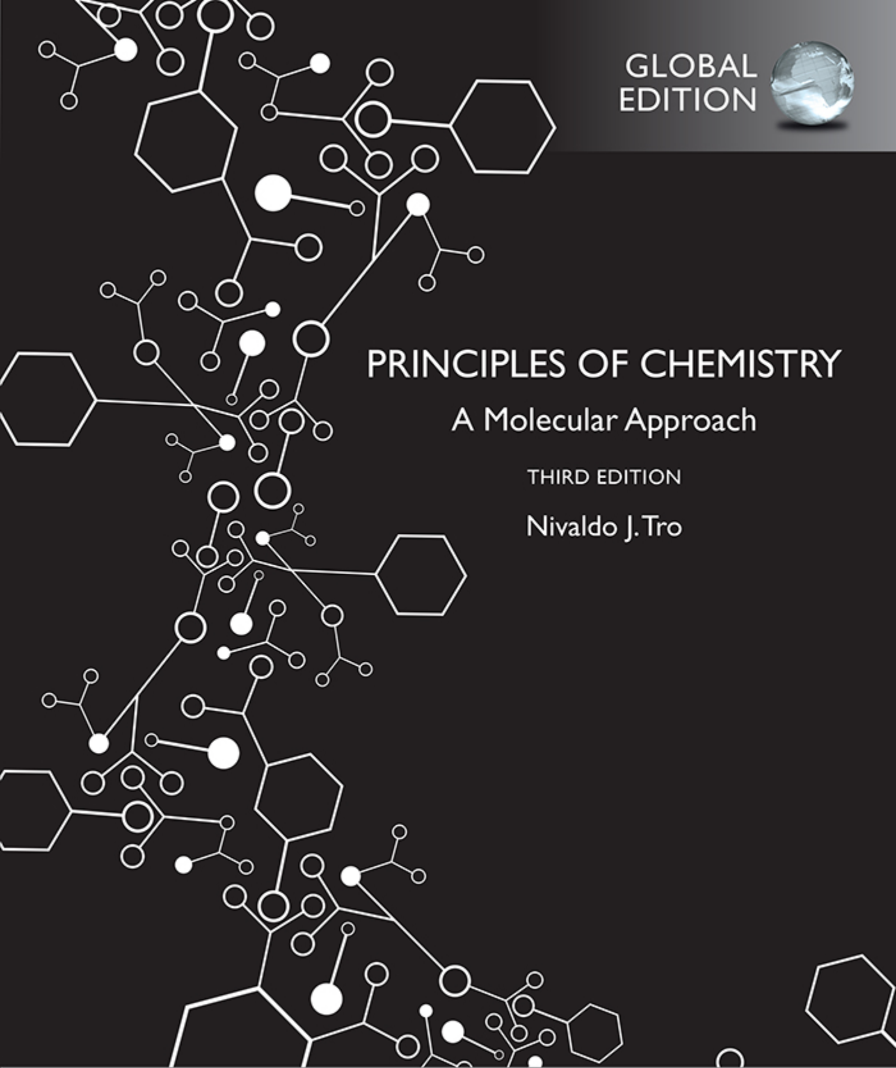

GLOBAL EDITION

PRINCIPLES OF CHEMISTRY

A Molecular Approach

THIRD EDITION

Nivaldo J. Tro

ALWAYS LEARNING

PEARSON

Principles of Chemistry

A Molecular Approach

THIRD EDITION

Global Edition

NIVALDO J. TRO
Westmont College

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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.

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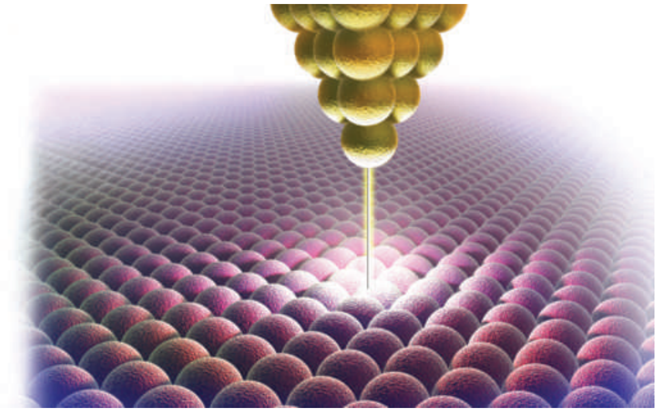
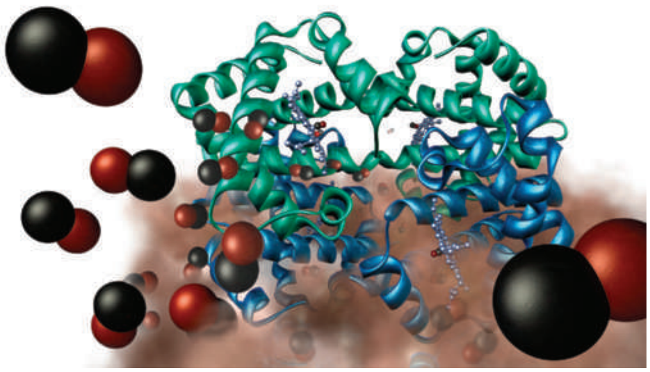
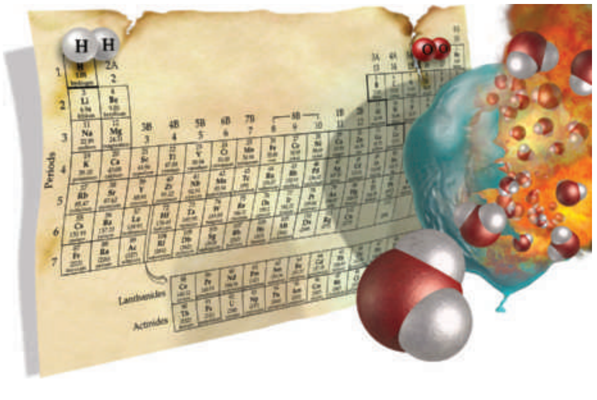
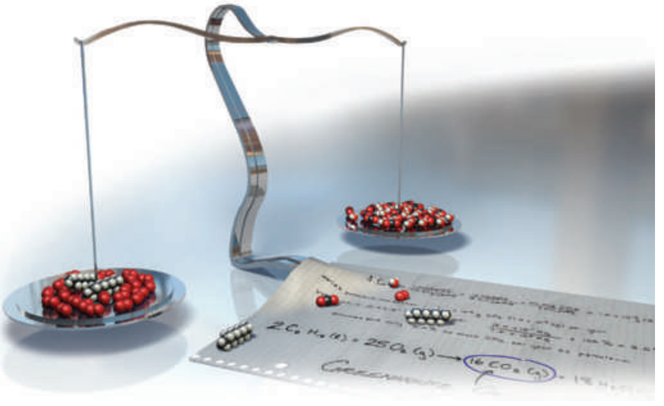




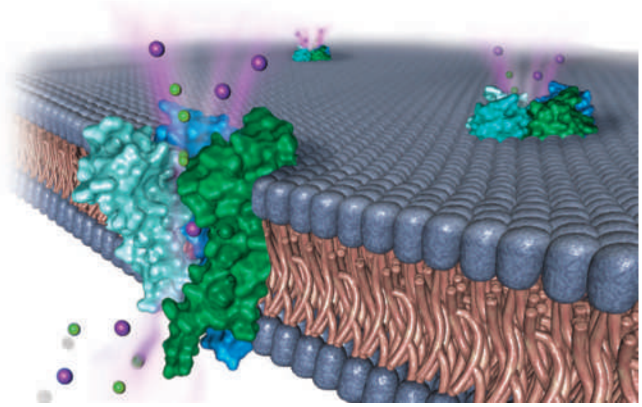


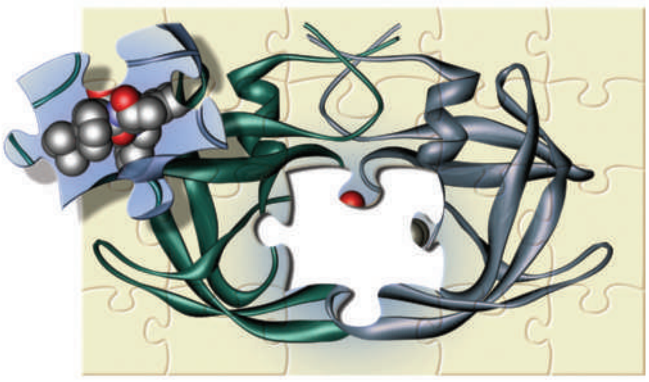


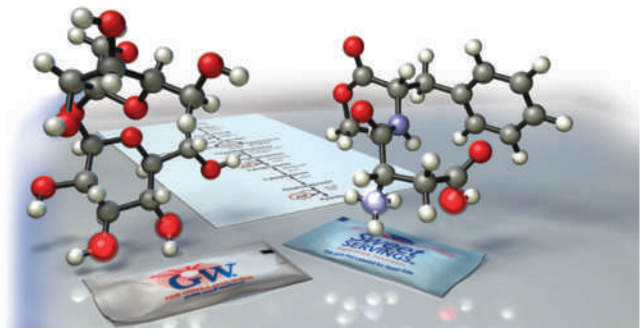

PV=nRT

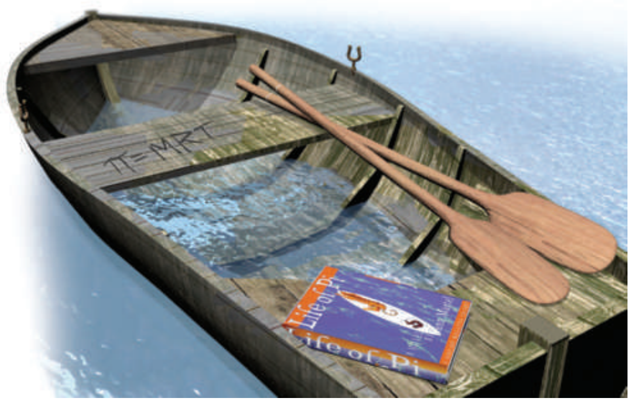

Fe(s) + 3 O2(g) → 2 Fe2

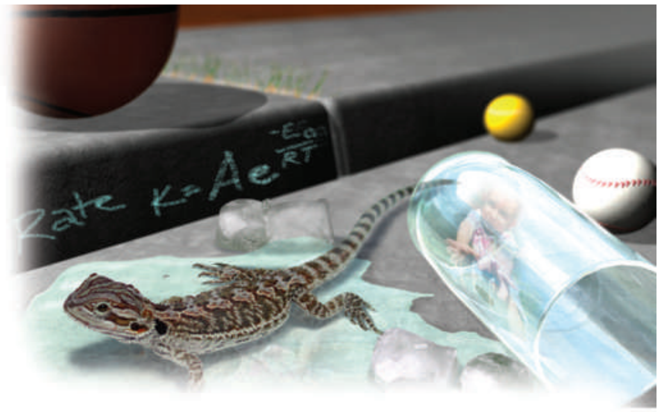

Schrödinger's Cat








T=MRT
Life of Pi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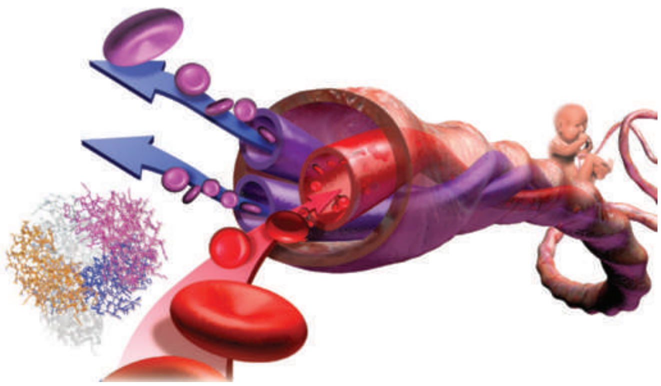

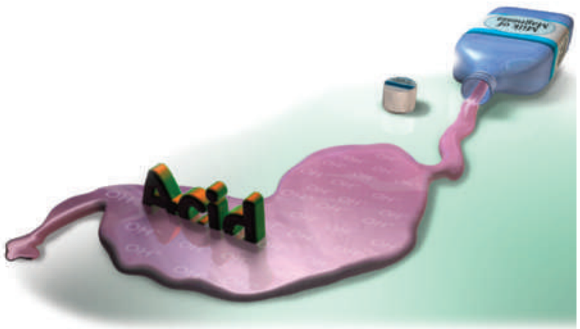
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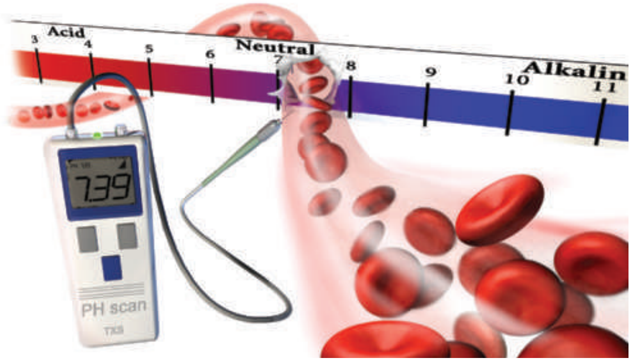
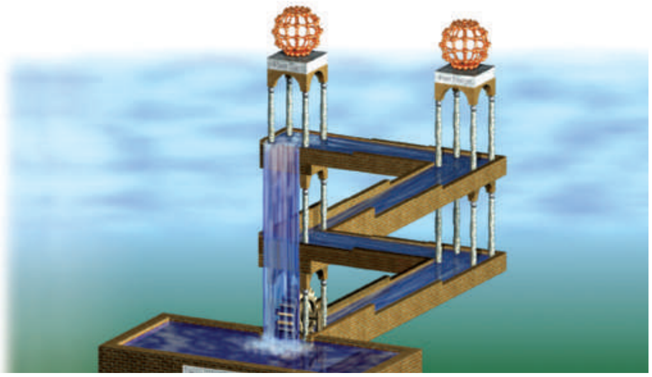
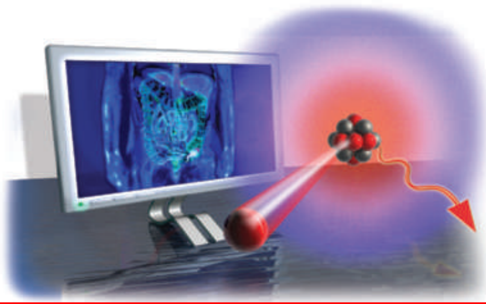


Acid
Neutral
Alkalin
7.39
PH scan




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.

I am also grateful to my marketing managers, Will Moore and Chris Barker, who have helped to develop a great marketing campaign for my books and are all good friends. I am deeply grateful to Gary Hespenheide for crafting the design of this text. I would like to thank Beth Sweeten and the rest of the Pearson production team. I also thank Francesca Monaco and her co-workers at CodeMantra. I am a picky author and Francesca is endlessly patient and a true professional. I am also greatly indebted to my copy editor, Betty Pessagno, for her dedication and professionalism, and to Lauren McFalls, for her exemplary photo research. I owe a special debt of gratitude to Quade and Emiko Paul, who continue to make my ideas come alive in their art. Thanks also to Derek Bacchus for his work on the cover and with design.

I would like to acknowledge the help of my colleagues Allan Nishimura, Michael Everest, Kristi Lazar, Steve Contakes, David Marten, and Carrie Hill, who have supported me in my department while I worked on this book. Double thanks to Michael Everest for also authoring the Questions for Group Work. I am also grateful to those who have supported me personally. First on that list is my wife, Ann. Her love rescued a broken man fifteen years ago and without her, none of this would have been possible. I am also indebted to my children, Michael, Ali, Kyle, and Kaden, whose smiling faces and love of life always inspire me. I come from a large Cuban family whose closeness and support most people would envy. Thanks to my parents, Nivaldo and Sara; my siblings, Sarita, Mary, and Jorge; my siblings-in-law, Nachy, Karen, and John; my nephews and nieces, Germain, Danny, Lisette, Sara, and Kenny. These are the people with whom I celebrate life.

I would like to thank all of the general chemistry students who have been in my classes throughout my years as a professor at Westmont College. You have taught me much about teaching that is now in this book. I would also like to express my appreciation to Michael Tro, who also helped in manuscript development, proofreading, and working new problems.

Lastly, I am indebted to the many reviewers whose ideas are embedded throughout this book. They have corrected me, inspired me, and sharpened my thinking on how best to teach this subject we call chemistry. I deeply appreciate their commitment to this project. Thanks also to Frank Lambert for helping us all to think more clearly about entropy and for his review of the entropy sections of the book. Last but by no means least, I would like to record my gratitude to Brian Gute, Milton Johnston, Jessica Parr, and John Vincent whose alertness, keen eyes, and scientific astuteness help make this a much better book.

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Chemistry through Relevancy

Chemistry is relevant to every process occurring around us at every second. Niva Tro helps students understand this connection by weaving specific, vivid examples throughout the text and media that tell the story of chemistry. Every chapter begins with a brief story showing how chemistry is relevant to all people, at every moment.

11 Liquids, Solids, and Intermolecular Forces

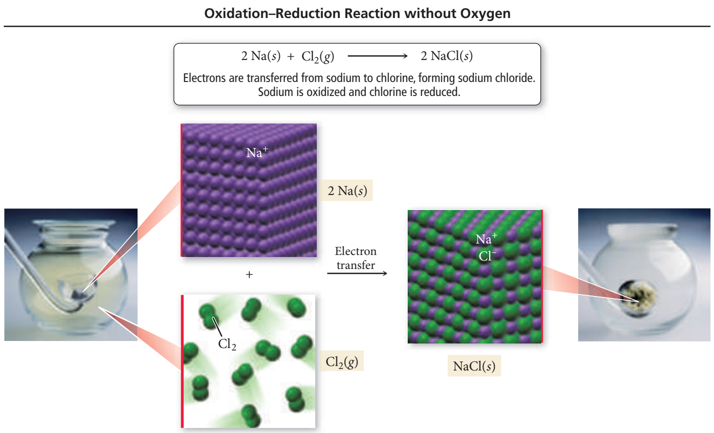
It's a wild dance floor there at the molecular level.
—Roald Hoffmann (1937–)

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?



▲ 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.

The reaction between sodium and oxygen forms other oxides as well.

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).

Interactive Problem-Solving Strategy

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

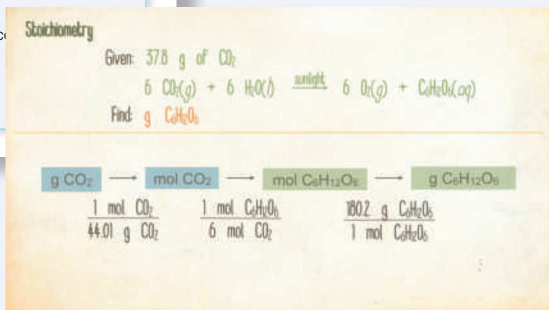
CHECK The units of the answer are correct. The magnitude of the answer (25.8 g) is less than the initial mass of CO_2 (37.8 g). This is reasonable because each carbon in CO_2 has two oxygen atoms associated with it, while in $C_6H_{12}O_6$ each carbon has only one oxygen atom associated with it and two 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

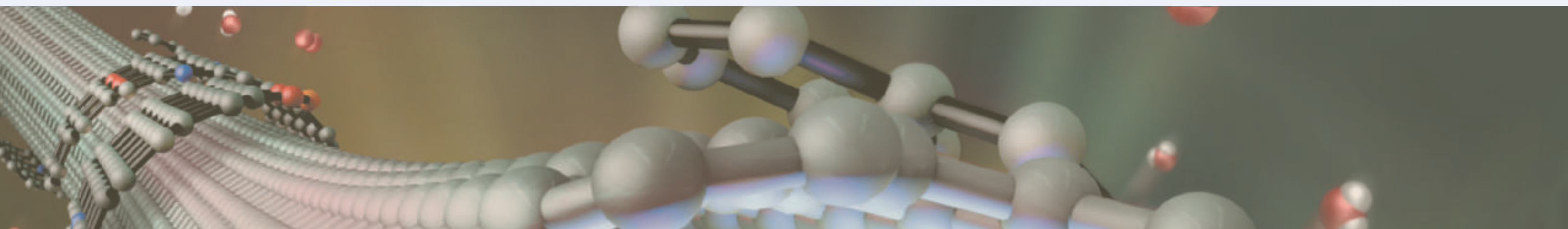
Magnesium hydroxide, the active ingredient in milk of magnesia, neutralizes stomach acid, primarily HCl, ac reaction:

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

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



NEW! 80 Interactive Worked Examples make Tro's unique problem-solving strategies interactive, bringing his award-winning teaching directly to all students using his text. In these digital, mobile versions, students are instructed how to break down problems using Tro's proven *Sort*, *Strategize*, *Solve*, and *Check* technique.

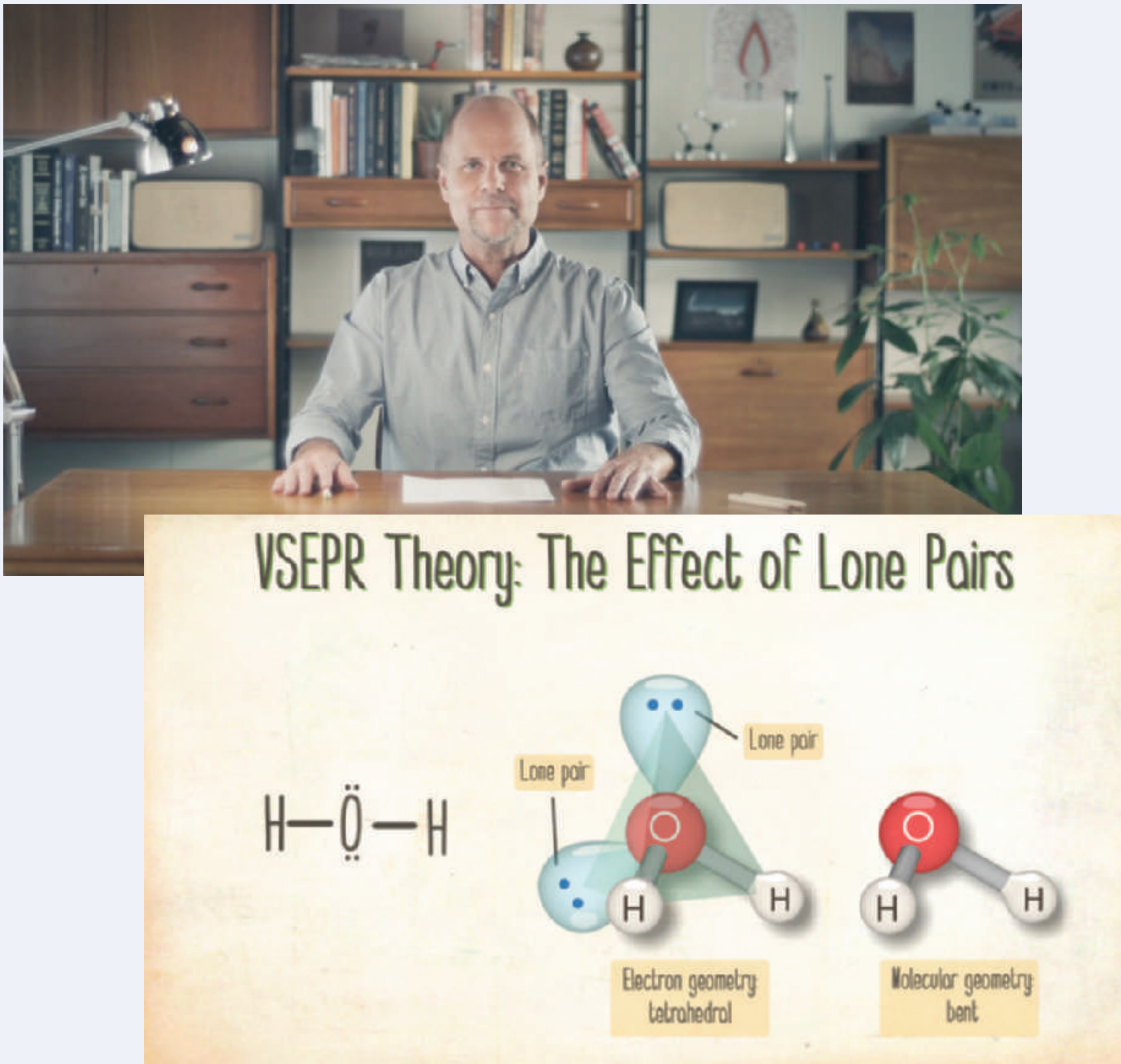


A Focus on Conceptual Understanding

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



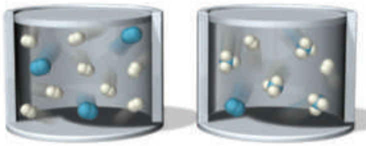
Conceptual Connections

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.

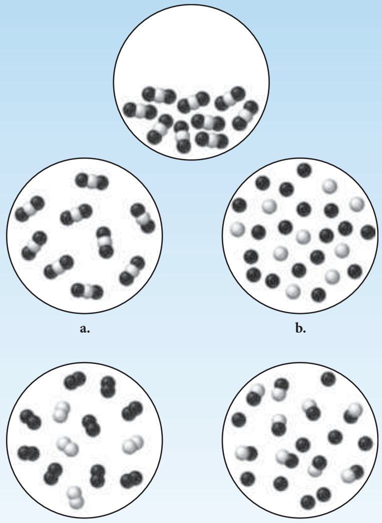
$$43.998 \times 0.00552/2.002$$

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

Active and Adaptive

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MasteringChemistry® from Pearson is the leading online homework, tutorial, and assessment system, designed to improve results by engaging students before, during, and after class with powerful content. Instructors ensure 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 and adaptive homework assignments that provide hints and answer-specific feedback. The Mastering gradebook records scores for all automatically graded assignments in one place, while diagnostic tools give instructors access to rich data to assess student understanding and misconceptions.

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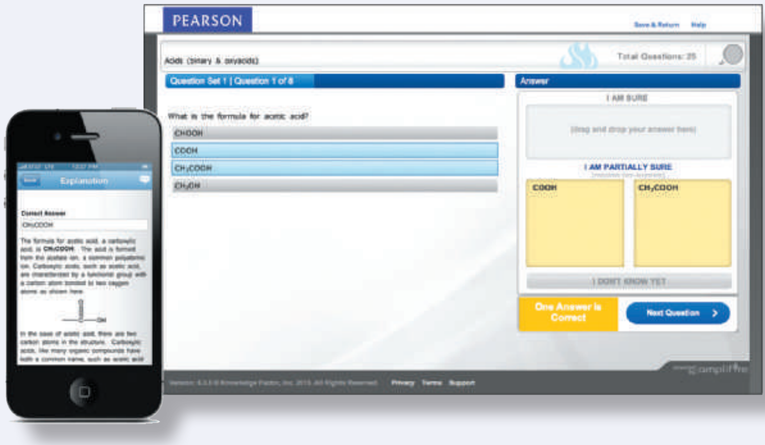

DURING CLASS

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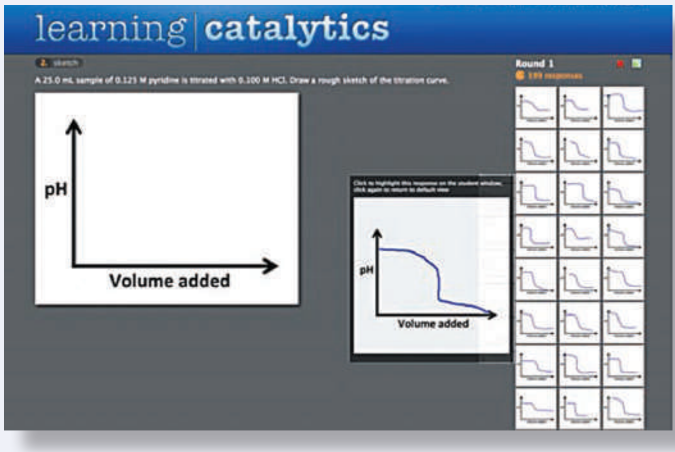
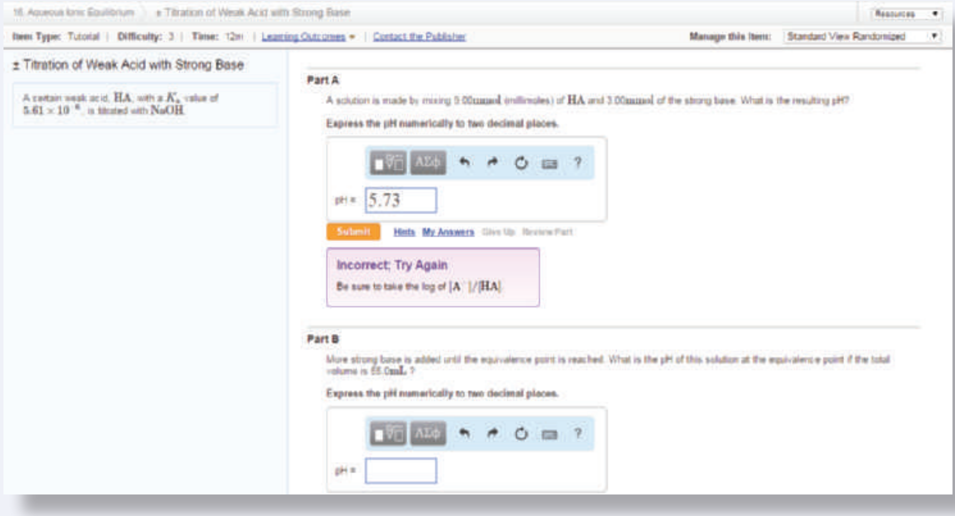


Learning Catalytics is a technology that has grown out of twenty years of cutting edge research, innovation, and implementation of interactive teaching and peer instruction.

AFTER CLASS

Tutorials

Tutorials, which feature 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 instruction similar to what students would experience in an office hour visit, allowing them to learn from their mistakes without being given the answer.



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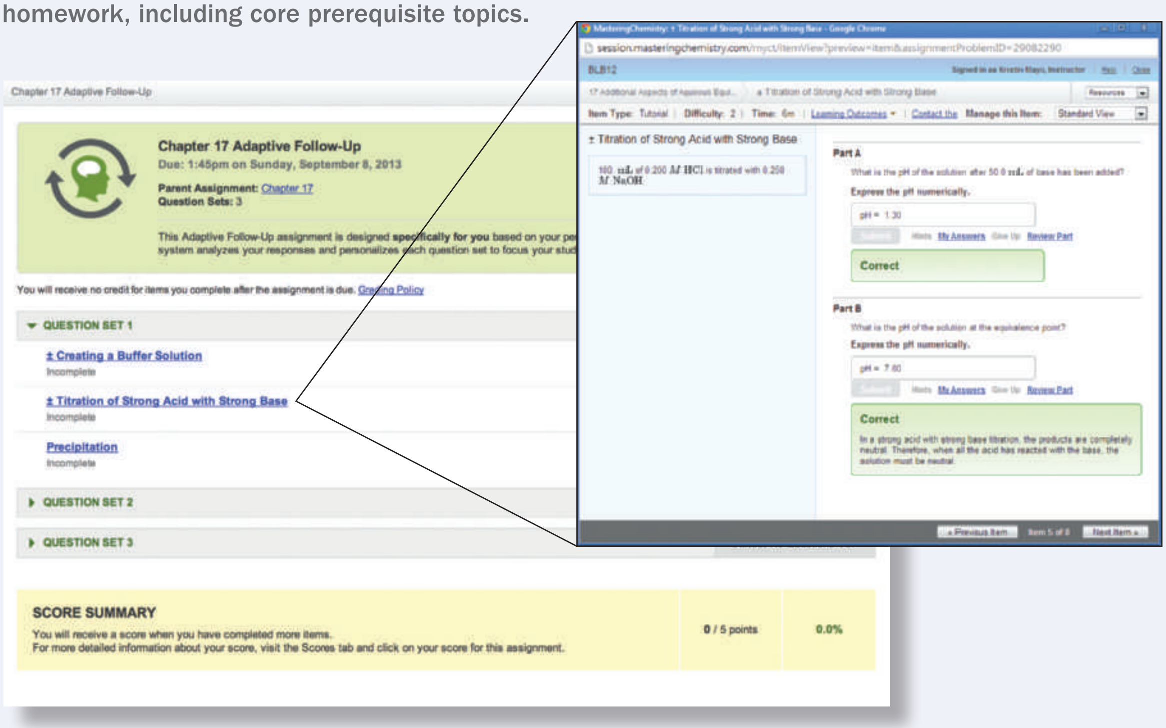

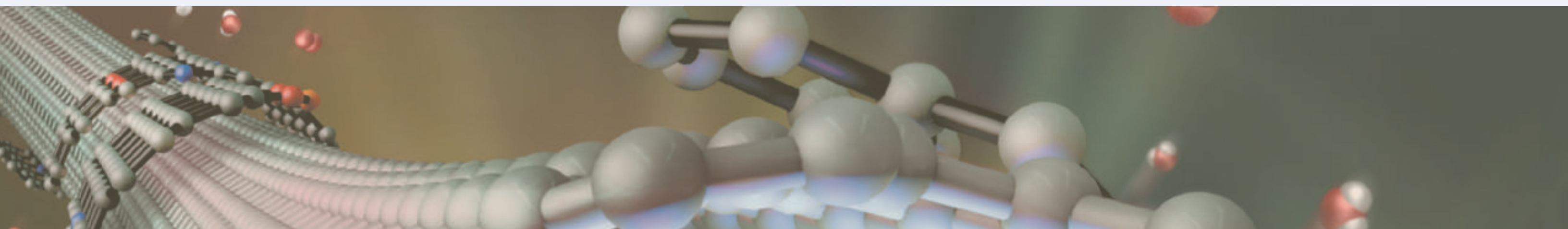

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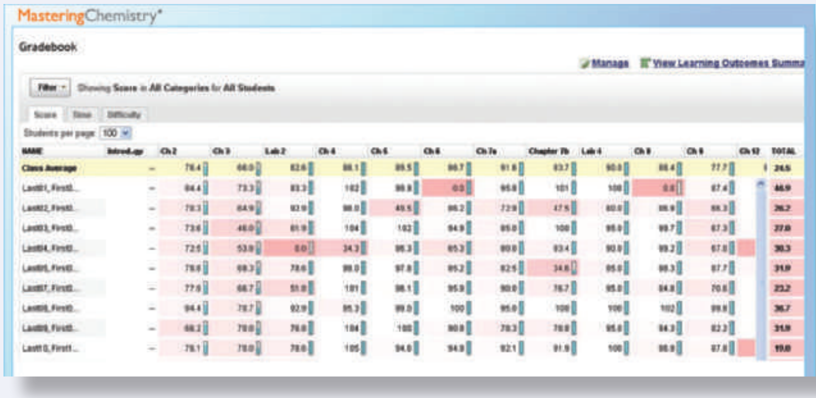

Gradebook Diagnostics

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.

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

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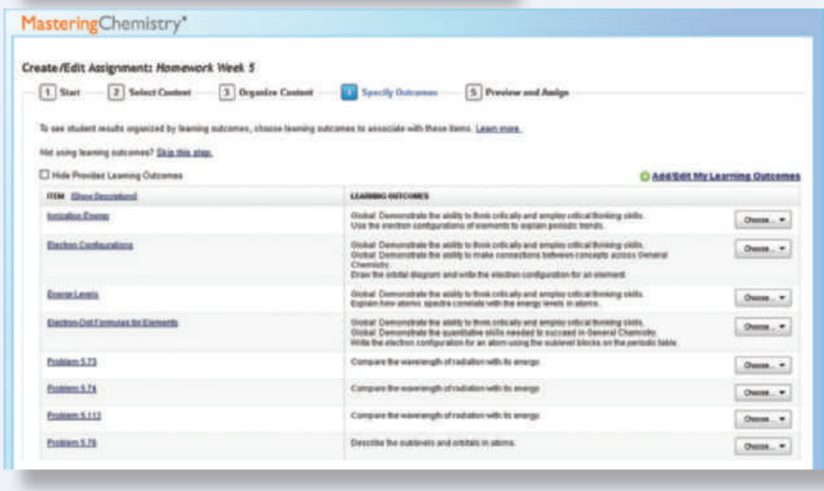
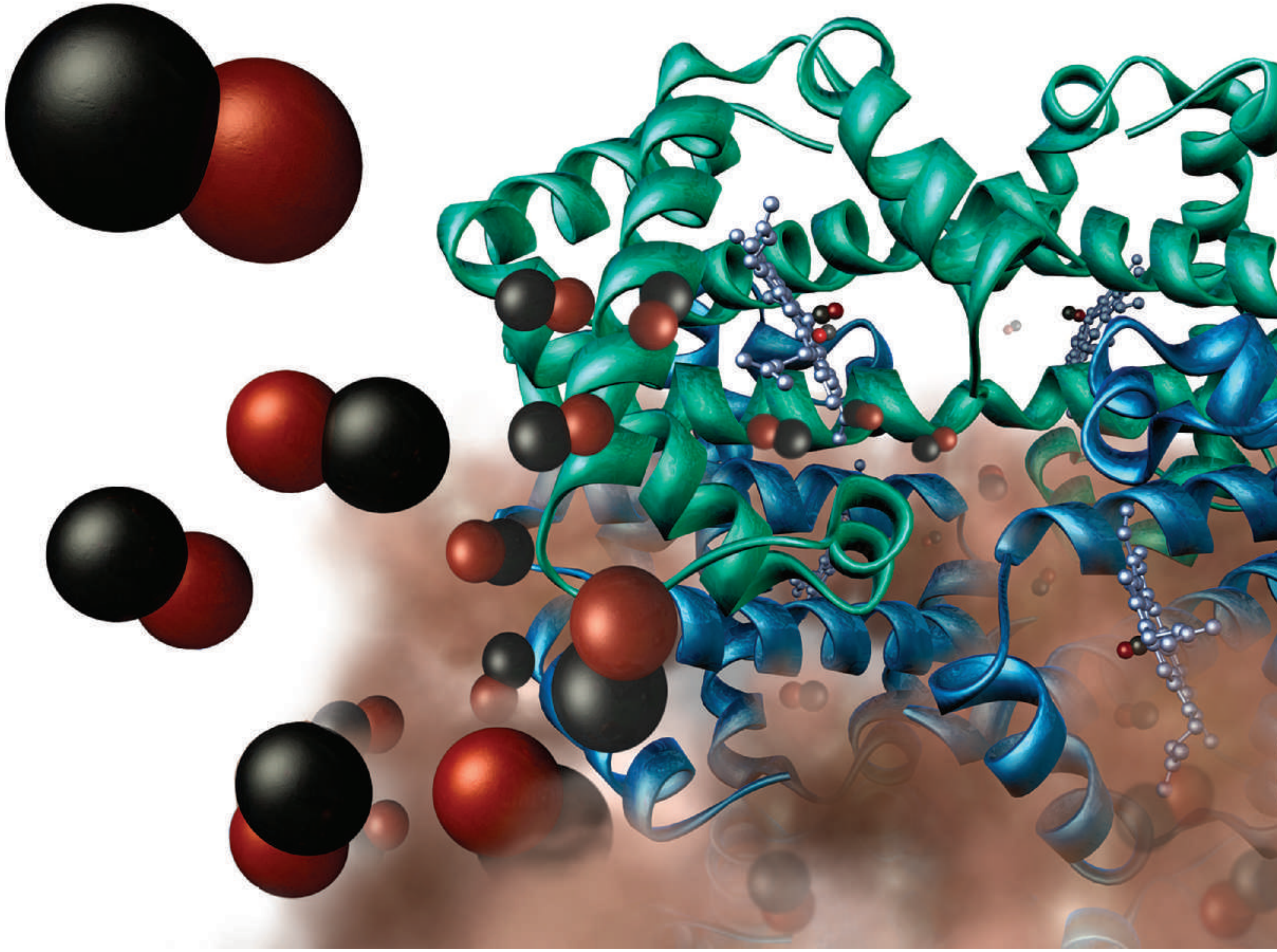


Instructor and Student Resources

Resource	*Available in Print*	*Available Online*	*Instructor or Student Resource*	*Description*
Instructor Resource Center		✓	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		✓	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		✓	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	✓		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

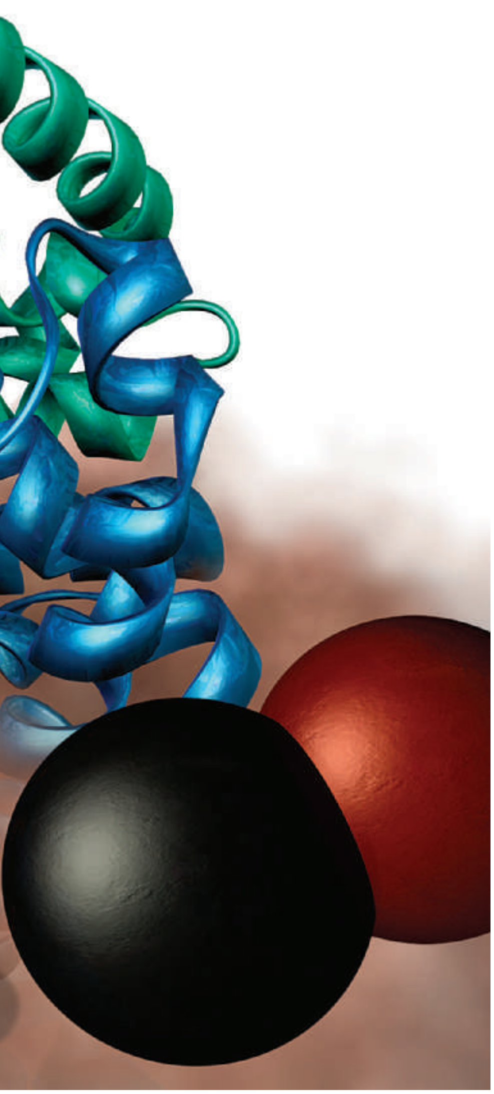
Hemoglobin, the oxygen-carrying protein in blood (depicted schematically here), can bind carbon monoxide molecules (the linked red and black spheres) as well as oxygen.



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

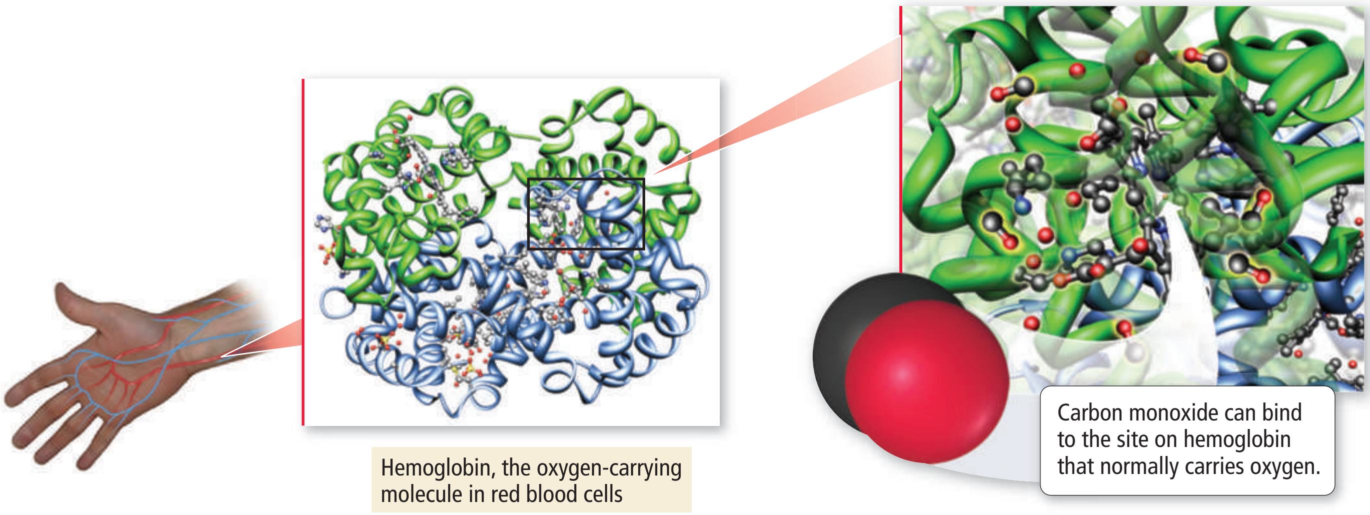
—Albert Einstein (1879–1955)

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

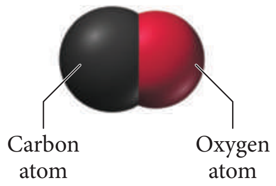
The air over most U.S. cities, including my own, contains at least some pollution. A significant component of that pollution is carbon monoxide, a colorless gas emitted in the exhaust of cars and trucks. Carbon monoxide *gas* is composed of carbon monoxide *molecules*, each of which contains a carbon 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**.



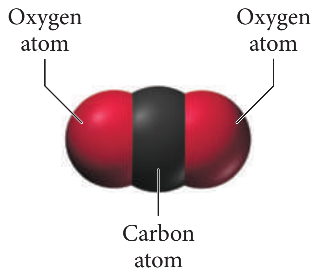
▲ **FIGURE 1.1 Binding of Oxygen and Carbon Monoxide to Hemoglobin** Hemoglobin, a large protein molecule, is the oxygen carrier in red blood cells. Each subunit of the hemoglobin molecule contains an iron atom to which oxygen binds. Carbon monoxide molecules can take the place of oxygen, thus reducing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

KEY CONCEPT VIDEO
Atoms and Molecules

Carbon monoxide molecule



Carbon dioxide molecule



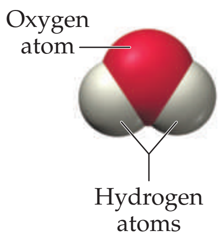
In the study of chemistry, atoms are often portrayed as colored spheres, with each color representing a different kind of atom. For example, a black sphere represents a carbon atom, a red sphere represents an oxygen atom, and a white sphere represents a hydrogen atom. For a complete color code of atoms,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

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.

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