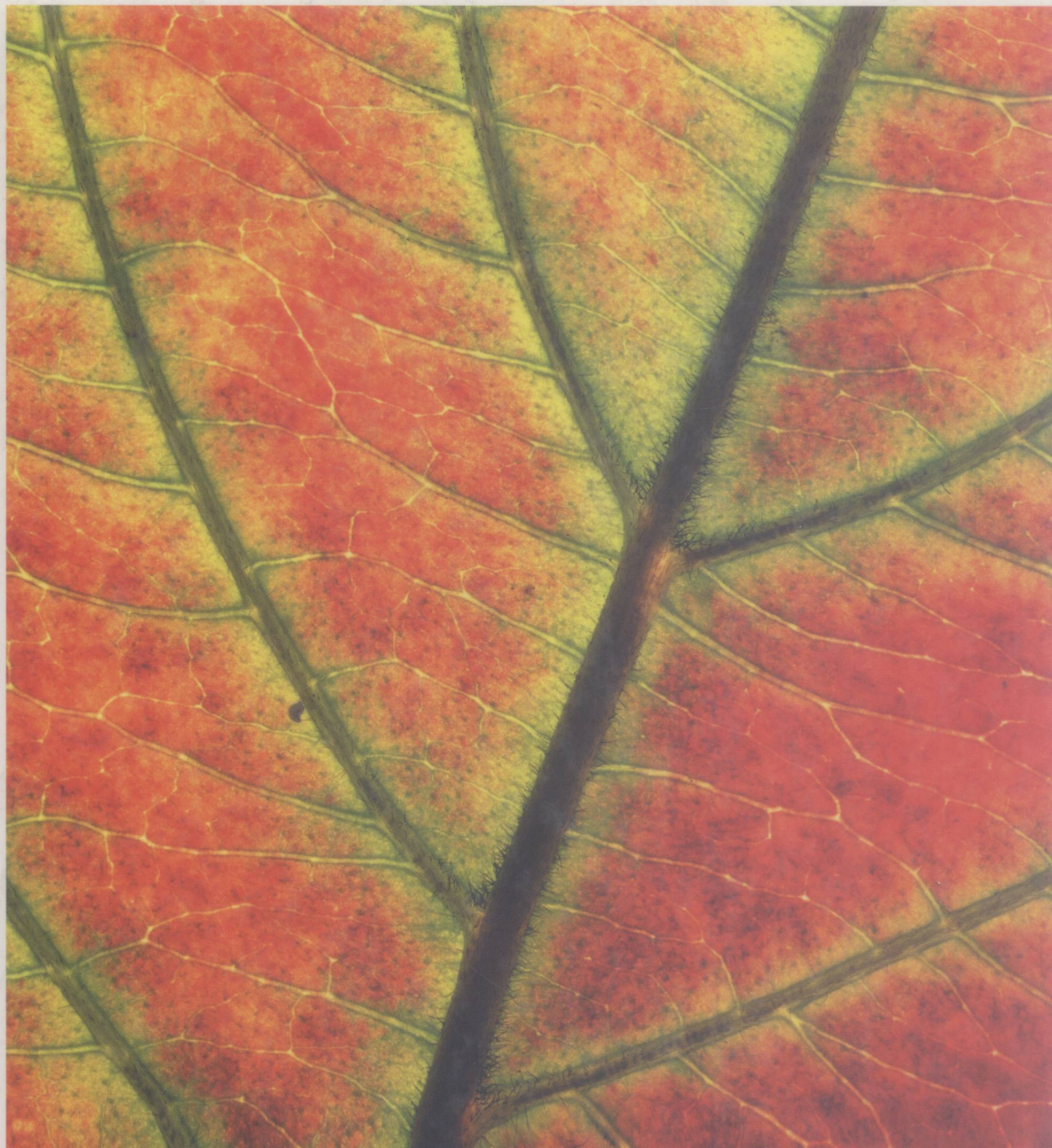
Zumdahl

Introductory Chemistry

A Foundation

FIFTH EDITION



Introductory Chemistry

A Foundation

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University of Illinois

Fifth Edition

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To David Scott Hendrie

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Introductory Chemistry A Foundation

Preface

In revising *Introductory Chemistry* we have rededicated ourselves to the goals we pursued in the first four editions: to make chemistry interesting, accessible, and understandable to the beginning student. For this edition, we have added unprecedented instructor support and additional student study support to further these goals in today's chemistry classroom.

Learning chemistry can be very rewarding. And even the novice, we believe, can relate the macroscopic world of chemistry—the observation of color changes and precipitate formation—to the microscopic world of ions and molecules. To achieve that goal, instructors are making a sincere attempt to provide more interesting and more effective ways to learn chemistry, and we hope that *Introductory Chemistry* will be perceived as a part of that effort. In this text we have presented concepts in a clear and sensible manner using language and analogies that students can relate to. We have also written the book in a way that supports active learning. In particular, the In-Class Discussion Questions, found at the end of each chapter, provide excellent material for collaborative work by students. In addition, we have connected chemistry to real-life experience at every opportunity, from chapter opening discussions of chemical applications to "Chemistry in Focus" features throughout the book. We are convinced that this approach will foster enthusiasm and real understanding as the student uses this text.

New to this Edition

Building on the success of previous editions of *Introductory Chemistry,* the following changes have been made to further enhance the text:

- **The Instructor's Toolkit** To assist instructors, coordinators, and the many adjunct professors teaching introductory chemistry we have created a new, comprehensive and integrated instructor support package. We have consolidated print and electronic resources to help instructors save time and to prepare effectively for class. (For more details of each resource see Supplements to the Text). The toolkit contains:

  A new *Instructor's Annotated Edition* with a wrap-around margin that appears as a "frame" around the student text page and consolidates much of the support previously supplied in separate manuals

  Complete Solutions Guide with detailed solutions

  HM ClassPrep, HM Testing, and *Chemistry Animations and Videos CD-ROMs* all conveniently located in one package

  Enhanced *Instructor web site*

  Updated printed *Test Bank*

- **Enhanced student support package** We have developed a range of student materials to address the needs of the increasing number of students who are less well prepared for this course. These resources have been designed to help students improve their basic math skills and to support good study habits. (For more details of each resource see Supplements to the Text). The following resources are automatically packaged with the text:

  Student web site including quizzes, interactive molecules, flashcards, problems linked to the text, and "Chemistry in Focus" boxes

SMARTHINKING™, live online tutoring by qualified chemistry professors

New *Math Review CD-ROM* (plus math tips in the text itself)

Student Study Card with formulas and study reminders

- A **new art program** enhances the visual impact of the text while clarifying important concepts. Illustrations have been updated to make it easier for students to connect molecular-level activity to macroscopic phenomena. Students can more readily see the connection between abstract chemical concepts and real-life situations, motivating them to learn the material.
- **Chapter 3 (Matter and Energy)** We have expanded our coverage of energy by adding a new section (3.6) that explains the concept of energy transfer as heat. In addition, we have explained exothermic and endothermic processes. Also, in this section, we give a full explanation of the concept of temperature as it relates to the microscopic motions of the particles in a system.
- **Chapter 10 (Modern Atomic Theory)** In Chapter 10 we have expanded our treatment of the atom by adding a section on the historical development of the structure of the atom. This material on Rutherford's work will give students a better perspective on how the current model of the atom was conceived. We have also greatly expanded our treatment of light with new emphasis on the properties of waves and the dual nature of light.
- We have replaced approximately one-third of the "Chemistry in Focus" boxes with new up-to-date topics.
- We have replaced many end-of-chapter questions and problems. For the instructor, answers to all the Self-Check and end-of-chapter exercises now appear in the wrap-around margins of the Instructor's Annotated Edition. In the student text, answers to Self-Checks and to even-numbered exercises are still provided at the back of the book.
- Content is now provided for WebCT and Blackboard systems. All content from the student web site, along with HMTesting content and assets from the instructor web site, is now available for professors using either of these popular course management systems.

Emphasis on Reaction Chemistry

We continue to emphasize chemical reactions early in the book, leaving the more abstract material on orbitals for later chapters. In a course in which many students encounter chemistry for the first time, it seems especially important that we present the chemical nature of matter before we discuss the theoretical intricacies of atoms and orbitals. Reactions are inherently interesting to students and can help us draw them to chemistry. In particular, reactions can form the basis for fascinating classroom demonstrations and laboratory experiments.

We have therefore chosen to emphasize reactions before going on to the details of atomic structure. Relying only on very simple ideas about the atom, Chapters 6 and 7 represent a thorough treatment of chemical reactions, including how to recognize a chemical change and what a chemical equation means. The properties of aqueous solutions are discussed in detail,

and careful attention is given to precipitation and acid–base reactions. In addition, a simple treatment of oxidation–reduction reactions is given. These chapters should provide a solid foundation, relatively early in the course, for reaction-based laboratory experiments.

For instructors who feel that it is desirable to introduce orbitals early in the course, prior to chemical reactions, the chapters on atomic theory and bonding (Chapters 10 and 11) can be covered directly after Chapter 4. Chapter 5 deals solely with nomenclature and can be used wherever it is needed in a particular course.

Development of Problem-Solving Skills

Problem-solving is a high priority in chemical education. We all want our students to acquire problem-solving skills. Fostering the development of such skills has been a central focus of the earlier editions of this text and we have maintained this approach in this edition.

In the first chapters we spend considerable time guiding students to an understanding of the importance of learning chemistry. At the same time, we explain that the complexities that can make chemistry frustrating at times can also provide the opportunity to develop the problem-solving skills that are beneficial in any profession. Learning to think like a chemist is useful to everyone. To emphasize this idea, we apply scientific thinking to some real-life problems in Chapter 1.

One reason chemistry can be challenging for beginning students is that they often do not possess the required mathematical skills. Thus we have paid careful attention to such fundamental mathematical skills as using scientific notation, rounding off to the correct number of significant figures, and rearranging equations to solve for a particular quantity. And we have meticulously followed the rules we have set down, so as not to confuse students.

Attitude plays a crucial role in achieving success in problem solving. Students must learn that a systematic, thoughtful approach to problems is better than brute force memorization. We foster this attitude early in the book, using temperature conversions as a vehicle in Chapter 2. Throughout the book we encourage an approach that starts with trying to represent the essence of the problem using symbols and/or diagrams, and ends with thinking about whether the answer makes sense. We approach new concepts by carefully working through the material before we give mathematical formulas or overall strategies. We encourage a thoughtful step-by-step approach rather than the premature use of algorithms. Once we have provided the necessary foundation, we highlight important rules and processes in skill development boxes so that students can locate them easily.

Many of the worked examples are followed by Self-Check exercises, which provide additional practice. The Self-Check exercises are keyed to end-of-chapter exercises to offer another opportunity for students to practice a particular problem-solving skill or understand a particular concept.

We have expanded the number of end-of-chapter exercises. As in the first four editions, the end-of-chapter exercises are arranged in "matched pairs," meaning that both problems in the pair explore similar topics. An Additional Problems section includes further practice in chapter concepts as well as more challenging problems. Cumulative reviews, which appear after every few chapters, test concepts from the preceding chapter block. Answers for all even-numbered exercises appear in a special section at the end of the student edition.

Handling the Language of Chemistry and Applications

We have gone to great lengths to make this book "student friendly" and have received enthusiastic feedback from students who have used it.

As in the earlier editions, we present a systematic and thorough treatment of chemical nomenclature. Once this framework is established, students can progress through the book comfortably.

Along with chemical reactions, applications form an important part of descriptive chemistry. Because students are interested in chemistry's impact on their lives, we have included many new "Chemistry in Focus" boxes, which describe current applications of chemistry. These special interest boxes cover such topics as using light as a sex attractant, the effects of asteroid impacts on the earth, plants that help control arsenic pollution, and the science behind common household materials such as broccoli, stainless steel, and carbonated beverages.

Visual Impact of Chemistry

Responding to instructors' requests to include graphic illustrations of chemical reactions, phenomena, and processes, our full-color design enables color to be used functionally, thoughtfully, and consistently to help students understand chemistry and to make the subject more inviting to them. We have included only those photos that illustrate a chemical reaction or phenomenon or that make a connection between chemistry and the real world. Many new photos enhance the fifth edition.

Choices of Coverage

For the convenience of instructors, four versions of the fifth edition are available: two paperback versions and two hardbound versions. *Basic Chemistry,* Fifth Edition, a paperback text, provides basic coverage of chemical concepts and applications through acid–base chemistry and has fifteen chapters. *Introductory Chemistry,* Fifth Edition, available in hardcover and paperback, expands the coverage to eighteen chapters with the addition of equilibrium, oxidation–reduction reactions and electrochemistry, radioactivity, and nuclear energy. Finally, *Introductory Chemistry: A Foundation,* Fifth Edition, a hardbound text, has twenty chapters, with the final two chapters providing a brief introduction to organic and biological chemistry.

Supplements for the Text

A main focus of this revision is to provide instructors and students with an unparalleled level of support. We considered all aspects of the ancillary package and how we could make them better suited to student and instructor needs.

For the Student

Student web site (chemistry.college.hmco.com/students)

Generic user name and password packaged automatically with all new texts. Includes Houghton Mifflin's ACE self-quizzing, interactive molecules, flashcards of key terms and concepts, and "Chemistry in Focus" boxes.

SMARTHINKING™ is our free, **live online tutoring service.** A passkey that is valid for twelve months from initial sign-on is packaged

automatically with all new texts. It allows access to support from a real professor or study resources from wherever students are, whenever they need help. With SMARTHINKING students can:

- Connect immediately to live help Sunday-Thursday, 2 P.M.–5 P.M. and 9 P.M.–1 A.M. EST
- Submit a question to get a response from an e-structor, usually within 24 hours
- Use the whiteboard with full scientific notation and graphics
- Preschedule time with an e-structor
- View past online sessions, questions, or essays in an archive on their personal academic homepage
- View their tutoring schedule
- Work on other projects while waiting for help

Math Review CD-ROM Packaged automatically with all new texts, this CD includes review and practice material for key math skills that students need in order to succeed in the course.

Student Study Card A laminated, two-sided study card with chemical formulas/reminders is included automatically with all new texts for students to use as a quick study aid.

***Introductory Chemistry Interactive* CD-ROM with Printed Media Activities package** This package is available for bundling with copies of Zumdahl, *Introductory Chemistry,* Fifth Edition, and is also available for sale separately. The handy guide provides information and access to technology resources available with the fifth edition. Package includes:

***Introductory Chemistry Interactive* Student CD-ROM** Highly interactive, offering topic summaries, conceptual enhancement, dynamic visualization, and more. Cross-platform (Macintosh/Windows) CD.

Printed Media Activities booklet These activities direct students to the technology resources provided to explore topics, learn concepts, and solve problems.

Study Guide by Donald DeCoste of the University of Illinois contains Chapter Discussions and Learning Review (practice chapter tests).

Solutions Guide by James F. Hall, University of Massachusetts—Lowell contains detailed solutions for the even-numbered end-of-chapter questions and exercises and Cumulative Review exercises.

Introductory Chemistry in the Laboratory by James F. Hall, University of Massachusetts—Lowell, contains experiments organized according to the topical presentation in the text. Annotations in the Instructors Annotated Edition indicate where the experiments from this manual are relevant to chapter content. The lab manual has been updated and revised for this edition.

For the Instructor

Instructors Annotated Edition The new Instructors Annotated Edition gathers a wealth of teaching support in one convenient package.

The IAE contains all 20 chapters (the full contents *of Introductory Chemistry: A Foundation,* Fifth Edition). Annotations in the new wrap-around margins of the IAE include:

- **Answers to Self-Check exercises,** at point-of-use.
- **Answers to all end-of-chapter questions and exercises,** at point-of-use
- **Additional Examples** with answers to supplement worked-out examples in the text
- **Using Technology** Information about incorporating animations and video clips from the electronic support materials in lecture
- **Teaching Support** Suggestions for specific lecture/instruction methods, activities, and in-class demonstrations to help convey concepts
- **Overview** An overview of the chapter's learning objectives
- **Teaching Tips** Guidelines for highlighting critical information in the chapter
- **Misconceptions** Tips on where students may have trouble or confusion with a topic
- **Demonstrations** Detailed instructions for in-class demonstrations and activities. (These are similar to material in Teaching Support, and may be referenced in Teaching Support annotations.)
- **Laboratory Experiments** Information on which labs in the *Laboratory Manual* are relevant to chapter content
- **Background Information** Explanations of conventions used in the text
- **Icons** mark material correlations between the main text and the electronic support materials, the *Test Bank,* the *Laboratory Manual,* and the figures available in the overhead transparency package.
- **Historical Notes** Biographical or other historical information about science and scientists

Complete Solutions Guide by James F. Hall, University of Massachusetts—Lowell, contains detailed solutions for all end-of-chapter questions and exercises and Cumulative Review exercises.

HMClass Prep with *HMTesting* Version 6.0 and *Chemistry Animations and Videos* CD-ROM package

This package is a 2-CD set containing the electronic lecture support materials for instructors. The set includes both the *HMClass Prep* with *HMTesting* CD-ROM and the *Chemistry Animations and Videos* CD listed below. It allows instructors to access both lecture aids and testing software in one place. The two CDs cannot be ordered separately from each other.

***HMClass Prep* with *HMTesting* Version V.6.0 and CD-ROM (Cross-platform—Macintosh/Windows)** *HMClass Prep* includes everything an instructor will need to develop lectures: Teaching note annotations from the IAE, PowerPoint slides with all text figures, tables, and many photos, as well as the *Test Bank* (MS Word files of the printed *Test Bank*).

HM Testing Version 6.0 combines a flexible test-editing program with a comprehensive gradebook function for easy administration and

tracking. *HM Testing* enables instructors to administer tests via network server or the Web. The *HM Testing* database can produce multiple-choice, true/false, fill-in-the-blank, and essay tests. Questions can be customized based on the chapter being covered, the question format, level of difficulty, and specific topics. *HM Testing* provides for the utmost security in accessing both test questions and grades.

Chemistry Animations and Videos V.2.0 CD-ROM (Cross-platform—Macintosh/Windows) Includes animations and video files that may be integrated into PowerPoint. Video files are selected from Video Series C. References to materials on this CD appear under the Using Technology annotations in the IAE and are marked with the CD icon.

Test Bank by Steven S. Zumdahl and Donald DeCoste, provides over 1600 multiple-choice, true-false, short-answer, matching, and completion questions. Approximately 300 questions from the previous edition have been replaced.

Instructor web site (chemistry.college.hmco.com/instructors) includes PowerPoint slides with all text figures, tables, and many photos; a list of lecture demos; discussion questions; and teaching notes from the textbook margins. User name and password required.

WebCT ePack and Blackboard Course Cartridge All content from the student web site, along with *HMTesting* content, is available for professors using either of these popular course management systems.

Transparencies package includes nearly 100 full-color acetates of selected illustrations from the text. Icons in the IAE margins indicate the figures that are available as acetates; all images are also available PowerPoint-ready on the *HMClassPrep* CD.

DVD contains all the video clips of lecture demonstrations from Video Series C, plus the animations of important chemical processes and concepts that are also available on the *Chemistry Animations and Videos* V.2.0 CD-ROM. The DVD is designed to provide another presentation option for instructors with DVD presentation technology.

Instructor's Guide for Introductory Chemistry in the Laboratory by James F. Hall includes general notes about each experiment, estimated completion time, materials required, and answers to both pre- and post-laboratory questions. Annotations in the IAE indicate where the experiments from this manual are relevant to chapter content. The lab manual has been updated and revised for this edition.

Houghton Mifflin Videotape Series A, B, C and D provide over 100 lecture demonstrations performed by John Luoma, Cleveland State University; John J. Fortman and Rubin Battino, Wright State University; Patricia L. Samuel; and Paul Kelter, University of North Carolina—Greensboro. Series C demonstrations appear on the *Chemistry Animations and Videos* V.2.0 CD-ROM and DVD as well.

We have worked hard to make this book and its supplements clear, interesting, and accurate. We would appreciate any comments that would make the book more useful to students and instructors.

Acknowledgments

A book such as this one depends on the expertise and dedication of many talented people. Richard Stratton, Executive Editor, is the ideal editor. He is knowledgeable, organized, considerate, and always supportive. Not only is he a great pleasure to work with, but he has outstanding taste in restaurants. Sara Wise and Bess Deck, development editors, have done an excellent job of helping to plan this revision and organizing its execution. They have been a tremendous help. Cathy Brooks, Senior Project Editor, is a truly outstanding project editor. It is a very secure feeling to know that she will always get it right. Sharon Donahue, Photo Researcher, has a real flair for choosing the right photos and I very much appreciate her efforts. Many thanks also to Jill Haber, Senior Production/Design Coordinator, who managed the design and typesetting of the book, and to Henry Rachlin, Designer, for a beautiful interior design.

I especially appreciate the efforts of Jim Hall of the University of Lowell who has been of tremendous help with the end-of-chapter questions and exercises and the Cumulative Review exercises. I also very much appreciate the help of my colleague Don DeCoste from the University of Illinois. Don designed the In-Class Discussion Questions and has had a big impact on my own teaching philosophy. As always I am especially grateful for the love and support of my wife Susan who truly understands the stresses and rewards of being an author. Finally I send my love and appreciation to my wonderful family: Mom and Dad, Scott, Whitney, Jessica, Joshua, Moriah and David, and Leslie and Steve and Tyler and Sunshine.

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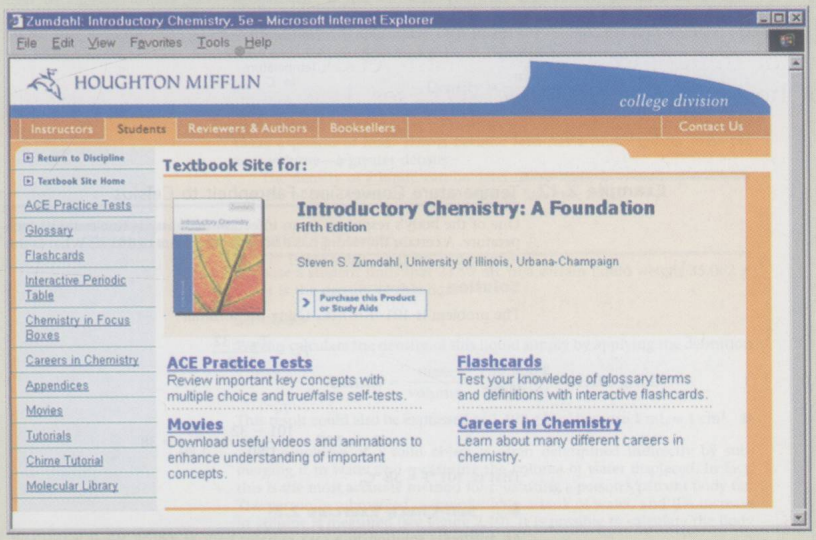
Features of *Introductory Chemistry,* Fifth Edition

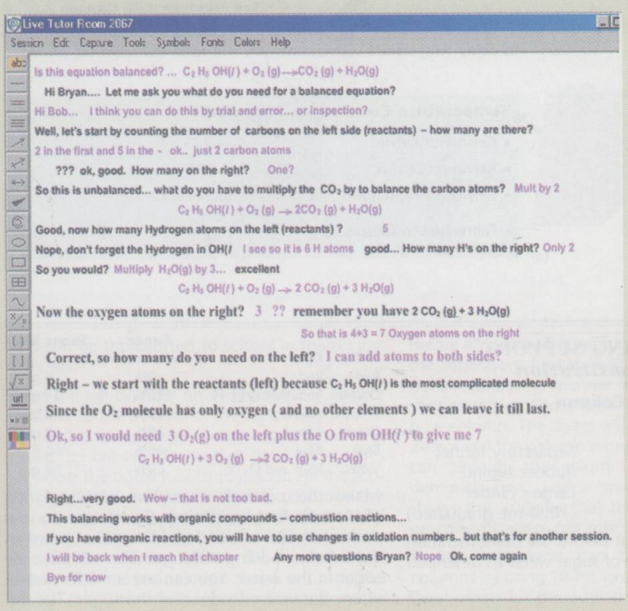
The fifth edition of *Introductory Chemistry* retains all of the qualities that have made it a trusted and authoritative first-year text. Its hallmark abilities to make chemistry interesting, accessible, and understandable to the beginning student are enhanced through superior teaching and learning support.

Unparalleled Learning Support

The Student Support Package comes automatically with all new texts. It includes the following resources to help students develop math and study skills.

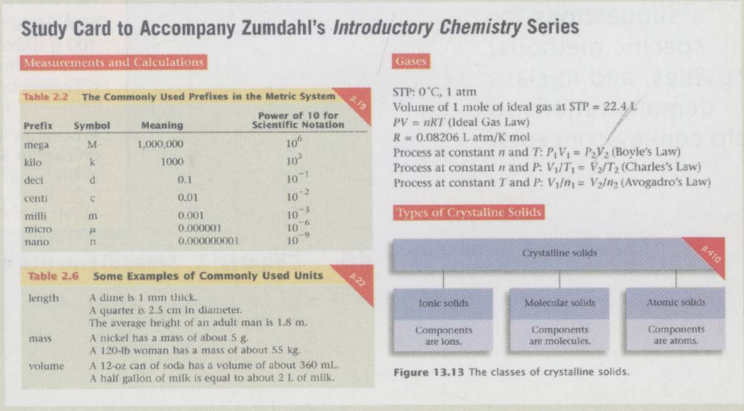


- The **Student web site** provides a full suite of interactive learning tools such as **ACE self-quizzing exercises** and **flashcards** to help students learn important concepts and terms. Generic user name and password packaged automatically with all new texts.



- **SMARTHINKING™** is **live, online tutoring.** A passkey offers twelve months of online, text-specific tutoring when students need it. Students can work one-on-one with an online tutor using a state-of-the-art whiteboard; submit a question anytime and receive a response, usually within 24 hours; and access additional study resources at any time.

- The **Student Study Card** is a two-sided quick study aid with chemical formulas and reminders.



The **Math Review CD-ROM** includes review and practice material for key math skills that students need in order to succeed in the course.

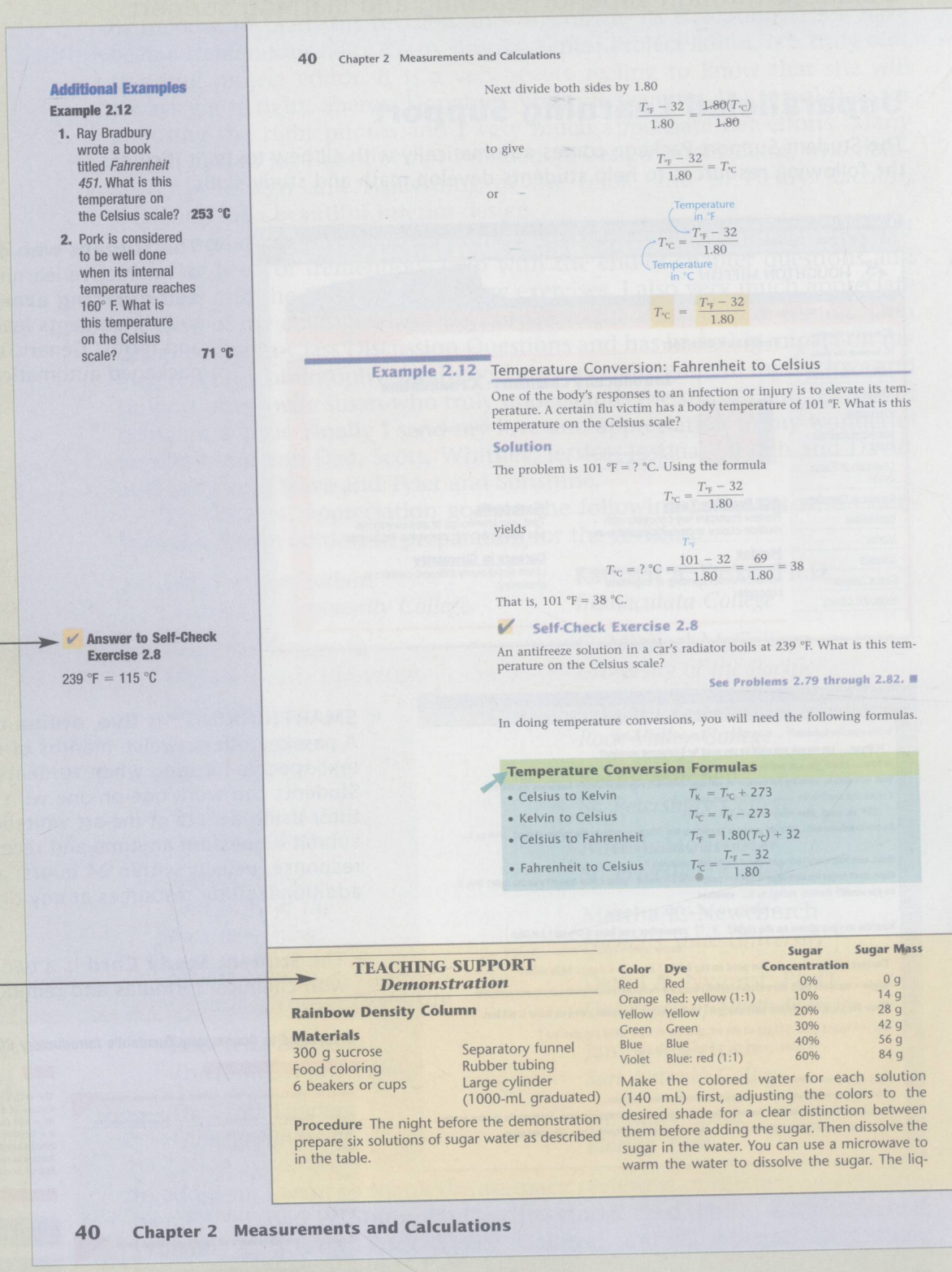
Unparalleled Teaching Support

We provide a comprehensive instructor support package to help save time in preparing for class.

The new **Instructor's Annotated Edition** is the capstone of an unprecedented package of instructor support. In addition to the entire contents of the student edition, the wrap-around margins of the IAE gather teaching support, additional examples, background material, suggestions for in-class demonstrations, references to print and technology resources, and answers to all questions and problems in the text, all at point-of-use.

Answers to Self-Check Exercises are provided at point-of-use, in the margin next to the corresponding exercises.

Teaching Support annotations are suggestions for specific methods, activities, and in-class demonstrations to help convey concepts.



Additional Examples

Example 2.12

1. Ray Bradbury wrote a book titled *Fahrenheit 451*. What is this temperature on the Celsius scale? **253 °C**
2. Pork is considered to be well done when its internal temperature reaches 160° F. What is this temperature on the Celsius scale? **71 °C**

Answer to Self-Check Exercise 2.8

239 °F = 115 °C

Next divide both sides by 1.80

$$\frac{T_F - 32}{1.80} = \frac{1.80(T_C)}{1.80}$$

to give

$$\frac{T_F - 32}{1.80} = T_C$$

or

$$T_C = \frac{T_F - 32}{1.80}$$

(Temperature in °F; Temperature in °C)

$$T_C = \frac{T_F - 32}{1.80}$$

Example 2.12 Temperature Conversion: Fahrenheit to Celsius

One of the body's responses to an infection or injury is to elevate its temperature. A certain flu victim has a body temperature of 101 °F. What is this temperature on the Celsius scale?

Solution

The problem is 101 °F = ? °C. Using the formula

$$T_C = \frac{T_F - 32}{1.80}$$

yields

$$T_C = ? \text{ °C} = \frac{101 - 32}{1.80} = \frac{69}{1.80} = 38$$

(T_F = 101)

That is, 101 °F = 38 °C.

Self-Check Exercise 2.8

An antifreeze solution in a car's radiator boils at 239 °F. What is this temperature on the Celsius scale?

See Problems 2.79 through 2.82. ■

In doing temperature conversions, you will need the following formulas.

Temperature Conversion Formulas

• Celsius to Kelvin	$T_K = T_C + 273$
• Kelvin to Celsius	$T_C = T_K - 273$
• Celsius to Fahrenheit	$T_F = 1.80(T_C) + 32$
• Fahrenheit to Celsius	$T_C = \frac{T_F - 32}{1.80}$

TEACHING SUPPORT
Demonstration

Rainbow Density Column

Materials

300 g sucrose
Food coloring
6 beakers or cups
Separatory funnel
Rubber tubing
Large cylinder (1000-mL graduated)

Procedure The night before the demonstration prepare six solutions of sugar water as described in the table.

Color	Dye	Sugar Concentration	Sugar Mass
Red	Red	0%	0 g
Orange	Red: yellow (1:1)	10%	14 g
Yellow	Yellow	20%	28 g
Green	Green	30%	42 g
Blue	Blue	40%	56 g
Violet	Blue: red (1:1)	60%	84 g

Make the colored water for each solution (140 mL) first, adjusting the colors to the desired shade for a clear distinction between them before adding the sugar. Then dissolve the sugar in the water. You can use a microwave to warm the water to dissolve the sugar. The liq-

Other components of the instructor support package include the **Complete Solutions Guide, chemistry animations and video clips, Instructor web site,** and complete print and electronic testing support. Content for **WebCT** and **Blackboard** users, **transparencies, lab materials,** and more are also available. (For more detail on each of these materials, see the supplements section in the Preface.)

2.8

Density

AIM: To define density and its units.

Lead has a greater density than feathers.

When you were in elementary school, you may have been embarrassed by your answer to the question "Which is heavier, a pound of lead or a pound of feathers?" If you said lead, you were undoubtedly thinking about density, not mass. **Density** can be defined as the amount of matter present *in a given volume* of substance. That is, density is mass per unit volume, the ratio of the mass of an object to its volume:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

It takes a much bigger volume to make a pound of feathers than to make a pound of lead. This is because lead has a much greater mass per unit volume—a greater density.

The density of a liquid can be determined easily by weighing a known volume of the substance as illustrated in Example 2.13.

Example 2.13 Calculating Density

Suppose a student finds that 23.50 mL of a certain liquid weighs 35.062 g. What is the density of this liquid?

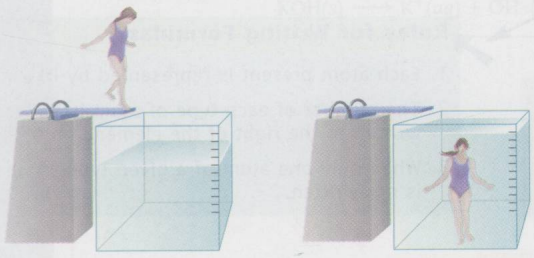
Solution

We can calculate the density of this liquid simply by applying the definition

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{35.062\ \text{g}}{23.50\ \text{mL}} = 1.492\ \text{g/mL}$$

This result could also be expressed as 1.492 g/cm^3 because 1 mL = 1 cm^3. ■

The volume of a solid object is often determined indirectly by submerging it in water and measuring the volume of water displaced. In fact, this is the most accurate method for measuring a person's percent body fat. The person is submerged momentarily in a tank of water, and the increase in volume is measured (see Figure 2.10). It is possible to calculate the body



(a) (b)

Figure 2.10
(a) Tank of water. (b) Person submerged in the tank, raising the level of the water.

uids can be transported to school in foam cups with lids.

Place the tall cylinder on a ring stand. Connect the hose to the bottom of the separatory funnel. Suspend the separatory funnel in an iron ring above the tall cylinder so that the hose reaches very near the bottom of the cylinder. Fill the separatory funnel with red solution (be sure the stopcock is closed). Add the red solution to the cylinder, being careful to fill the tube completely with the solution. Close the stopcock just before all of the red solution drains out. Add the orange solution and slowly open the stopcock to add it to the column. Again, close the stopcock before all of the solution has quite drained out of the separatory funnel. Add the remaining solutions in the same manner in order of increasing concentration. You should end up with a rainbow column. The layers will be visible for at least 24 hours if the column remains undisturbed. You can also stir the column at the end of the demonstration, which mixes the colors and shows the students that the density was based on concentration, not miscibility.

Variation Students can construct their own columns by using 10-mL graduated cylinders and Beral pipets for the addition of the colors. They must add the solutions from most to least dense.

Lecture Demonstration: 1.7, 1.8

Test Bank: 100–123

Section 2.8

DEMONSTRATION

Use a 1-L soda bottle to prepare a demonstration of density. Add 500 mL of vegetable oil and 500 mL of water (colored with food coloring). Tighten the top and shake. Allow the liquids to settle. Ask the students which liquid is more dense. You can extend your discussion to include an introduction to the immiscibility of oil and water. You can then ask students if a density column could be made from different concentrations of the same substance. See Teaching Support for the construction of such a column.

LABORATORY EXPERIMENT

A relevant laboratory experiment for this section is Experiment 4 from *Introductory Chemistry in the Laboratory*, by James Hall.

Additional Examples

Example 2.13

1. A block has a volume of 25.3 cm^3. Its mass is 21.7 g. Calculate the density of the block. **0.858 g/cm^3**

Demonstration annotations offer detailed instructions for additional in-class demonstrations and activities.

Laboratory Experiment annotations, marked with an icon, indicate which labs in the lab manual, *Introductory Chemistry in the Laboratory*, are relevant to chapter content.

Additional Examples, with answers, are provided to instructors to supplement worked examples in the text.

The **Chemistry in Focus** boxes describe current applications of chemistry. These special interest boxes help students see how chemistry applies to their lives by covering such topics as fat substitutes, the ozone layer, and alternative fuels.

CHEMISTRY IN FOCUS

Putting the Brakes on Arsenic

The toxicity of arsenic is well known. Indeed, arsenic has often been the poison of choice in classic plays and films—rent *Arsenic and Old Lace* sometime. Contrary to its treatment in the aforementioned movie, arsenic poisoning is a serious, contemporary problem. For example, the World Health Organization estimates that 77 million people in Bangladesh are at risk from drinking water that contains large amounts of naturally occurring arsenic. Recently, the Environmental Protection Agency announced more stringent standards for arsenic in U.S. public drinking water supplies. Studies show that prolonged exposure to arsenic can lead to a higher risk of bladder, lung, and skin cancers as well as other ailments, although the levels of arsenic that induce these symptoms remain in dispute in the scientific community.

Cleaning up arsenic-contaminated soil and water poses a significant problem. One approach is to find plants that will leach arsenic from the soil. Such a plant, the brake fern, recently has been shown to have a voracious appetite for arsenic. Research led by Lenna Ma, a chemist at the University of Florida in Gainesville, has shown that the brake fern accumulates arsenic at a rate 200 times that of the average plant. The arsenic, which becomes concentrated in fronds that grow up to 5 feet long, can be easily harvested and hauled away. Researchers are now investigating the best way to dispose of the plants so the arsenic can be isolated. The fern (*Pteris vittata*) looks promising for putting the brakes on arsenic pollution.

Lenna Ma and *Pteris vittata*—called the brake fern.

Important rules and steps appear in colored boxes so that students can locate them easily.

Many **Examples,** titled for easy reference, are located throughout the text. They model a thoughtful, step-by-step approach to solving problems.

Most examples are followed by **Self-Check Exercises,** which provide students with the opportunity to practice the skills they have just learned. The solutions to these exercises are provided at the back of the book.

Cross-references to similar end-of-chapter exercises are provided.

subscript 1 is always understood and not written). Following are some general rules for writing formulas:

Rules for Writing Formulas

1. Each atom present is represented by its element symbol.
2. The number of each type of atom is indicated by a subscript written to the right of the element symbol.
3. When only one atom of a given type is present, the subscript 1 is not written.

Example 4.1 Writing Formulas of Compounds

Write the formula for each of the following compounds, listing the elements in the order given.

a. Each molecule of a compound that has been implicated in the formation of acid rain contains one atom of sulfur and three atoms of oxygen.

b. Each molecule of a certain compound contains two atoms of nitrogen and five atoms of oxygen.

c. Each molecule of glucose, a type of sugar, contains six atoms of carbon, twelve atoms of hydrogen, and six atoms of oxygen.

Self-Check Exercise 4.1

Write the formula for each of the following compounds, listing the elements in the order given.

a. A molecule contains four phosphorus atoms and ten oxygen atoms.

b. A molecule contains one uranium atom and six fluorine atoms.

c. A molecule contains one aluminum atom and three chlorine atoms.

See Problems 4.19 and 4.20. ■

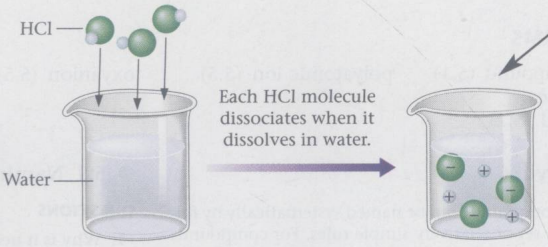
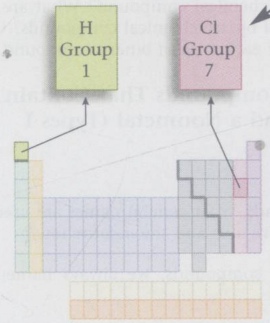


Figure 7.5
When gaseous HCl is dissolved in water, each molecule dissociates to produce H^+ and Cl^- ions. That is, HCl behaves as a strong electrolyte.



The Arrhenius definition of an acid: a substance that produces H^+ ions in aqueous solution.

$$HCl \xrightarrow{H_2O} H^+(aq) + Cl^-(aq)$$
$$HNO_3 \xrightarrow{H_2O} H^+(aq) + NO_3^-(aq)$$
$$H_2SO_4 \xrightarrow{H_2O} H^+(aq) + HSO_4^-(aq)$$

Arrhenius proposed that an **acid** *is a substance that produces H^+ ions (protons) when it is dissolved in water.*

Studies show that when HCl, HNO_3, and H_2SO_4 are placed in water, *virtually every molecule* dissociates to give ions. This means that when 100 molecules of HCl are dissolved in water, 100 H^+ ions and 100 Cl^- ions are produced. Virtually no HCl molecules exist in aqueous solution (see Figure 7.5). Because these substances are strong electrolytes that produce H^+ ions, they are called **strong acids.**

Arrhenius also found that *aqueous solutions that exhibit basic behavior* always contain hydroxide ions. He defined a **base** as a *substance that produces hydroxide ions (OH^-) in water.* The base most commonly used in the chemical laboratory is sodium hydroxide, NaOH, which contains Na^+ and OH^- ions and is very soluble in water. Sodium hydroxide, like all ionic substances, produces separated cations and anions when it is dissolved in water.

$$NaOH(s) \xrightarrow{H_2O} Na^+(aq) + OH^-(aq)$$

Although dissolved sodium hydroxide is usually represented as NaOH(*aq*), you should remember that the solution really contains separated Na^+ and OH^- ions. In fact, for every 100 units of NaOH dissolved in water, 100 Na^+ and 100 OH^- ions are produced.

Potassium hydroxide (KOH) has properties markedly similar to those of sodium hydroxide. It is very soluble in water and produces separated ions.

$$KOH(s) \xrightarrow{H_2O} K^+(aq) + OH^-(aq)$$

The marsh marigold is a beautiful but poisonous plant. Its toxicity results partly from the presence of erucic acid.

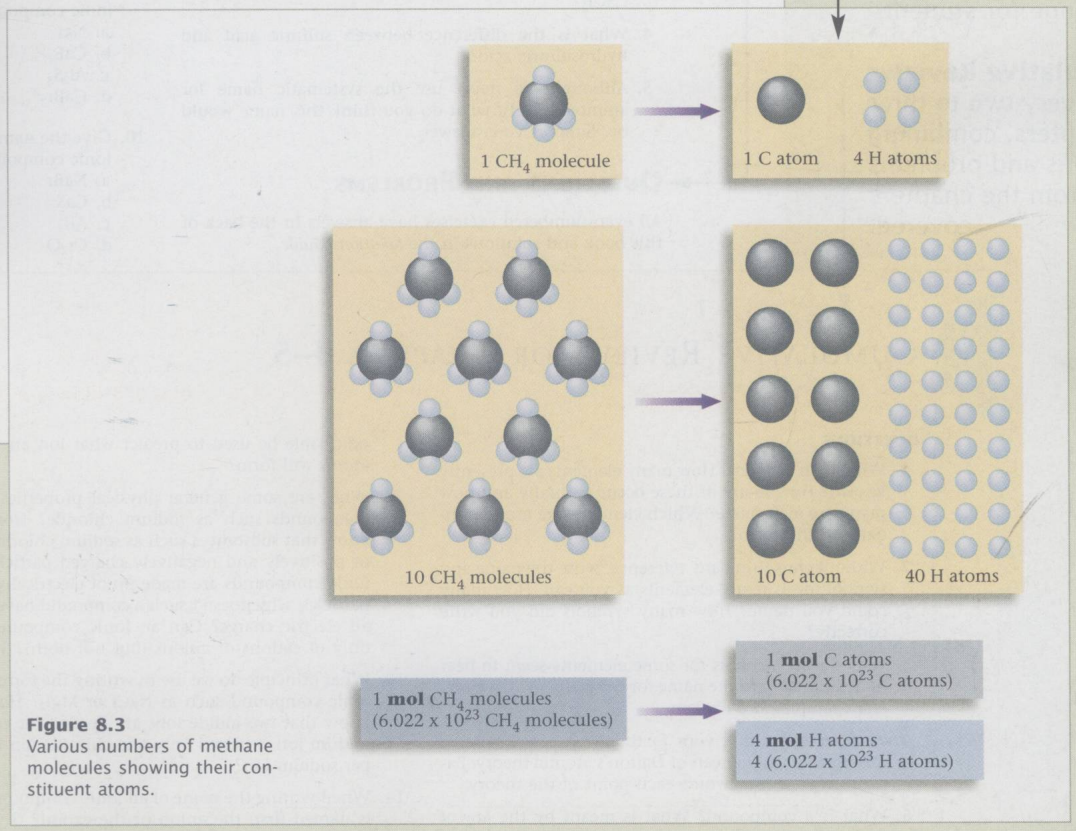


Figure 8.3
Various numbers of methane molecules showing their constituent atoms.

- The **illustrations and photos** provide visual representation of chemical reactions, phenomena, and processes to help students understand chemistry and to make it more inviting to them.
- Some of the more common elements are highlighted in **periodic table icons** to remind students about the position of selected elements and to help them become more familiar with the periodic table.
- **Revised drawings** make artwork more realistic and easier to read. The art program helps students understand the molecular basis for chemical phenomena.