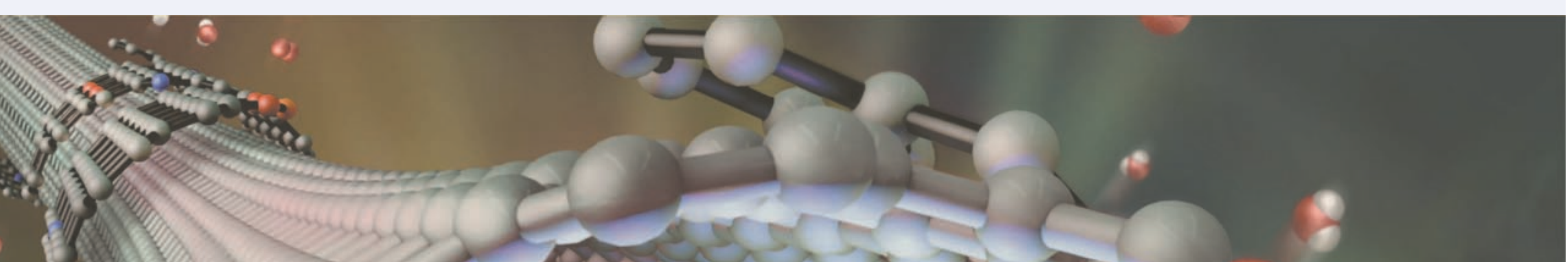
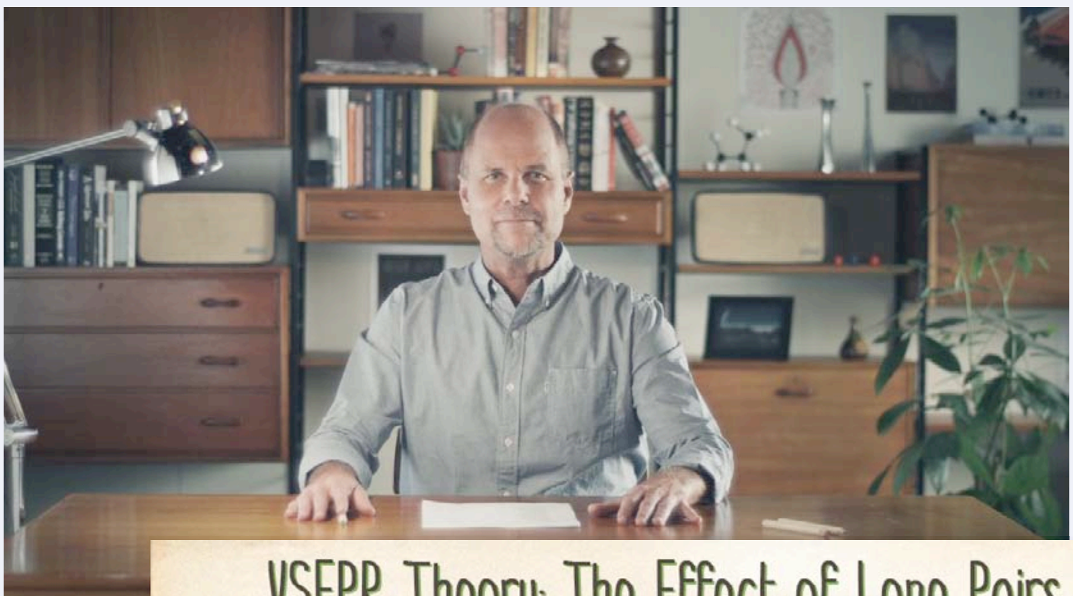


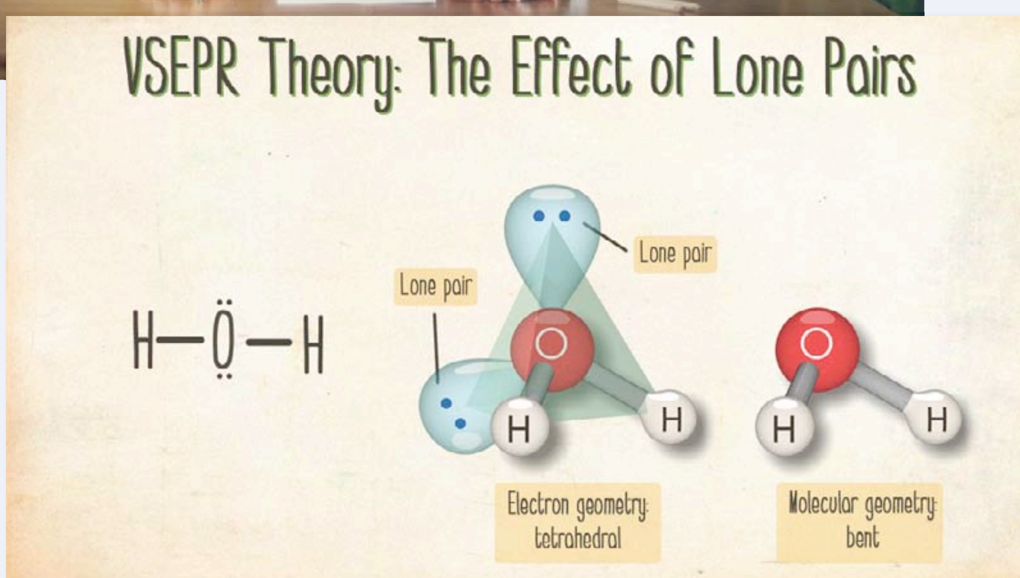
A Focus on Conceptual Understanding

Key Concept Videos

NEW! 39 Key Concept Videos combine artwork from the textbook with both 2D and 3D animations to create a dynamic on-screen viewing and learning experience. These short videos include narration and brief live-action clips of author Niva Tro explaining the key concepts of each chapter.

KEY CONCEPT VIDEO
VSEPR Theory: The Effect of Lone Pairs





Conceptual Connections

Conceptual Connections are strategically placed to reinforce conceptual understanding of the most complex concepts.

CONCEPTUAL CONNECTION 5.5 PRESSURE AND NUMBER OF MOLES

Nitrogen and hydrogen react to form ammonia according to the equation:

$$N_2(g) + 3\,H_2(g) \rightleftharpoons 2\,NH_3(g)$$

Consider the representations shown here of the initial mixture of reactants and the resulting mixture after the reaction has been allowed to react for some time.

If the volume is kept constant, and nothing is added to the reaction mixture, what happens to the ... course of the reaction?

(a) The pressure increases.
(b) The pressure decreases.
(c) The pressure does not change.

CONCEPTUAL CONNECTION 17.7 K AND ΔG°_{rxn}

The reaction $A(g) \rightleftharpoons B(g)$ has an equilibrium constant that is less than one. What can you conclude about ΔG°_{rxn} for the reaction?

(a) $\Delta G^\circ_{rxn} = 0$ **(b)** $\Delta G^\circ_{rxn} < 0$ **(c)** $\Delta G^\circ_{rxn} > 0$

Enhanced End-of-Chapter Material

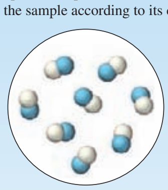
NEW! Self Assessment Quizzes contain 10–15 multiple-choice questions, authored in the ACS-exam and MCAT style to help students optimize the use of quizzing to improve their understanding and class performance.

The Self Assessment Quizzes are also assignable in MasteringChemistry and contain wrong-answer feedback as well as links to the eText.

Self-Assessment QUIZ

Q1. A chemist mixes sodium with water and witnesses a violent reaction between the metal and water. This is best classified as:
a. an observation **b.** a law
c. a hypothesis **d.** a theory

Q2. This image represents a particulate view of a sample of matter. Classify the sample according to its composition.



a. The sample is a pure element.
b. The sample is a homogeneous mixture.
c. The sample is a compound.
d. The sample is a heterogeneous mixture.

Q3. Which change is a physical change?
a. wood burning **b.** iron rusting
c. dynamite exploding **d.** gasoline evaporating

Q4. Which property of rubbing alcohol is a chemical property?
a. its density (0.786 g/cm^3)
b. its flammability
c. its boiling point (82.5 °C)
d. its melting point (−89 °C)

Q5. Convert 85.0 °F to K.
a. 181.1 K **b.** 358 K **c.** 29.4 K **d.** 302.6 K

Q6. Express the quantity 33.2×10^{-4} m in mm.
a. 33.2 mm **b.** 3.32 mm
c. 0.332 mm **d.** 3.32×10^{-6} mm

Q7. Determine the mass of a 1.75 L sample of a liquid that has a density of 0.921 g/mL.
a. 1.61×10^3 g **b.** 1.61×10^{-3} g
c. 1.90×10^3 g **d.** 1.90×10^{-3} g

Q8. Perform the calculation to the correct number of significant figures.

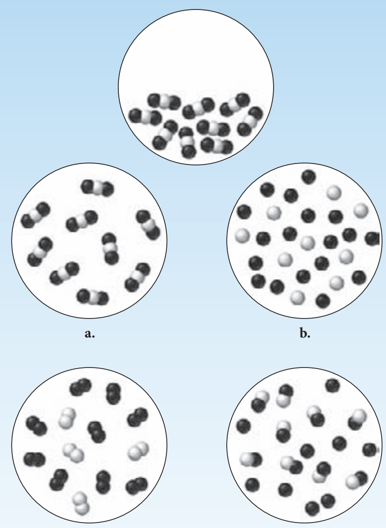
$$43.998 \times 0.00552/2.002$$

a. 0.121 **b.** 0.12 **c.** 0.12131 **d.** 0.1213

Q9. Perform the calculation to the correct number of significant figures.
$(8.01 - 7.50)/3.002$
a. 0.1698867 **b.** 0.17 **c.** 0.170 **d.** 0.1700

Q10. Convert 1285 cm^2 to m^2.
a. 1.285×10^7 m^2
b. 12.85 m^2
c. 0.1285 m^2
d. 1.285×10^5 m^2

Q11. The first diagram shown here depicts a compound in its liquid state. Which of the diagrams that follow best depicts the compound after it has evaporated into a gas?



Q12. Three samples, each of a different substance, are weighed and their volume is measured. The results are tabulated here. List the substances in order of decreasing density.

	Mass	Volume
Substance I	10.0 g	10.0 mL
Substance II	10.0 kg	12.0 L
Substance III	12.0 mg	10.0 μL

a. III > II > I **b.** I > II > III
c. III > I > II **d.** II > I > III

Q13. A solid metal sphere has a radius of 3.53 cm and a mass of 1.796 kg. What is the density of the metal in g/cm^3? (The volume of a sphere is $V = \frac{4}{3}\pi r^3$.)
a. 34.4 g/cm^3 **b.** 0.103 g/cm^3
c. 121 g/cm^3 **d.** 9.75 g/cm^3

Q14. A European automobile's gas mileage is 22 km/L. Convert this quantity to miles per gallon.
a. 9.4 mi/gal **b.** 1.3×10^2 mi/gal
c. 52 mi/gal **d.** 3.6 mi/gal

Q15. A wooden block has a volume of 18.5 in^3. What is its volume in cm^3?
a. 303 cm^3 **b.** 47.0 cm^3
c. 1.13 cm^3 **d.** 7.28 cm^3

Answers: 1:a; 2:c; 3:d; 4:b; 5:d; 6:b; 7:a; 8:a; 9:b; 10:c; 11:a; 12:c; 13:d; 14:c; 15:a

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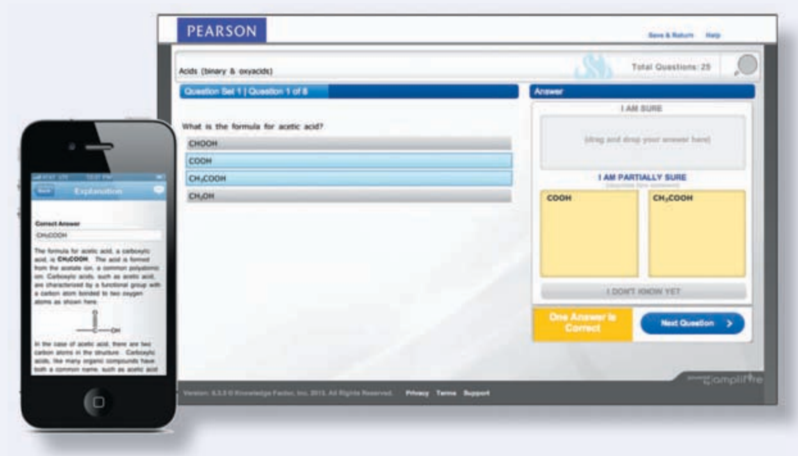

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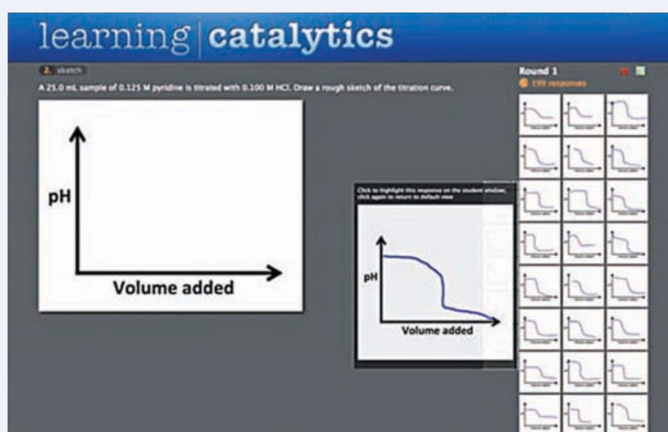

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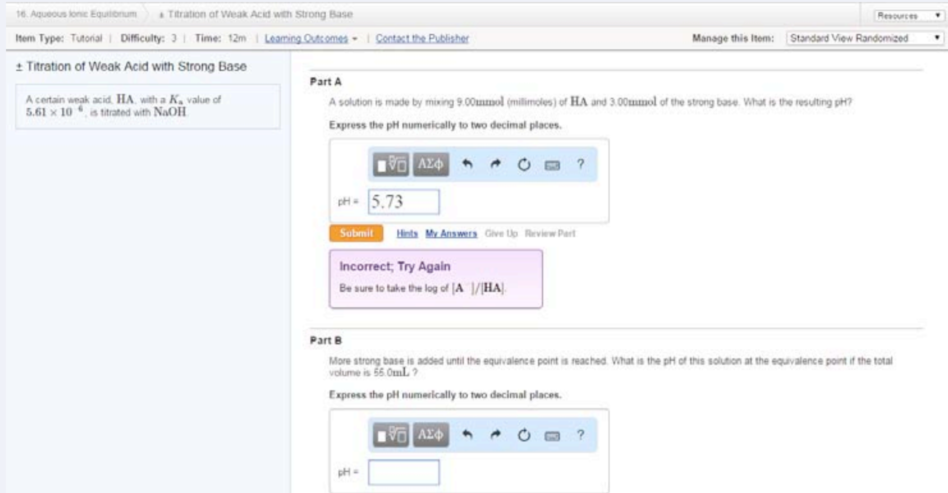

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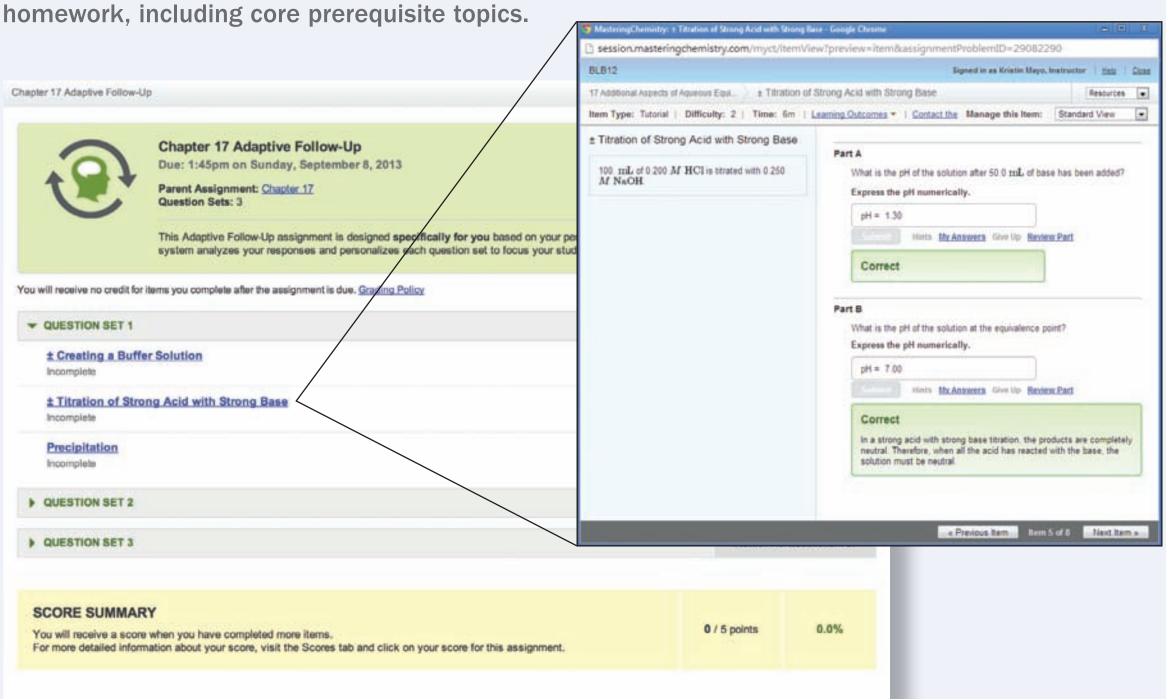

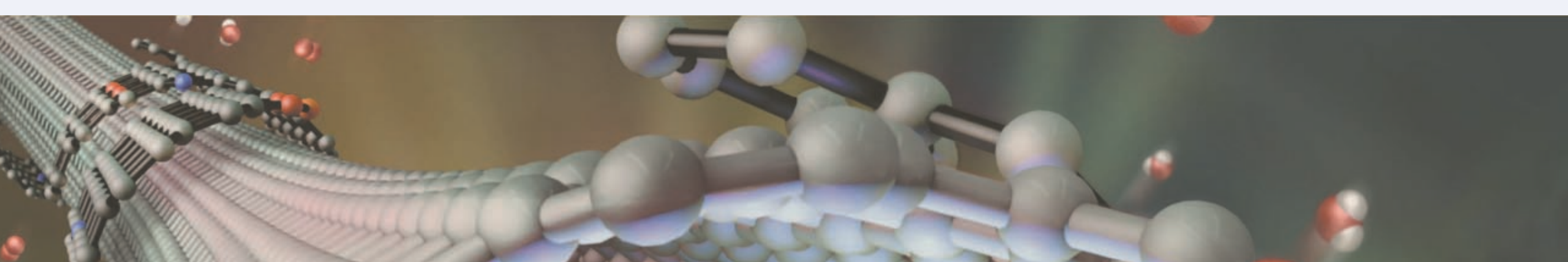

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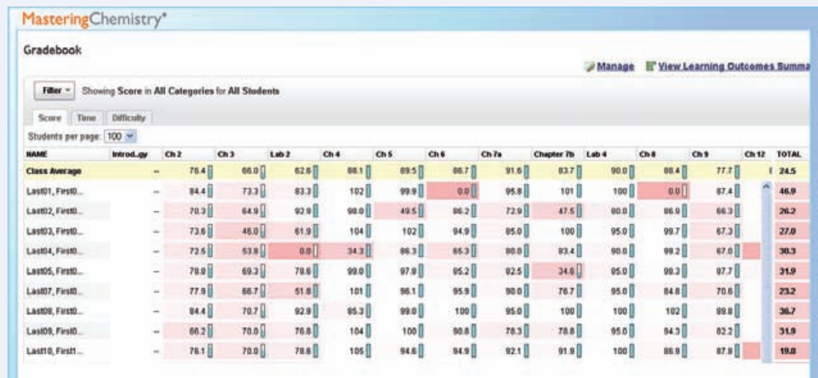

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This screen provides you with your favorite diagnostics. With a single click, charts summarize the most difficult problems, vulnerable students, grade distribution, and even score improvement over the course.

Learning Outcomes

Let Mastering do the work in tracking student performance against your learning outcomes:

- **Add your own or use the publisher provided learning outcomes.**
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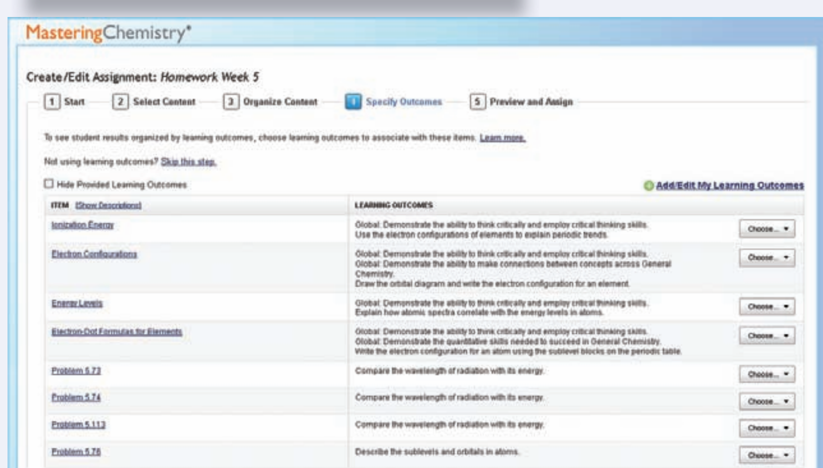
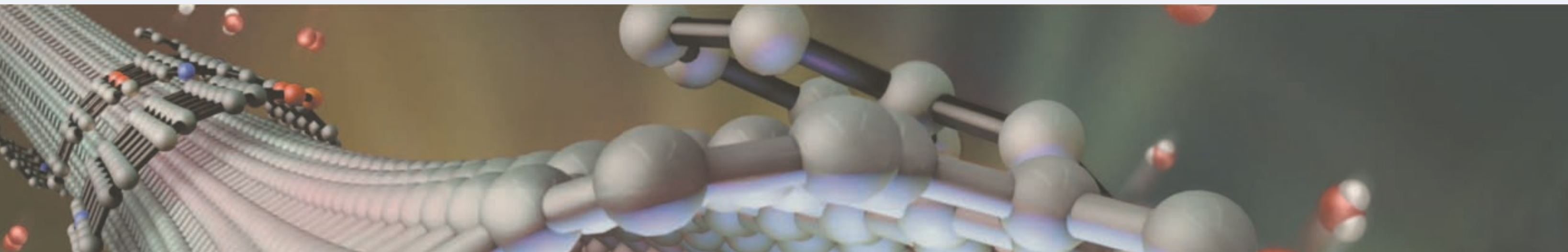


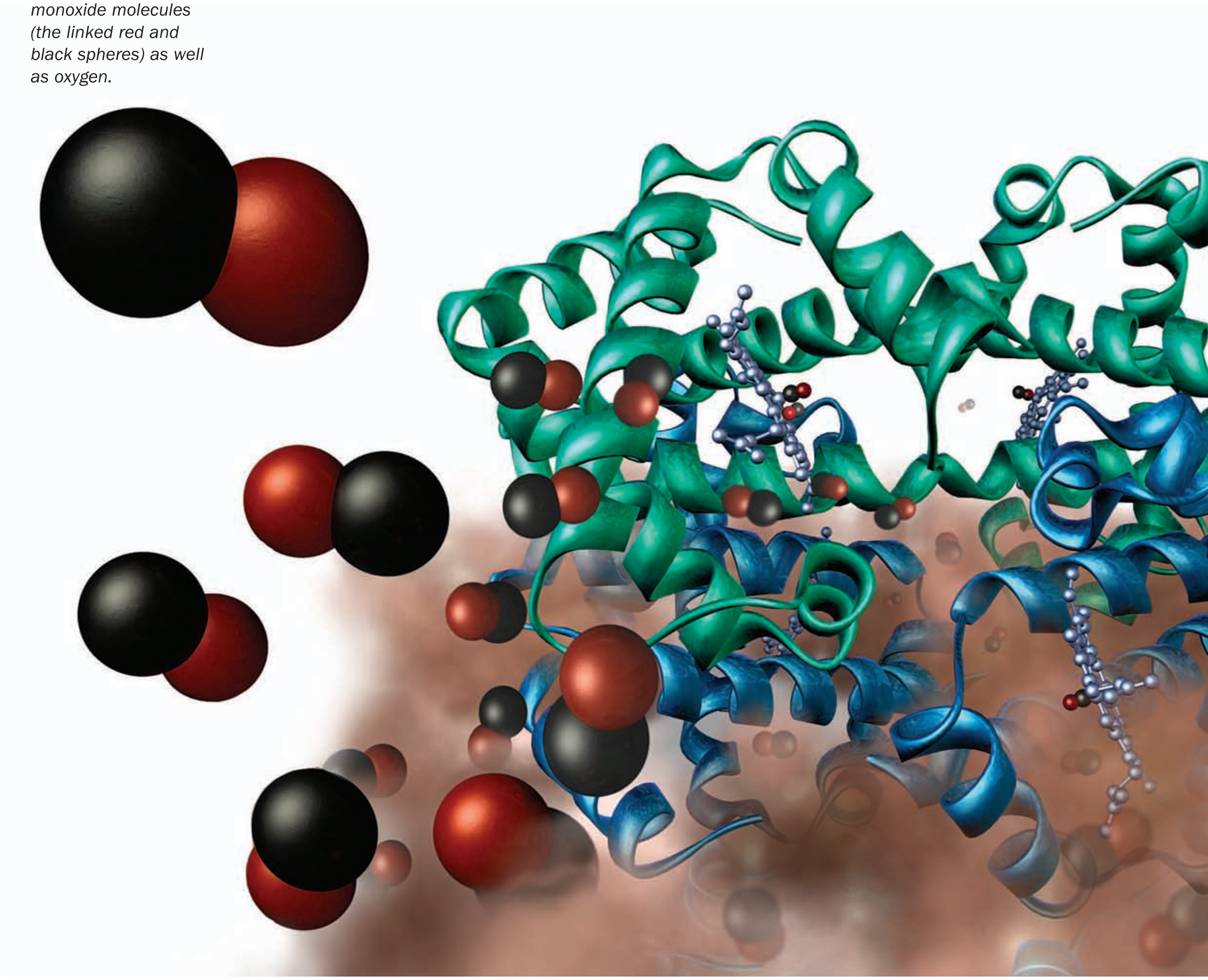
Instructor and Student Resources

Resource	Available in Print	Available Online	Instructor or Student Resource	Description
Selected Solutions Manual 0133889416/ 9780133889413	✓		Student	Prepared by Kathy Shaginaw, the selected solutions manual for students contains complete, step-by-step solutions to selected odd-numbered, end-of-chapter problems.
Selected Solutions Manual, Books a la Carte Edition 013392825X/ 9780133928259	✓		Student	The selected solutions manual for students contains complete, step-by-step solutions to selected odd-numbered, end-of-chapter problems.
Instructor Resource Center 013389066X/ 9780133890662		✓	Instructor	This resource contains the following: • All illustrations, tables, and photos from the text in JPEG format • Three pre-built PowerPoint Presentations (lecture, worked examples, and images) • TestGen computerized software with the TestGen version of the Testbank • Word files of the Test Item File
Instructor Resource Manual 0133889394/ 9780133889390		✓	Instructor	Organized by chapter, this useful guide prepared by Sandra Chimon-Peszek (*Calumet College of St. Joseph*), includes objectives, lecture outlines, references to figures and solved problems, as well as teaching tips.
Test Bank 0133890651/ 9780133890655		✓	Instructor	The Test Bank, prepared by Anil Bangeree (*Columbus State University*), contains more than 2,200 multiple choice, true/false, and short-answer questions.
Solutions Manual 0133890678/ 9780133890679	✓		Instructor	Prepared by Kathy Shaginaw, this manual contains step-by-step solutions to all end-of-chapter exercises. With instructor permission, this manual may be made available to students.



1 Matter, Measurement, and Problem Solving

Hemoglobin, the oxygen-carrying protein in blood (depicted schematically here), can bind carbon monoxide molecules (the linked red and black spheres) as well as oxygen.



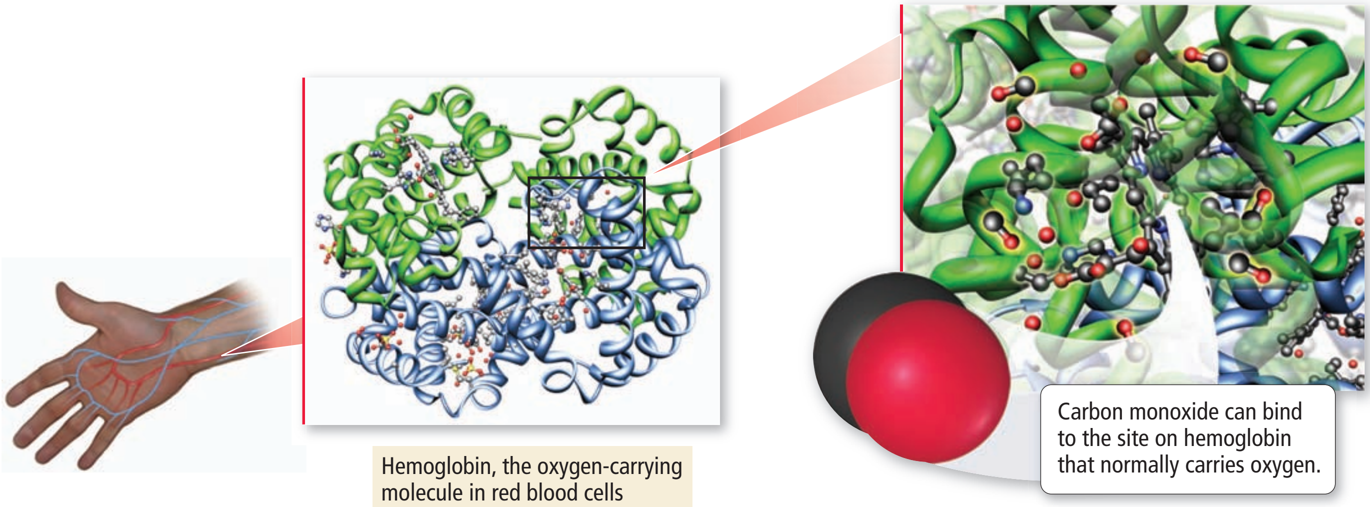
The most incomprehensible thing about the universe is that it is comprehensible.

—Albert Einstein (1879–1955)

WHAT DO YOU THINK IS THE MOST important idea in all of human knowledge? There are, of course, many possible answers to this question—some practical, some philosophical, and some scientific. If we limit ourselves only to scientific answers, mine would be this: **The properties of matter are determined by the properties of molecules and atoms.** Atoms and molecules determine how matter behaves—if they were different, matter would be different. The properties of water molecules, for example, determine how water behaves; the properties of sugar molecules determine how sugar behaves; and the molecules that compose our bodies determine how our bodies behave. The understanding of matter at the molecular level gives us unprecedented control over that matter. For example, our understanding of the details of the molecules that compose living organisms has revolutionized biology over the last 50 years.

1.1 Atoms and Molecules

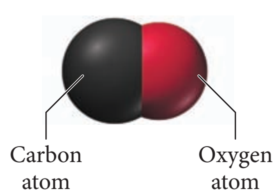
The air over most U.S. cities, including my own, contains at least some pollution. A significant component of that pollution is carbon monoxide, a colorless gas emitted in the exhaust of cars and trucks. Carbon monoxide *gas* is composed of carbon monoxide *molecules*, each of which contains a carbon atom and an oxygen atom held together by a chemical bond. **Atoms** are the submicroscopic particles that constitute the fundamental building blocks of ordinary matter. However, free atoms are rare in nature; instead, they bind together in specific geometric arrangements to form **molecules**.



▲ FIGURE 1.1 **Binding of Oxygen and Carbon Monoxide to Hemoglobin** Hemoglobin, a large protein molecule, is the oxygen carrier in red blood cells. Each subunit of the hemoglobin molecule contains an iron atom to which oxygen binds. Carbon monoxide molecules can take the place of oxygen, thus reducing the amount of oxygen reaching the body's tissues.

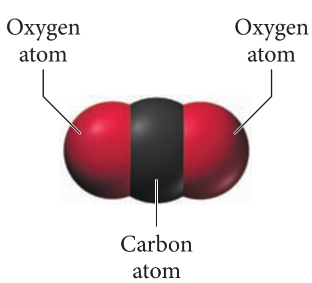
KEY CONCEPT VIDEO
Atoms and Molecules

Carbon monoxide molecule



The properties of the substances around us depend on the atoms and molecules that compose them, so the properties of carbon monoxide *gas* depend on the properties of carbon monoxide *molecules*. Carbon monoxide molecules happen to be just the right size and shape, and happen to have just the right chemical properties, to fit neatly into cavities within hemoglobin—the oxygen-carrying molecule in blood—that normally carry oxygen molecules (FIGURE 1.1▲). Consequently, carbon monoxide diminishes the oxygen-carrying capacity of blood. Breathing air containing too much carbon monoxide (greater than 0.04% by volume) can lead to unconsciousness and even death because not enough oxygen reaches the brain. Carbon monoxide deaths have occurred, for example, as a result of running an automobile in a closed garage or using a propane burner in an enclosed space for too long. In smaller amounts, carbon monoxide causes the heart and lungs to work harder and can result in headache, dizziness, weakness, and confusion.

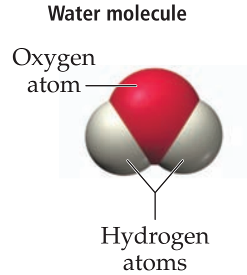
Carbon dioxide molecule



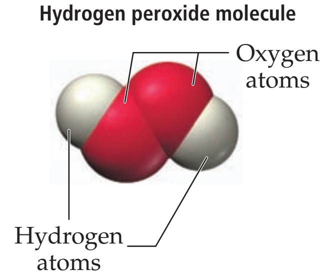
Cars and trucks emit a closely related molecule, called carbon dioxide, in far greater quantities than carbon monoxide. The only difference between carbon dioxide and carbon monoxide is that carbon dioxide molecules contain two oxygen atoms instead of just one. This extra oxygen atom dramatically affects the properties of the gas. We breathe much more carbon dioxide—which composes 0.04% of air and is a product of our own respiration as well—than carbon monoxide, yet it does not kill us. Why? Because the presence of the second oxygen atom prevents carbon dioxide from binding to the oxygen-carrying site in hemoglobin, making it far less toxic. Although high levels of carbon dioxide (greater than 10% of air) can be toxic for other reasons, lower levels can enter the bloodstream with no adverse effects. Such is the molecular world. Any differences between molecules—such as the presence of the extra oxygen atom in carbon dioxide compared to carbon monoxide—results in differences between the substances that the molecules compose.

As another example, consider two other closely related molecules, water and hydrogen peroxide:

Water molecule



Hydrogen peroxide molecule



In the study of chemistry, atoms are often portrayed as colored spheres, with each color representing a different kind of atom. For example, a black sphere represents a carbon atom, a red sphere represents an oxygen atom, and a white sphere represents a hydrogen atom. For a complete color code of atoms, see Appendix IIA.

A water molecule is composed of *one* oxygen atom and two hydrogen atoms. A hydrogen peroxide molecule is composed of *two* oxygen atoms and two hydrogen atoms. This seemingly small molecular difference results in a huge difference in the properties of water and hydrogen peroxide. Water is the familiar and stable liquid we all drink and bathe in. Hydrogen peroxide, in contrast, is an unstable liquid that, in its pure form, burns the skin on contact and is used in rocket fuel. When you pour water onto your hair, your hair simply becomes wet. However, if you put hydrogen peroxide in your hair—which you may have done if you have ever bleached your hair—a chemical reaction occurs that turns your hair blonde.

The hydrogen peroxide used as an antiseptic or bleaching agent is considerably diluted.

The details of how specific atoms bond to form a molecule—in a straight line, at a particular angle, in a ring, or in some other pattern—as well as the type of atoms in the molecule, determine everything about the substance that the molecule composes. If we want to understand the substances around us, we must understand the atoms and molecules that compose them—this is the central goal of chemistry. A good simple definition of **chemistry** is, therefore,

Chemistry—the science that seeks to understand the behavior of matter by studying the behavior of atoms and molecules.

1.2 The Scientific Approach to Knowledge

Scientific knowledge is *empirical*—it is based on *observation* and *experiment*. Scientists observe and perform experiments on the physical world to learn about it. Some observations and experiments are *qualitative* (noting or describing how a process happens), but many are *quantitative* (measuring or quantifying something about the process). For example, Antoine Lavoisier (1743–1794), a French chemist who studied combustion, made careful measurements of the mass of objects before and after burning them in closed containers. He noticed that there was no change in the total mass of material within the container during combustion. Lavoisier made an important observation about the physical world.

▲ *A painting of the French chemist Antoine Lavoisier. Lavoisier, who also made significant contributions to agriculture, industry, education, and government administration, was executed during the French Revolution.*

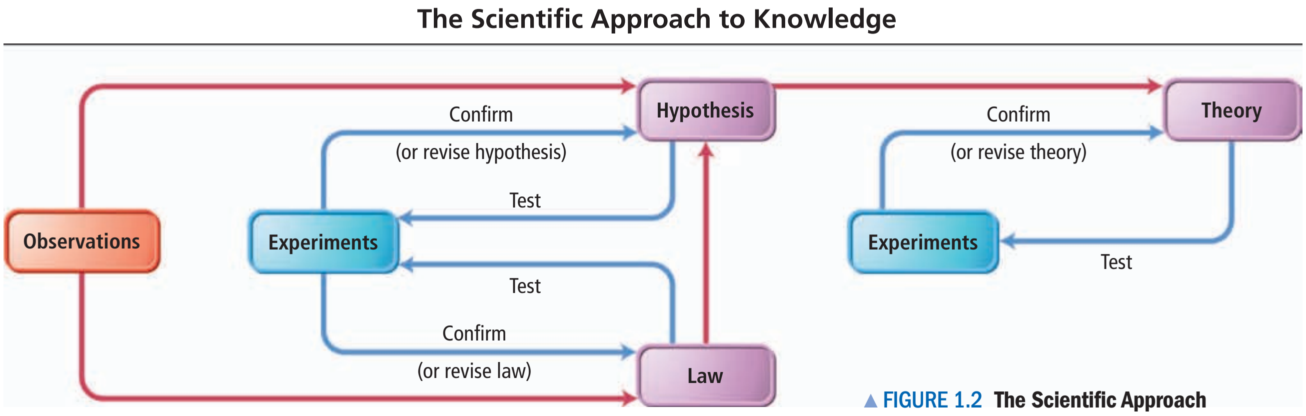
Observations often lead a scientist to formulate a **hypothesis**, a tentative interpretation or explanation of the observations. For example, Lavoisier explained his observations on combustion by hypothesizing that when a substance burns, it combines with a component of air. A good hypothesis is *falsifiable*, which means that it makes predictions that can be confirmed or refuted by further observations. Hypotheses are tested by **experiments**, highly controlled procedures designed to generate observations that can confirm or refute a hypothesis. The results of an experiment may support a hypothesis or prove it wrong. If it is proven wrong, the hypothesis must be modified or discarded.

In some cases, a series of similar observations can lead to the development of a **scientific law**, a brief statement that summarizes past observations and predicts future ones. For example, Lavoisier summarized his observations on combustion with the **law of conservation of mass**, which states, "In a chemical reaction, matter is neither created nor destroyed." This statement summarizes Lavoisier's observations on chemical reactions and predicts the outcome of future observations on reactions. Laws, like hypotheses, are also subject to experiments, which can add support to them or prove them wrong.

Scientific laws are not *laws* in the same sense as civil or governmental laws. Nature does not follow laws in the way that we obey the laws against speeding or running a red light. Rather, scientific laws *describe* how nature behaves—they are generalizations about what nature does. For that reason, some people find it more appropriate to refer to them as *principles* rather than laws.

One or more well-established hypotheses may form the basis for a scientific **theory**. A scientific theory is a model for the way nature is and tries to explain not merely what nature does, but why. As such, well-established theories are the pinnacle of scientific knowledge, often predicting behavior far beyond the observations or laws from which they were developed. A good example of a theory is the **atomic theory** proposed by English chemist John Dalton (1766–1844). Dalton explained the law of conservation of mass, as well as other laws and observations of the time, by proposing that matter is composed of small, indestructible particles called atoms. Since these particles merely rearrange in chemical changes (and do not form or vanish), the total amount of mass remains

In Dalton's time, atoms were thought to be indestructible. Today, because of nuclear reactions, we know that atoms can be broken apart into their smaller components.



▲ FIGURE 1.2 **The Scientific Approach**

the same. Dalton's theory is a model for the physical world—it gives us insight into how nature works, and therefore *explains* our laws and observations.

Finally, the scientific approach returns to observation to test theories. For example, scientists can test the atomic theory by trying to isolate single atoms, or by trying to image them (both of which, by the way, have already been accomplished). Theories are validated by experiments; however, theories can never be conclusively proven because some new observation or experiment always has the potential to reveal a flaw. Notice that the scientific approach to knowledge begins with observation and ends with observation, because an experiment is simply a highly controlled procedure for generating critical observations designed to test a theory or hypothesis. Each new set of observations has the potential to refine the original model. FIGURE 1.2▲ is one way to map the scientific approach to knowledge. Scientific laws, hypotheses, and theories are all subject to continued experimentation. If a law, hypothesis, or theory is proved wrong by an experiment, it must be revised and tested with new experiments. Over time, poor theories and laws are eliminated or corrected and good theories and laws—those consistent with experimental results—remain.

Established theories with strong experimental support are the most powerful pieces of scientific knowledge. You may have heard the phrase, "That is just a theory," as if theories are easily dismissible. Such a statement reveals a deep misunderstanding of the nature of a scientific theory. Well-established theories are as close to truth as we get in science. The idea that all matter is made of atoms is "just a theory," but it has over 200 years of experimental evidence to support it. It is a powerful piece of scientific knowledge on which many other scientific ideas have been built.

One last word about the scientific approach to knowledge: Some people wrongly imagine science to be a strict set of rules and procedures that automatically leads to inarguable, objective facts. This is not the case. Even the diagram of the scientific approach to knowledge in Figure 1.2 is only an idealization of real science, useful to help us see key distinctions. Doing real science requires hard work, care, creativity, and even a bit of luck. Scientific theories do not just fall out of data—they are crafted by men and women of great genius and creativity. A great theory is not unlike a master painting, and many see a similar kind of beauty in both.

CONCEPTUAL CONNECTION 1.1 **LAWS AND THEORIES**

Which statement best explains the difference between a law and a theory?

(a) A law is truth, whereas a theory is mere speculation.

(b) A law summarizes a series of related observations, whereas a theory gives the underlying reasons for them.

(c) A theory describes *what* nature does, whereas a law describes *why* nature does it.

You can find the answers to conceptual connection questions at the end of each chapter.

1.3 The Classification of Matter

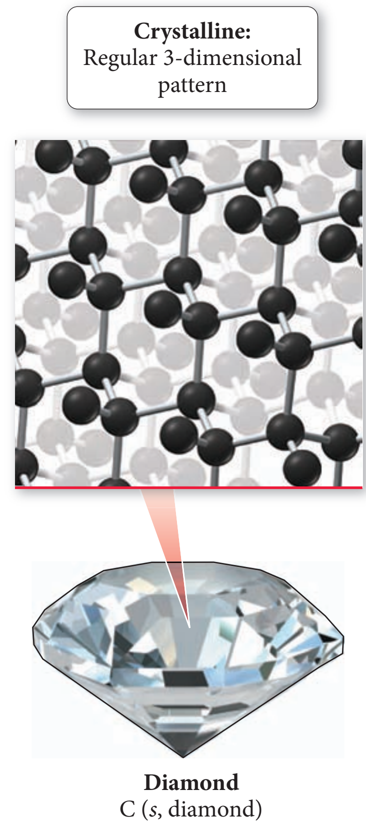
Matter is anything that occupies space and has mass. This book, your desk, your chair, and even your body are all composed of matter. Less obviously, the air around you is also matter—it too occupies space and has mass. We often call a specific instance of matter—such as air, water, or sand—a **substance**. We classify matter according to its state—solid, liquid, or gas—and according to its composition.

The States of Matter: Solid, Liquid, and Gas

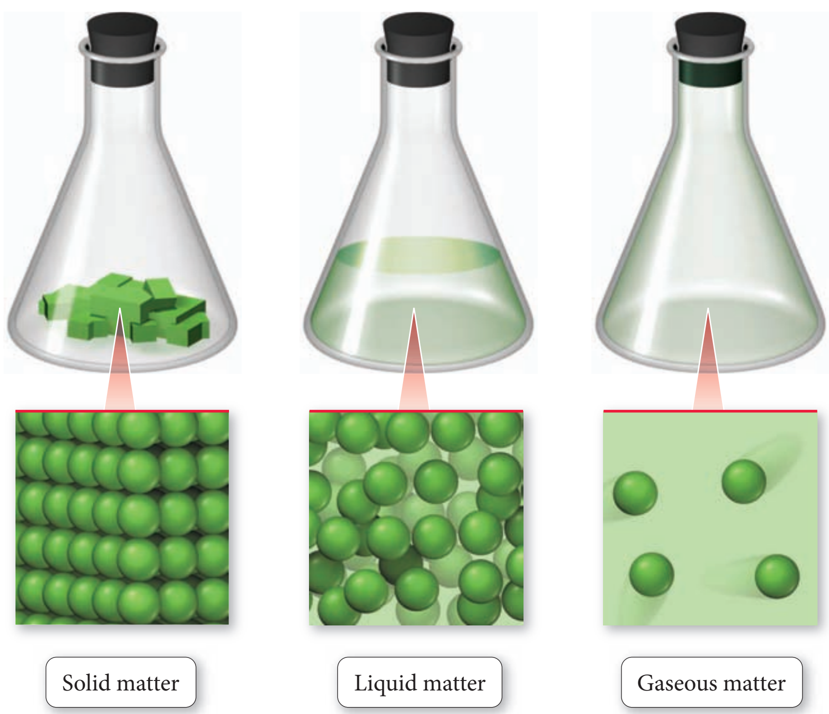
Matter exists in three different **states: solid, liquid**, and **gas**. In *solid matter*, atoms or molecules pack closely to each other in fixed locations. Although the atoms and molecules in a solid vibrate, they do not move around or past each other. Consequently, a solid has a fixed volume and rigid shape. Ice, aluminum, and diamond are examples of solids. Solid matter may be **crystalline**, in which case its atoms or molecules are arranged in patterns with long-range, repeating order (FIGURE 1.3▶), or it may be **amorphous**, in which case its atoms or molecules do not have any long-range order. Examples of *crystalline* solids include table salt and diamond; the well-ordered geometric shapes of salt and diamond crystals reflect the well-ordered geometric arrangement of their atoms. Examples of *amorphous* solids include glass and most plastics.

In *liquid matter*, atoms or molecules pack about as closely as they do in solid matter, but are free to move relative to each other, giving liquids a fixed volume but not a fixed shape. Liquids assume the shape of their container. Water, alcohol, and gasoline are substances that are liquids at room temperature.

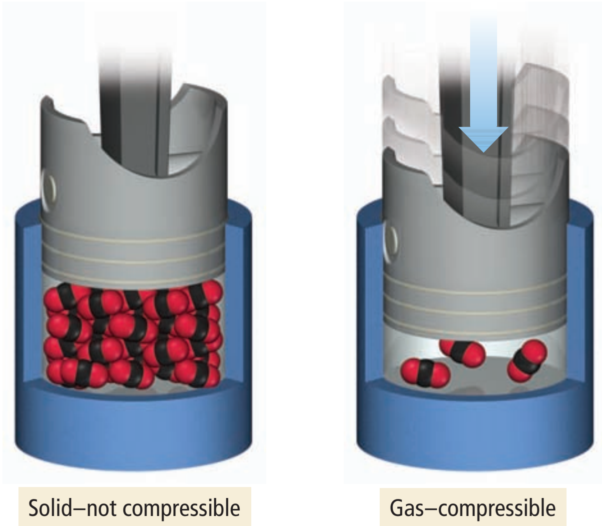
The state of matter changes from solid to liquid to gas with increasing temperature.



▲ FIGURE 1.3 **Crystalline Solids** Diamond is a crystalline solid composed of carbon atoms arranged in a regular, repeating pattern.



▲ *In a solid, the atoms or molecules are fixed in place and can only vibrate. In a liquid, although the atoms or molecules are closely packed, they can move past one another, allowing the liquid to flow and assume the shape of its container. In a gas, the atoms or molecules are widely spaced, making gases compressible as well as fluid.*

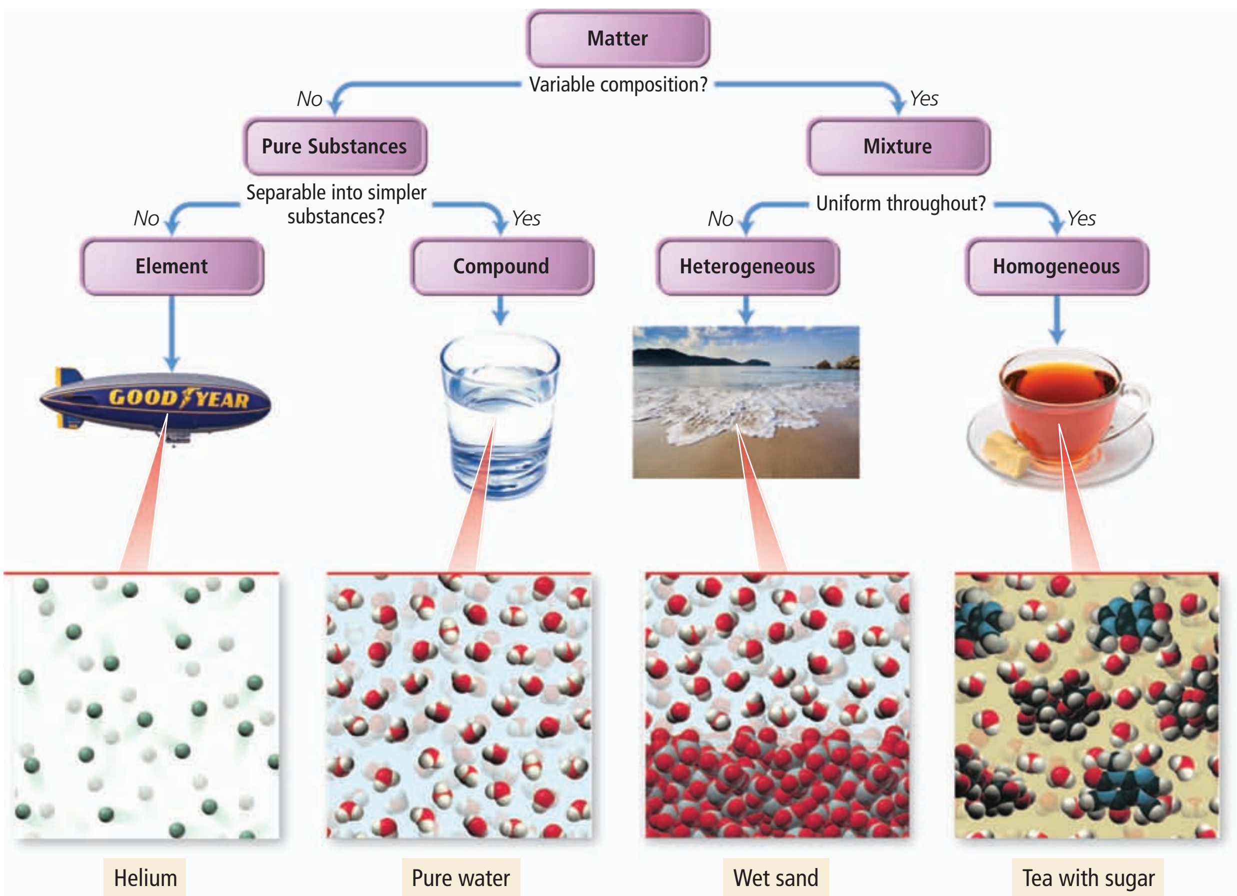


▲ FIGURE 1.4 **The Compressibility of Gases** Gases can be compressed—squeezed into a smaller volume—because there is so much empty space between atoms or molecules in the gaseous state.

In *gaseous matter*, atoms or molecules have a lot of space between them and are free to move relative to one another, making gases *compressible* (FIGURE 1.4◄). When you squeeze a balloon or sit down on an air mattress, you force the atoms and molecules into a smaller space, so that they are closer together. Gases always assume the shape *and* volume of their container. Substances that are gases at room temperature include helium, nitrogen (the main component of air), and carbon dioxide.

Classifying Matter According to Its Composition: Elements, Compounds, and Mixtures

In addition to classifying matter according to its state, we can classify it according to its **composition**, that is, the kinds and amounts of substances that compose it. The following chart classifies matter according to its composition:



The first division in the classification of matter depends on whether or not its composition can vary from one sample to another. For example, the composition of distilled (or pure) water never varies—it is always 100% water and is therefore a **pure substance**, a substance composed of only a single type of atom or molecule. In contrast, the composition of sweetened tea can vary considerably from one sample to another, depending, for instance, on the strength of the tea or how much sugar has been added. Sweetened tea is an example of a **mixture**, a substance composed of two or more different types of atoms or molecules that can be combined in continuously variable proportions.

We can categorize pure substances into two types—elements and compounds—depending on whether or not they can be broken down into simpler substances. The helium in a blimp or party balloon is an example of an **element**, a substance that cannot be chemically broken down into simpler substances. Water is an example of a **compound**, a substance composed of two or more elements (hydrogen and oxygen) in fixed, definite proportions. On Earth, compounds are more common than pure elements because most elements combine with other elements to form compounds.

All known elements are listed in the periodic table in the inside front cover of this book.

We can also categorize mixtures into two types—heterogeneous and homogeneous—depending on how uniformly the substances within them mix. Wet sand is an example of a **heterogeneous mixture**, one in which the composition varies from one region to another. Sweetened tea is an example of a **homogeneous mixture**, one with the same composition throughout. Homogeneous mixtures have uniform compositions because the atoms or molecules that compose them mix uniformly. Heterogeneous mixtures are made up of distinct regions because the atoms or molecules that compose them separate. Here again we see that the properties of matter are determined by the atoms or molecules that compose it.

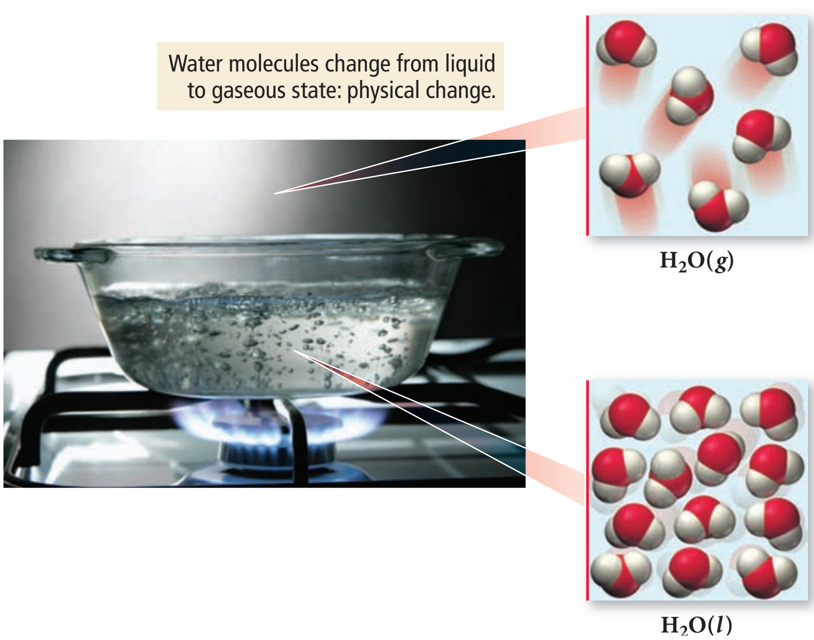
PURE SUBSTANCES AND MIXTURES — CONCEPTUAL CONNECTION 1.2

Let a small circle represent an atom of one type of element and a small square represent an atom of a second type of element. Make a drawing of: **(a)** a pure substance composed of the two elements (in a one-to-one ratio); **(b)** a homogeneous mixture composed of the two elements; and **(c)** a heterogeneous mixture composed of the two elements.

You can find the answers to conceptual connection questions at the end of each chapter.

1.4 Physical and Chemical Changes and Physical and Chemical Properties

Every day we witness changes in matter: ice melts, iron rusts, gasoline burns, fruit ripens, and water evaporates. What happens to the molecules that compose these samples of matter during such changes? The answer depends on the type of change. Changes that alter only state or appearance, but not composition, are **physical changes**. The atoms or molecules that compose a substance *do not change* their identity during a physical change. For example, when water boils, it changes its state from a liquid to a gas, but the gas remains composed of water molecules, which means that this is a physical change (FIGURE 1.5▼).



◀ FIGURE 1.5 **Boiling, a Physical Change** When water boils, it turns into a gas but does not alter its chemical identity—the water molecules are the same in both the liquid and gaseous states. Boiling is a physical change, and the boiling point of water is a physical property.