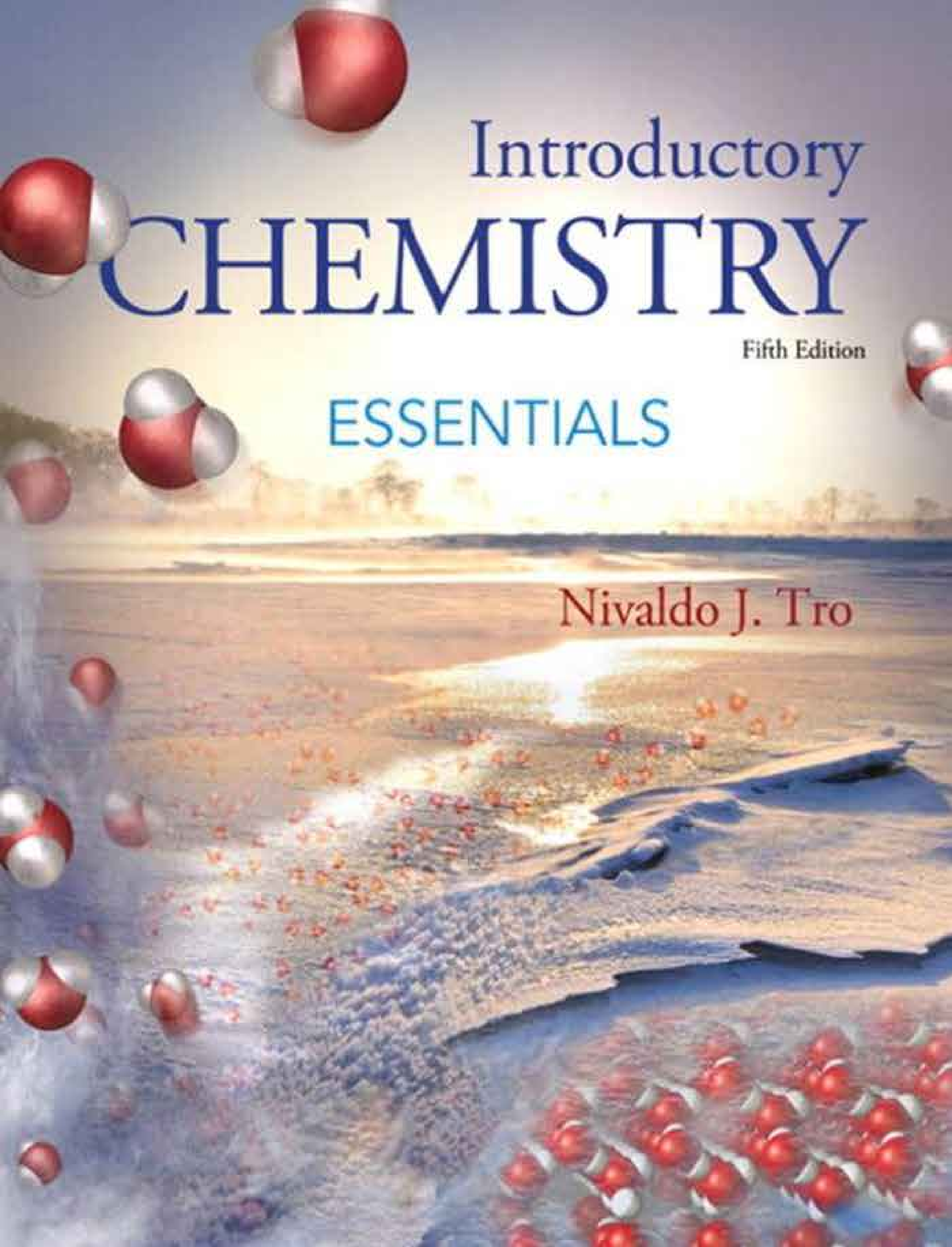
Introductory CHEMISTRY

Fifth Edition

ESSENTIALS

Nivaldo J. Tro



Periodic Table of the Elements

Key	
1	Atomic number
H	Element symbol
1.01	Atomic mass*
hydrogen	Element name

PERIOD	GROUP 1 1A	2 2A	3 3B	4 4B	5 5B	6 6B	7 7B	8 8B	9 8B
1	1 **H** 1.01 hydrogen								
2	3 **Li** 6.94 lithium	4 **Be** 9.01 beryllium							
3	11 **Na** 22.99 sodium	12 **Mg** 24.31 magnesium							
4	19 **K** 39.10 potassium	20 **Ca** 40.08 calcium	21 **Sc** 44.96 scandium	22 **Ti** 47.88 titanium	23 **V** 50.94 vanadium	24 **Cr** 52.00 chromium	25 **Mn** 54.94 manganese	26 **Fe** 55.85 iron	27 **Co** 58.93 cobalt
5	37 **Rb** 85.47 rubidium	38 **Sr** 87.62 strontium	39 **Y** 88.91 yttrium	40 **Zr** 91.22 zirconium	41 **Nb** 92.91 niobium	42 **Mo** 95.95 molybdenum	43 **Tc** (99) technetium	44 **Ru** 101.07 ruthenium	45 **Rh** 102.91 rhodium
6	55 **Cs** 132.91 cesium	56 **Ba** 137.33 barium	57 **La** 138.91 lanthanum	72 **Hf** 178.49 hafnium	73 **Ta** 180.95 tantalum	74 **W** 183.85 tungsten	75 **Re** 186.21 rhenium	76 **Os** 190.23 osmium	77 **Ir** 192.22 iridium
7	87 **Fr** (223) francium	88 **Ra** (226) radium	89 **Ac** (227) actinium	104 **Rf** (261) rutherfordium	105 **Db** (262) dubnium	106 **Sg** (263) seaborgium	107 **Bh** (262) bohrium	108 **Hs** (265) hassium	109 **Mt** (266) meitnerium

Lanthanide series	58 **Ce** 140.12 cerium	59 **Pr** 140.91 praseodymium	60 **Nd** 144.24 neodymium	61 **Pm** (147) promethium	62 **Sm** 150.36 samarium	63 **Eu** 151.97 europium
Actinide series	90 **Th** (232) thorium	91 **Pa** (231) protactinium	92 **U** (238) uranium	93 **Np** (237) neptunium	94 **Pu** (244) plutonium	95 **Am** (243) americium

*The mass number of an important radioactive isotope—not the atomic mass—is shown in parentheses for those elements with no stable isotopes.

Metals

Metalloids

Nonmetals

10 8B	11 1B	12 2B	13 3A	14 4A	15 5A	16 6A	17 7A	18 8A
								2 **He** 4.00 helium
			5 **B** 10.81 boron	6 **C** 12.01 carbon	7 **N** 14.01 nitrogen	8 **O** 16.00 oxygen	9 **F** 19.00 fluorine	10 **Ne** 20.18 neon
			13 **Al** 26.98 aluminum	14 **Si** 28.09 silicon	15 **P** 30.97 phosphorus	16 **S** 32.06 sulfur	17 **Cl** 35.45 chlorine	18 **Ar** 39.95 argon
28 **Ni** 58.69 nickel	29 **Cu** 63.55 copper	30 **Zn** 65.39 zinc	31 **Ga** 69.72 gallium	32 **Ge** 72.63 germanium	33 **As** 74.92 arsenic	34 **Se** 78.97 selenium	35 **Br** 79.90 bromine	36 **Kr** 83.80 krypton
46 **Pd** 106.42 palladium	47 **Ag** 107.87 silver	48 **Cd** 112.41 cadmium	49 **In** 114.82 indium	50 **Sn** 118.71 tin	51 **Sb** 121.75 antimony	52 **Te** 127.60 tellurium	53 **I** 126.90 iodine	54 **Xe** 131.29 xenon
78 **Pt** 195.08 platinum	79 **Au** 196.97 gold	80 **Hg** 200.59 mercury	81 **Tl** 204.38 thallium	82 **Pb** 207.2 lead	83 **Bi** 208.98 bismuth	84 **Po** (209) polonium	85 **At** (210) astatine	86 **Rn** (222) radon
110 **Ds** (281) darmstadtium	111 **Rg** (280) roentgenium	112 **Cn** (285)	113 **—** (284)	114 **Fl** (289)	115 **—** (288)	116 **Lv** (293)	117 ** (292)	118 **—** (294)

64 **Gd** 157.25 gadolinium	65 **Tb** 158.93 terbium	66 **Dy** 162.50 dysprosium	67 **Ho** 164.93 holmium	68 **Er** 167.26 erbium	69 **Tm** 168.93 thulium	70 **Yb** 173.04 ytterbium	71 **Lu** 174.97 lutetium
96 **Cm** (247) curium	97 **Bk** (247) berkelium	98 **Cf** (251) californium	99 **Es** (252) einsteinium	100 **Fm** (257) fermium	101 **Md** (258) mendelevium	102 **No** (259) nobelium	103 **Lr** (260) lawrencium

**Discovered in 2010, element 117 is currently under review by IUPAC.

INTRODUCTORY

CHEMISTRY

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INTRODUCTORY CHEMISTRY

Fifth Edition

Nivaldo J. Tro

Westmont College

PEARSON

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To Annie

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 ultra high vacuum. He then went on to the University of California at Berkeley, where he did post doctoral 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 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

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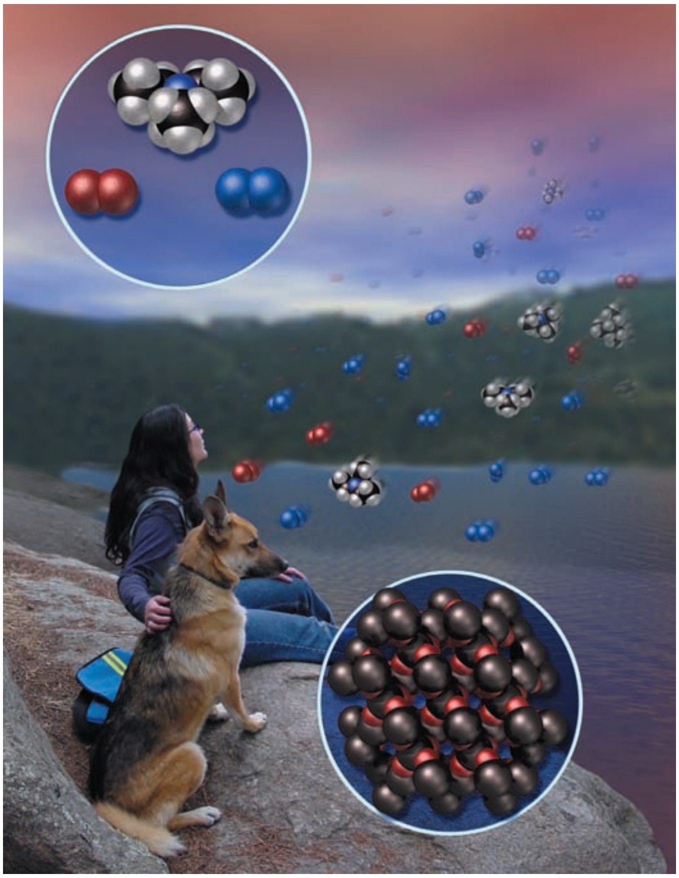

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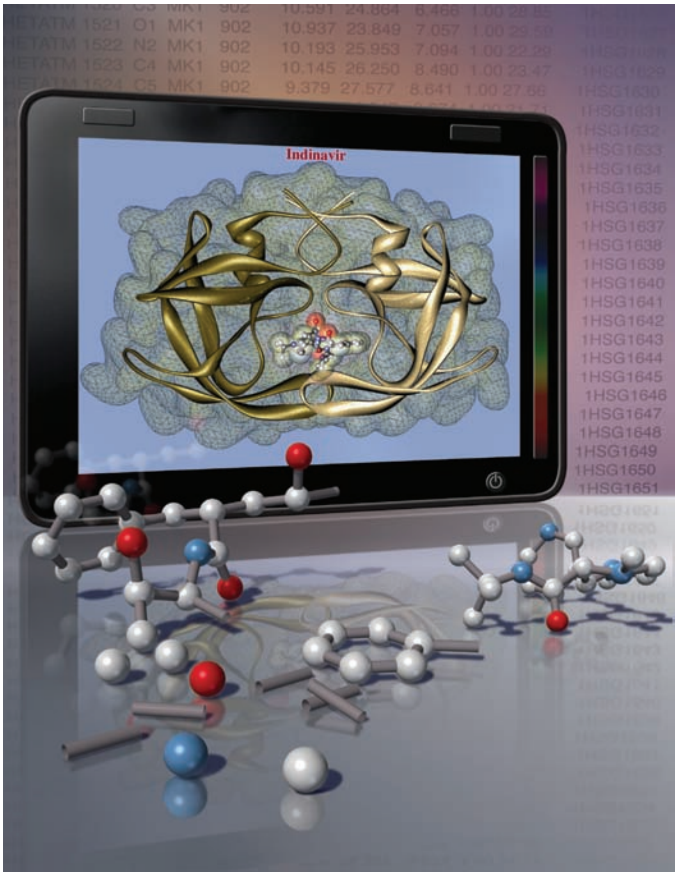
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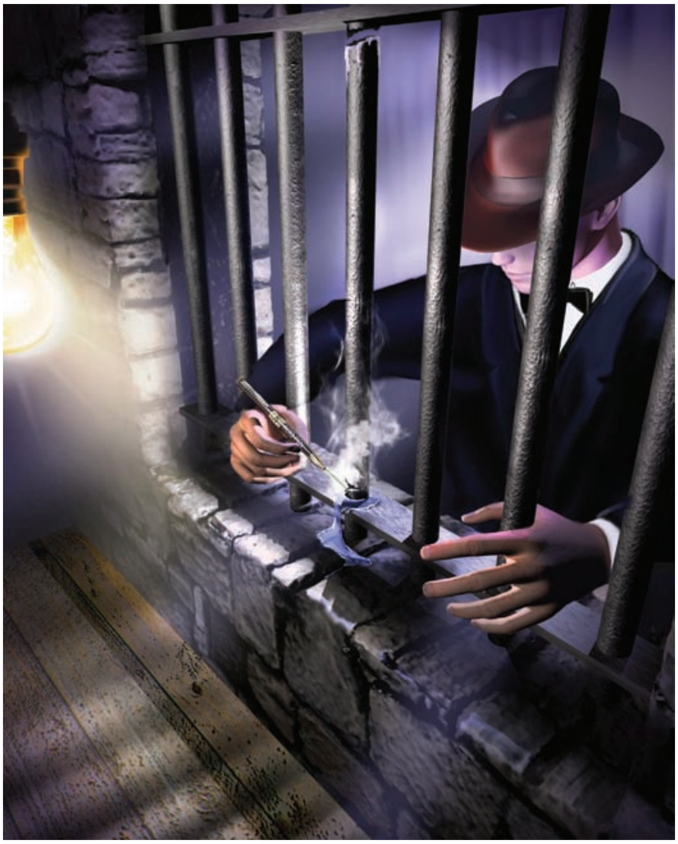

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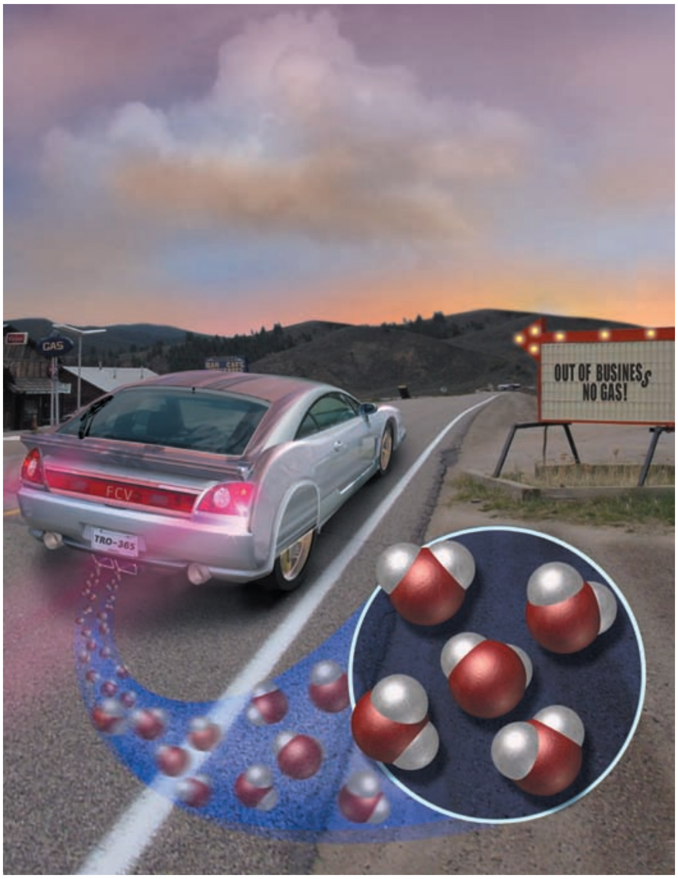

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Problem-Solving Procedures

To the Student

This book is for *you*, and every text feature is meant to help you learn. I have two main goals for you in this course: to see chemistry as you never have before and to develop the problem-solving skills you need to succeed in chemistry.

I want you to experience chemistry in a new way. I have written each chapter to show you that chemistry is not just something that happens in a laboratory; chemistry surrounds you at every moment. I have worked with several outstanding artists to develop photographs and art that will help you visualize the molecular world. From the opening example to the closing chapter, you will *see* chemistry. My hope is that when you finish this course, you will think differently about your world because you understand the molecular interactions that underlie everything around you.

My second goal is for you to develop problem-solving skills. No one succeeds in chemistry—or in life, really—without the ability to solve problems. I can't give you a formula for problem solving, but I can give you strategies that will help you develop the *chemical intuition* you need to understand chemical reasoning.

Look for several recurring structures throughout this book designed to help you master problem solving. The most important ones are (1) a four-step process (Sort, Strategize, Solve, and Check) designed to help you learn how to solve problems; (2) the solution map, a visual aid that helps you navigate your way through problems; (3) the two-column Examples, in which the left column explains in clear and simple language the purpose of each step of the solution shown in the right column; and (4) the three-column Examples, which describe a problem-solving procedure while demonstrating how it is applied to two different Examples. In addition, you will find a For More Practice feature at the end of each worked Example that directs you to the end-of-chapter problems that provide more opportunity to practice the skill(s) covered in the Example. In this edition, I have added a new tool for you at the end of each chapter: a Self-Assessment Quiz. These quizzes are designed to help you test yourself on the core concepts and skills of each chapter. You can also use them as you prepare for exams. Before an exam, take the quiz associated with each chapter that the exam will cover. The questions you miss on the quiz will reveal the areas you need to spend the most time studying.

Lastly, I hope this book leaves you with the knowledge that chemistry is *not* reserved only for those with some superhuman intelligence level. With the right amount of effort and some clear guidance, anyone can master chemistry, including you.

Sincerely,

Nivaldo J. Tro
tro@westmont.edu

To the Instructor

I thank all of you who have used any of the first four editions of *Introductory Chemistry*—you have made this book the most widely selling book in its market, and for that I am extremely grateful. The preparation of the fifth edition has enabled me to continue to refine the book to meet its fundamental purpose: teaching chemical skills in the context of relevance.

Introductory Chemistry is designed for a one-semester, college-level, introductory or preparatory chemistry course. Students taking this course need to develop problem-solving skills—but they also must see *why* these skills are important to them and to their world. *Introductory Chemistry* extends chemistry from the laboratory to the student's world. It motivates students to learn chemistry by demonstrating the role it plays in their daily lives.

This is a visual book. Wherever possible, I have used images to help communicate the subject. In developing chemical principles, for example, I worked with several artists to develop multipart images that show the connection between everyday processes visible to the eye and the molecular interactions responsible for those processes. This art has been further refined and improved in the fifth edition, making the visual impact sharper and more targeted to student learning. For example, you will note a hierarchical system of labeling in many of the images: The white-boxed labels are the most important, the tan-tint boxes are the second most important, and unboxed labels are the third most important. This allows me to treat related labels and annotations within an image in the same way, so that the relationships between them are immediately evident. My intent is to create an art program that teaches and that presents complex information clearly and concisely. Many of the illustrations showing molecular depictions of a real-world object or process have three parts: macroscopic (what we can see with our eyes); molecular and atomic (space-filling models that depict what the molecules and atoms are doing); and symbolic (how chemists represent the molecular and atomic world). The goal is for the student to begin to see the connections between the macroscopic world, the molecular world, and the representation of the molecular world with symbols and formulas.

I have also refined the problem-solving pedagogy to include four steps: Sort, Strategize, Solve, and Check. The *solution map*, which has been part of this book since the first edition, is now part of the *Strategize* step. This four-step procedure is meant to guide students as they learn chemical problem solving. Extensive flowcharts are also incorporated throughout the book, allowing students to visualize the organization of chemical ideas and concepts. The color scheme used in both the solution maps and the flowcharts is designed to have pedagogical value. More specifically, the solution maps utilize the colors of the visible spectrum—always in the same order, from violet to red.

Throughout the worked Examples in this book, I use a *two- or three-column* layout in which students learn a general procedure for solving problems of a particular type as they see this procedure applied to one or two worked Examples. In this format, the *explanation* of how to solve a problem is placed directly beside the actual steps in the *solution* of the problem. Many of you have said that you use a similar technique in lecture and office hours. Since students have specifically asked for connections between Examples and end-of-chapter problems, I include a For More Practice feature at the end of each worked Example that lists the review examples and end-of-chapter problems that provide additional opportunities to practice the skill(s) covered in the Example.

A successful new feature in the second edition was the Conceptual Checkpoints, a series of short questions that students can use to test their mastery of key concepts as they read through a chapter. Emphasizing understanding rather than calculation, they are designed to be easy to answer if the student has grasped the essential concept but difficult if he or she has not. Your positive remarks on this new feature prompted me to continue adding more of these to the fifth edition, including questions that highlight visualization of the molecular world.

This edition has allowed me to add four new global features to the book: Learning Outcomes (LOs), Group Questions, Self-Assessment Quizzes, and Interactive Worked Examples. You will find the learning outcomes underneath most section heads—many of the LOs are repeated in the end of chapter material with an associated worked example. You will find the Group Questions following the chapter exercises. You can assign these as homework if you would like, but you can also use them as in class activities to encourage active learning and peer-to-peer engagement. The Self-Assessment Quizzes are at the very beginning of the chapter review material. These quizzes are designed so that students can test themselves on the core concepts and skills of each chapter. I encourage my students to use these quizzes as they prepare for exams. For example, if my exam covers Chapters 5–8, I assign the quizzes for those chapters for credit (you can do this in MasteringChemistry®). Students then get a sort of pretest on the core material that will be on the exam. The Interactive Worked Examples are a new digital asset that we created for this edition. These examples are available in MasteringChemistry® and at the following website: www.pearsonhighered.com/irc. Each Interactive Worked Example walks the student through a key example from the book (the examples that have been made interactive are marked with a play icon in the book). At a key point in the Interactive Worked Example, the video pauses and the student is asked a question. These questions are designed to encourage students to be active in the learning process. Once the student answers the question, the video resumes to the end. A follow-up question can then be assigned for credit in MasteringChemistry®.

My goal in this new edition is to continue to help you make learning a more active (rather than passive) process for your students. The new Group Questions can help make your classroom more active. The new Conceptual Checkpoints, along with the new Self-Assessment Quizzes, make reading the book a more active process. The addition of the Interactive Worked Examples makes the media experience active as well. Research consistently shows that students learn better when they are actively engaged in the process. I hope the tools that I have provided here continue to aid you in teaching your students more effectively. Please feel free to e-mail me with any questions or comments you might have. I look forward to hearing from you as you use this book in your course.

Sincerely,

Nivaldo J. Tro
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Preface

New to This Edition

NEW! Key Learning Outcomes have been added to each chapter section. Learning outcomes correlate to the Chemical Skills and Examples in the end-of-chapter material and to MasteringChemistry®. Each section (after the introductory sections) has at least one learning outcome that summarizes the key learning objective of the material to help students focus their learning and assess their progress.

NEW! Self-Assessment Quizzes. Each chapter contains a 10-15 question multiple choice self-assessment quiz. These quizzes are designed to help students review the chapter material and prepare for exams.

NEW! 3–4 Questions for Group Work have been added to the end-of-chapter problems in each chapter to facilitate guided-inquiry learning both inside and outside the classroom.

NEW! 20 Interactive Worked Examples. Interactive Worked Examples are digital versions of the text's worked examples that make Tro's unique problem-solving strategies interactive, bringing his award-winning teaching directly to all students using his text. In these digital versions, students are instructed how to break down problems using Tro's proven Sort, Strategize, Solve, and Check technique. The Interactive Worked Examples can be accessed by scanning the QR code on the back cover allowing students to quickly access an office-hour type experience.

These problems are incorporated into MasteringChemistry® as assignable tutorial activities and are also available for download and distribution via the Instructor Resource Center (IRC) for instructional and classroom use.

More than 20 New Conceptual Checkpoints are in the fifth edition and are designed to make reading the book an active process. The checkpoints encourage students to stop and think about the ideas just presented before moving on and also provide a tool for self-assessment.

Interest Box Questions are now numbered in the Everyday Chemistry, Chemistry in the Environment, Chemistry in the Media, and Chemistry and Health boxes so that they can easily be assigned.

Cross-references to the Math Appendix, now indicated by a +/− icon in the fifth edition, are more visible and allow students to locate additional resources more easily.

Additional Features

- **A student-friendly, step-by-step, problem-solving approach is presented throughout** the book (fully introduced and explained in Chapter 2): Tro's unique two-and three-column examples help guide students through problems

step-by-step using Sort, Strategize, Solve, and Check. "Relationships Used" are also included in most worked examples.
- **In all chapters, figure labels follow a consistent hierarchy**. Three types of labels appear in the art. The most important information is in white shadow boxes; the second most important is in tinted boxes (with no border); and the third level of labels is unboxed.
- **All figures and figure captions have been carefully examined, and images and labels have been replaced or revised when needed** to improve the teaching focus of the art program.
- **Every end-of-chapter question has been carefully reviewed** by the author and editor and accordingly revised and/or replaced when necessary.

Some significant improvements have been made to key content areas as well. These include:

- To reflect recent changes made by IUPAC that introduce more uncertainty in atomic masses, the periodic tables on the inside front cover of the book and all subsequent periodic tables in the text containing atomic masses now include the modified following atomic masses: Li 6.94; S 32.06; Ge 72.63; Se 78.97; and Mo 95.95.
- In Chapter 1, *The Chemical World*, key wording about chemicals as well as the definition of chemistry have been changed to more strongly reflect particles and properties connection.
- In Section 2.3, *Significant Figures: Writing Numbers to Reflect Precision*, clarification has been added about trailing zeros in the significant digits discussion in Section 2.3.
- In Section 3.8, *Energy,* a new schematic has been added to the photo of the dam to better illustrate the concept of potential energy, and there is a new figure, Figure 3.15, *Potential Energy of Raised Weight*.
- Several new subheadings have been added to Chapter 5 to help students better navigate the material; Table 5.3, *Some Common Polyatomic Ions*, has been moved to an earlier place in Chapter 5; and fourth edition Example 5.7, *Writing Formulas for Ionic Compounds*, has been replaced with fifth edition Example 5.7, *Writing Formulas for Ionic Compounds Containing Polyatomic Ions*.
- In Chapter 6, Chemistry in the Environment box *Chlorine in Chlorofluorocarbons* has been revised and updated. Figure 6.3, *The Ozone Shield*, has been updated and revised to include a molecular perspective and be a better teaching tool and Figure 6.4, *Growth of the Ozone Hole*, has been updated with 2010 data.
- The transition between balancing chemical equations to investigating types of reactions at the beginning of Section 7.5, *Aqueous Solutions and Solubility: Compounds Dissolved in Water*, has been sharpened to help students relate Section 7.5 to the previous section.
- Figure 7.7, *Solubility Rules Flowchart*, has been edited so that Ca^{2+}, Sr^{2+}, and Ba^{2+} are in periodic table order throughout for easier memorization.
- The phrase "global warming" has been replaced with "climate change" throughout Chapter 8, *Quantities in Chemical Reactions*, and Figure 8.2, *Climate Change*, has been updated to include global temperature data for 2011 and 2012.
- In Section 9.1, *Blimps, Balloons, and Models of the Atom*, more emphasis has been placed on the relationship between atomic structure and properties in the discussion of helium and hydrogen.
- In Section 9.4, *The Bohr Model: Atoms with Orbits,* new introductory material has been added to emphasize the relationship between light emission and electron motion.

- Orbital representations in figures throughout Chapter 9 have been modified to be more accurate.
- Throughout Chapter 10, *Chemical Bonding*, the term *Lewis theory* has been replaced with *Lewis model*.
- In Chapter 11, *Gases,* an update about how newer jets pressurize their cabins has been added to the Everyday Chemistry box, *Airplane Cabin Pressurization*, and Table 11.5, *Changes in Pollutant Levels for Major U.S. Cities, 1980–2010*, has been updated to include the most recent available data.
- Content has been revised and material has been added to improve clarity in the subsection entitled *Surface Tension* in Section 12.3, *Intermolecular Forces in Action: Surface Tension and Viscosity*. Also, the caption for Figure 12.5, *Origin of Surface Tension*, has been revised and the phase inset figures in Figure 12.16, *Heating Curve during Melting*, have been corrected to show the phases more accurately.
- The new title for Section 12.6, *Types of Intermolecular Forces: Dispersion, Dipole–Dipole, Hydrogen Bonding, and Ion–Dipole*, reflects new content and new material about ion–dipole forces, including new Figure 12.25, *Ion–Dipole Forces*. Also, ion–dipole forces have been added to Table 12.5, *Types of Intermolecular Forces*, and the art in the table now depicts space-filling models of the molecules.
- Content in Section 13.3, *Solutions of Solids Dissolved in Water: How to Make Rock Candy*, links the discussion of solvent–solute interactions to the discussion of intermolecular forces in Chapter 12.
- Figure 14.19, *How Buffers Resist pH Change*, has been changed to be more useful and easier for students to understand.
- Section 14.11, *Acid Rain: An Environmental Problem Related to Fossil Fuel Combustion*, has been cut.
- New, brief introductory statements have been added to Section 15.6, *Calculating and Using Equilibrium Constants*, and in Section 15.10, *The Effect of a Temperature Change on Equilibrium*, numbers that indicate sequence have been added to the three unnumbered equations that indicate how equilibrium changes when heat is added or removed from exothermic and endothermic reactions.
- The title of Figure 16.12, *Used Voltaic Cell*, has been corrected, and the art has been slightly modified.
- Figure 16.18, *Schematic Diagram of a Fuel-Cell Breathalyzer*, in the box Everyday Chemistry: *The Fuel-Cell Breathalyzer* has also been modified for accuracy.
- Clarification has been added in Section 18.10, *Aromatic Hydrocarbons*, in the discussion of the carbon–carbon bonds in benzene.

The design and features of this text have been conceived to work together as an integrated whole with a single purpose: to help students understand chemical principles and to master problem-solving skills in a context of relevance. Students must be able not only to grasp chemical concepts and solve chemical problems, but also to understand how those concepts and problem-solving skills are relevant to their other courses, their eventual career paths, and their daily lives.

Teaching Principles

The development of basic chemical principles—such as those of atomic structure, chemical bonding, chemical reactions, and the gas laws—is one of the main goals of this text. Students must acquire a firm grasp of these principles in order to succeed in the general chemistry sequence or the chemistry courses that support the allied health curriculum. To that end, the book integrates qualitative and quantitative material and proceeds from concrete concepts to more abstract ones.

Organization of the Text

The main divergence in topic ordering among instructors teaching introductory and preparatory chemistry courses is the placement of electronic structure and chemical bonding. Should these topics come early, at the point where models for the atom are being discussed? Or should they come later, after the student has been exposed to chemical compounds and chemical reactions? Early placement gives students a theoretical framework within which they can understand compounds and reactions. However, it also presents students with abstract models before they understand why they are necessary. I have chosen a later placement for the following reasons:

1. **A later placement provides greater flexibility.** An instructor who wants to cover atomic theory and bonding earlier can simply cover Chapters 9 and 10 after Chapter 4. However, if atomic theory and bonding were placed earlier, it would be more difficult for the instructor to skip these chapters and come back to them later.
2. **A later placement allows earlier coverage of topics that students can more easily visualize.** Coverage of abstract topics too early in a course can lose some students. Chemical compounds and chemical reactions are more tangible than atomic orbitals, and their relevance is easier to demonstrate to the beginning student.
3. **A later placement gives students a reason to learn an abstract theory.** Once students learn about compounds and reactions, they are more easily motivated to learn a theory that explains compounds and reactions in terms of underlying causes.
4. **A later placement follows the scientific method.** In science, we normally make observations, form laws, and then build models or theories that explain our observations and laws. A later placement follows this ordering.

Nonetheless, I know that every course is unique and that each instructor chooses to cover topics in his or her own way. Consequently, I have written each chapter for maximum flexibility in topic ordering. In addition, the book is offered in two formats. The full version, *Introductory Chemistry*, contains 19 chapters, including organic chemistry and biochemistry. The shorter version, *Introductory Chemistry Essentials*, contains 17 chapters and omits these topics.

Print and Media Resources

For the Instructor

MasteringChemistry®

MasteringChemistry® is the first adaptive-learning online homework and tutorial system. Instructors can create online assignments for their students by choosing from a wide range of items, including end-of-chapter problems and research-enhanced tutorials. Assignments are automatically graded with up-to-date diagnostic information, helping instructors pinpoint where students struggle either individually or for the class as a whole. These questions can be used asynchronously outside of class as well. For the fifth edition, 20 new Interactive Worked Examples have been added to the Study Area. Icons appear next to examples indicating that a digital version is available.

NEW! Learning Catalytics™

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

- Assess students in real time, using open-ended tasks to probe student understanding.
- Understand immediately where students are and adjust your lecture accordingly.
- Improve your students' critical-thinking skills.
- Access rich analytics to understand student performance.
- Add your own questions to make Learning Catalytics™ fits your course exactly.
- Manage student interactions with intelligent grouping and timing.

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. Learning Catalytics™ is included with the purchase of Mastering with eText. Students purchasing Mastering without eText will be able to upgrade their Mastering accounts to include access to Learning Catalytics™. Michael Everest of Westmont College has written a set of questions in Learning Catalytics™ that correlates directly to the topics and concepts in *Introductory Chemistry*, 5e and encourages group-based inquiry learning.

NEW! Adaptive Follow-up Assignments in MasteringChemistry®

Instructors now have the ability to assign adaptive follow-up assignments to students. Content delivered to students as part of adaptive learning will be automatically personalized for each individual based on strengths and weaknesses identified by his or her performance on Mastering parent assignments.

NEW! Dynamic Study Modules, designed to enable students to study effectively on their own, as well as help students quickly access and learn the nomenclature they need to be more successful in chemistry. These modules can be accessed on smartphones, tablets, and computers and results can be tracked in the MasteringChemistry® Gradebook. How it works:

1. Students receive an initial set of questions and benefit from the metacognition involved with asking them to indicate how confident they are with their answer.
2. After answering each set of questions, students review their answers.
3. Each question has explanation material that reinforces the correct answer response and addresses the misconceptions found in the wrong answer choices.
4. Once students review the explanations, they are presented with a new set of questions. Students cycle through this dynamic process of test-learn-retest until they achieve mastery of the material.

Instructor's Manual with Complete Solutions (0-321-94906-4) by Mark Ott of Jackson Community College, and Matthew Johll of Illinois Valley Community College. This manual features lecture outlines with presentation suggestions, teaching tips, suggested in-class demonstrations, and topics for classroom discussion. It also contains full solutions to all the end-of-chapter problems from the text.

TestGen Testbank (0-321-94933-1) by Michael Hauser of St. Louis Community College. This download-only test bank includes more than 2000 questions and is available on the Instructor's Resource Center.

Instructor's Resource Materials (0-321-94932-3) This resource provides an integrated collection of resources to help instructors make efficient and effective use of their time and is available for download from the Instructor's Resource Center. The package features the following:

- All the art from the text, including figures and tables in JPG and PDF formats; movies; animations; Interactive Molecules; and the Instructor's Resource Manual files.
- Four PowerPoint™ presentations: (1) a lecture outline presentation for each chapter, (2) all the art from the text, (3) the worked Examples from the text, and (4) clicker questions.
- TestGen, a computerized version of the Test Item File that allows instructors to create and tailor exams to fit their needs.

Instructor's Guide for Student's Guided Activity Workbook (0-321-96118-8) by Michael Everest of Westmont College. This manual features assessible outcomes, facilitation tips, and demonstration suggestions to help integrate guided-inquiry learning in the classroom and is available for download on the Instructor's Resource Center.

For the Student

Pearson eText offers students the power to create notes, highlight text in different colors, create bookmarks, zoom, and view single or multiple pages. Access to the Pearson eText for *Introductory Chemistry*, Fifth Edition, is available for purchase either as a standalone item (ISBN 0-321-93363-X) or within MasteringChemistry® (ISBN 0-321-93434-2).

Study Guide (0-321-94905-6) by Donna Friedman of St. Louis Community College—Florissant Valley. Each chapter of the Study Guide contains an overview, key learning outcomes, a chapter review, as well as practice problems for each major concept in the text. Each chapter is followed by two or three self-tests with answers so students can check their work.

Student's Selected Solution Manual (0-321-94907-2) by Matthew Johll of Illinois Valley Community College. The manual provides solutions to those problems that have a short answer in the text's Answers section (problems numbered in blue in the text).

NEW! Student's Guided Activity Workbook (0-321-94908-0) by Michael Everest of Westmont College. This set of guided-inquiry activities enables students to construct chemical knowledge and related skills on their own. Each activity begins by presenting some information (as a table, figure, graph, text, etc.). Students, working in groups of 3–4, answer questions designed to draw their attention to the important concepts and trends exemplified in the information. Through their active participation in the learning process, students learn not only chemistry, but also a wide range of additional skills such as information processing, problem solving, deductive reasoning, and teamwork. There are approximately three complete worksheets to accompany each chapter in *Introductory Chemistry*, and each worksheet should take students from 50–60 minutes to complete. The activities can be used in place of, or as a supplement to, a lecture-based pedagogy. This supplement is available through Pearson Custom Library www.pearsoncustomlibrary.com.

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Lastly, I am indebted to the many reviewers, listed next, whose ideas are scattered 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.

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A Consistent Problem-Solving Strategy

Drawing from Professor Tro's experience in the classroom with his own students, ***Introductory Chemistry*, Fifth Edition** brings chemistry out of the laboratory and into the world—helping you learn chemistry by showing you how it manifests in your daily lives. Clear, specific examples are woven throughout to tell the story of chemistry. The **Fifth Edition** is also available with MasteringChemistry®, the premier online homework and assessment tool.

A CONSISTENT STRATEGY FOR SOLVING PROBLEMS helps you develop the skills you need to succeed in your chemistry course. Tro's unique two- and three-column examples help guide students through problems step-by-step using *Sort, Strategize, Solve, and Check*.

Two-Column Examples

All but the simplest examples are presented in a unique two-column format.

- The left column explains the purpose of each step, while the right column shows how the step is executed.
- This format will help you think about the reason for each step in the solution and fit the steps together.

EXAMPLE 2.13 SOLVING MULTISTEP CONVERSION PROBLEMS INVOLVING UNITS RAISED TO A POWER

The average annual per person crude oil consumption in the United States is 15,615 dm^3. What is this value in cubic inches?

SORT
You are given a volume in cubic decimeters and asked to convert it to cubic inches.

GIVEN: 15,615 dm^3

FIND: $in.^3$

STRATEGIZE
Build a solution map beginning with dm^3 and ending with $in.^3$ You must cube each of the conversion factors, because the quantities involve cubic units.

SOLUTION MAP

$$dm^3 \rightarrow m^3 \rightarrow cm^3 \rightarrow in.^3$$

$$\frac{(0.1\ m)^3}{(1\ dm)^3} \qquad \frac{(1\ cm)^3}{(0.01\ m)^3} \qquad \frac{(1\ in.)^3}{(2.54\ cm)^3}$$

RELATIONSHIPS USED
1 dm = 0.1 m (from Table 2.2)
1 cm = 0.01 m (from Table 2.2)
2.54 cm = 1 in. (from Table 2.3)

SOLVE
Follow the solution map to solve the problem. Begin with the given value in dm^3 and multiply by the string of conversion factors to arrive at $in.^3$ Be sure to cube each conversion factor as you carry out the calculation.

Round the answer to five significant figures to reflect the five significant figures in the least precisely known quantity (15,615 dm^3). The conversion factors are all exact and therefore do not limit the number of significant figures.

SOLUTION

$$15{,}615\ dm^3 \times \frac{(0.1\ m)^3}{(1\ dm)^3} \times \frac{(1\ cm)^3}{(0.01\ m)^3} \times \frac{(1\ in.)^3}{(2.54\ cm)^3} = 9.5289 \times 10^5\ in.^3$$

CHECK
Check your answer. Are the units correct? Does the answer make physical sense?

The units of the answer are correct, and the magnitude makes sense. A cubic inch is smaller than a cubic decimeter, so the value in cubic inches should be larger than the value in cubic decimeters.

▶SKILLBUILDER 2.13 | Solving Multistep Problems Involving Units Raised to a Power
How many cubic inches are there in 3.25 yd^3?

▶FOR MORE PRACTICE Problems 93, 94.

Solution Maps

Many of the examples use a unique visual approach in the *Strategize Step*, where you'll be shown how to draw a solution map for a problem.

Three-Column Examples

Procedures for solving certain problems are presented in a unique three-column format.

- The first column outlines the problem-solving procedure and explains the reasoning that underlies each step.
- The second and third columns show two similar but slightly different examples to solve this class of problem.
- Seeing the method applied to solve two related problems helps you understand the general procedure in a way that no single example could convey.

WRITING FORMULAS FOR IONIC COMPOUNDS	EXAMPLE 5.5 Write a formula for the ionic compound that forms from aluminum and oxygen.	EXAMPLE 5.6 Write a formula for the ionic compound that forms from magnesium and oxygen.
1. Write the symbol for the metal and its charge followed by the symbol of the nonmetal and its charge. For many elements, you can determine these charges from their group number in the periodic table (refer to Figure 4.14).	**SOLUTION** Al^{3+} O^{2-}	**SOLUTION** Mg^{2+} O^{2-}
2. Use the magnitude of the charge on each ion (without the sign) as the subscript for the other ion.	Al^{3+} O^{2-} → Al_2O_3	Mg^{2+} O^{2-} → Mg_2O_2
3. If possible, reduce the subscripts to give a ratio with the smallest whole numbers.	In this case, you cannot reduce the numbers any further; the correct formula is Al_2O_3.	To reduce the subscripts, divide both subscripts by 2. $Mg_2O_2 \div 2 = MgO$
4. Check to make sure that the sum of the charges of the cations exactly cancels the sum of the charges of the anions.	Cations: 2(3+) = 6+ Anions: 3(2−) = 6− The charges cancel.	Cations: 2+ Anions: 2− The charges cancel.
	▶SKILLBUILDER 5.5 | Write a formula for the compound that forms from strontium and chlorine.	**▶SKILLBUILDER 5.6 |** Write a formula for the compound that forms from aluminum and nitrogen. **▶FOR MORE PRACTICE** Problems 53, 54, 57.

Skillbuilder Exercises

Every worked example is followed by at least one similar (but unworked) Skillbuilder exercise.

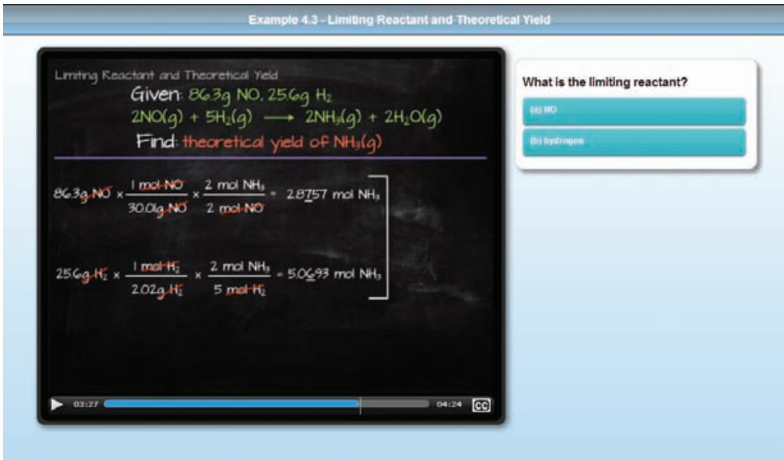
For More Practice

These follow every worked example, linking you to in-chapter examples and end-of-chapter problems that give you a chance to practice the skills explained in each worked example.

NEW! INTERACTIVE WORKED EXAMPLES

Interactive Worked Examples are digital versions of the text's worked examples that make Tro's unique problem-solving strategies interactive, bringing his award-winning teaching directly to all students using his text. In these digital versions, students are instructed how to break down problems using Tro's proven *Sort, Strategize, Solve, and Check* technique. The Interactive Worked Examples can be accessed by scanning the QR code on the back cover allowing students to quickly access an office-hour type experience.

These problems are incorporated into MasteringChemistry® as assignable tutorial activities and are also available for download and distribution via the Instructor Resource Center (IRC) for instructional and classroom use.



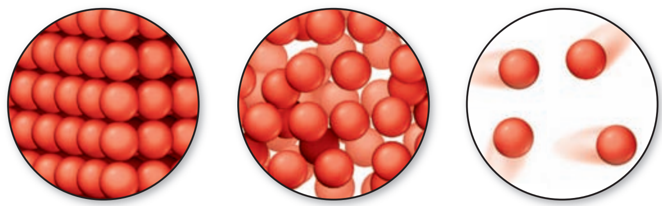
CONCEPTUAL UNDERSTANDING completes the picture. In every chemistry course you take, success requires more than problem-solving skills. Real understanding of concepts will help you see why these skills are important to you and to your world.

Conceptual Checkpoints

Conceptual questions enhance understanding of chemical principles, encourage you to stop and think about the ideas just presented, and provide a tool to assess your own progress. Answers and explanations are given at the end of each chapter. More than 20 new **Conceptual Checkpoints** have been added—many with a focus on visualization and drawing.

CONCEPTUAL CHECKPOINT 3.1

Which image best represents matter in the gas state?



(a) (b) (c)

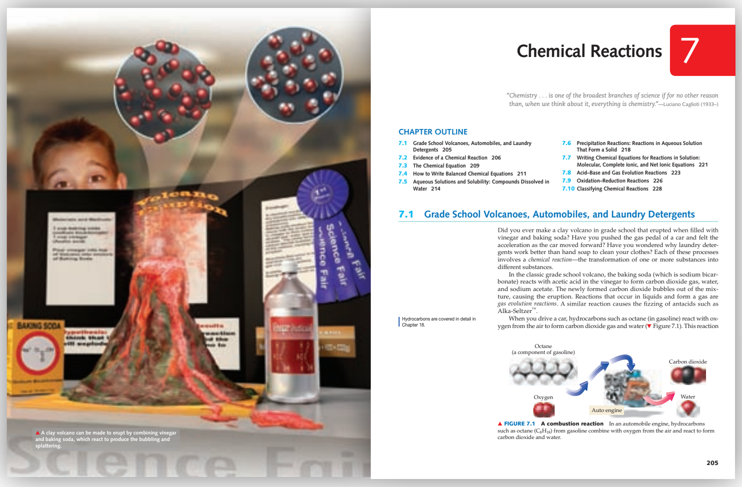
Note: You can find the answers to all Conceptual Checkpoints at the end of the chapter.

Visualizing Chemistry Creates Deeper Understanding

BY CONNECTING the macroscopic and microscopic worlds, visualizing concepts brings chemistry to life and creates a deeper understanding that will serve you throughout the course.

Chapter Openers

Dr. Tro opens each chapter with a specific example of a concept to grab your attention, stepping back to make a more general and relatable analogy, and then going back into specifics. This style reflects Dr. Tro's teaching methodology, effectively used in his own classroom.



Chemical Reactions 7

"Chemistry . . . is one of the broadest branches of science if for no other reason than, when we think about it, everything is chemistry."—Luciano Caglioti (1933–)

CHAPTER OUTLINE

7.1 Grade School Volcanoes, Automobiles, and Laundry Detergents

Did you ever make a clay volcano in grade school that erupted when filled with vinegar and baking soda? Have you pushed the gas pedal of a car and felt the acceleration as the car moved forward? Have you wondered why laundry detergents work better than hand soap to clean your clothes? Each of these processes involves a *chemical reaction*—the transformation of one or more substances into different substances.

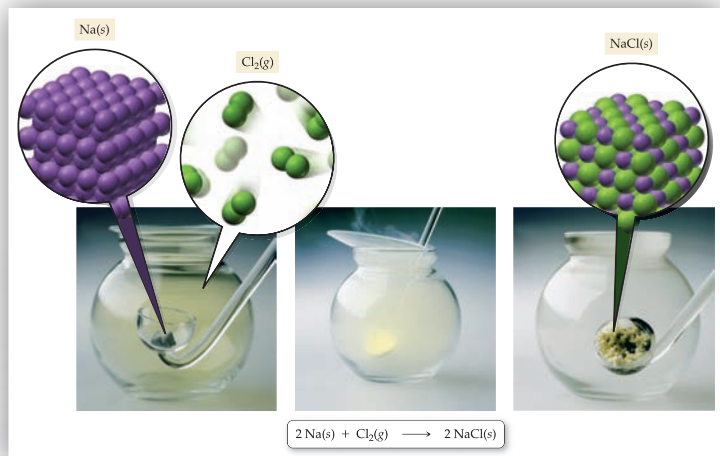
In the classic grade school volcano, the baking soda (which is sodium bicarbonate) reacts with acetic acid in the vinegar to form carbon dioxide gas, water, and sodium acetate. The newly formed carbon dioxide bubbles out of the mixture, causing the eruption. Reactions that occur in liquids and form a gas are *gas evolution reactions*. A similar reaction causes the fizzing of antacids such as Alka-Seltzer™.

Hydrocarbons are covered in detail in Chapter 18.

When you drive a car, hydrocarbons such as octane (in gasoline) react with oxygen from the air to form carbon dioxide gas and water (▼ Figure 7.1). This reaction

▲ FIGURE 7.1 **A combustion reaction** In an automobile engine, hydrocarbons such as octane (C_8H_{18}) from gasoline combine with oxygen from the air and react to form carbon dioxide and water.

205



MACROSCOPIC TO MICROSCOPIC ART

The goal is for you to connect what you see and experience with the molecules responsible and with the way chemists represent those molecules.

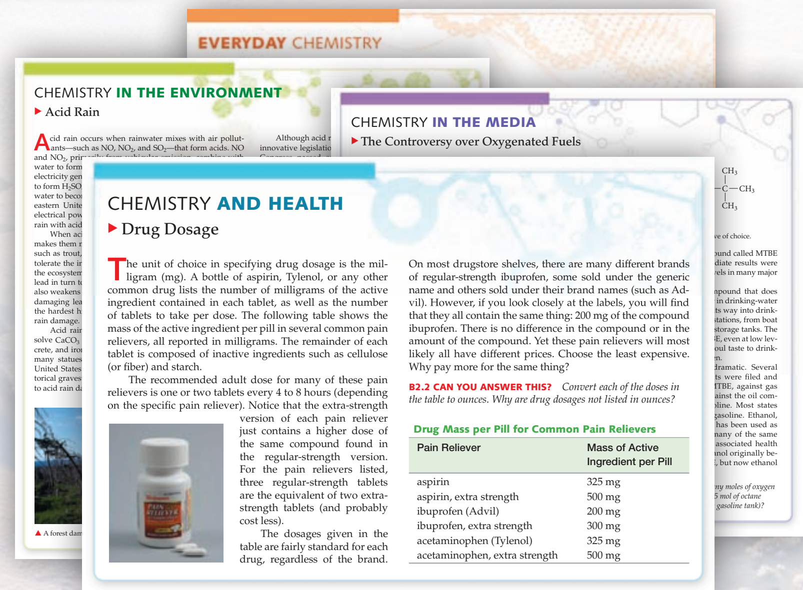
Many illustrations have three parts:

- a macroscopic image (what you can see with your eyes)
- a microscopic image (what the molecules are doing)
- a symbolic representation (how chemists represent the process with symbols and equations)

INTEREST BOXES

Four different types of interest boxes apply chemistry to everyday events and topics. The questions within these boxes have been numbered so they may be assigned.

- **Chemistry in the Environment** boxes discuss environmental issues that are closely tied to chemistry, such as the reactions involved in ozone depletion.
- **Everyday Chemistry** boxes demonstrate the importance of chemistry in everyday situations, such as bleaching your hair.
- **Chemistry in the Media** boxes discuss chemical topics that have been in the news recently, such as the controversy over oxygenated fuels.
- **Chemistry and Health** boxes focus on personal health and fitness topics, as well as biomedical topics.



EVERYDAY CHEMISTRY

CHEMISTRY IN THE ENVIRONMENT

▶ Acid Rain

CHEMISTRY IN THE MEDIA

▶ The Controversy over Oxygenated Fuels

CHEMISTRY AND HEALTH

▶ Drug Dosage

The unit of choice in specifying drug dosage is the milligram (mg). A bottle of aspirin, Tylenol, or any other common drug lists the number of milligrams of the active ingredient contained in each tablet, as well as the number of tablets to take per dose. The following table shows the mass of the active ingredient per pill in several common pain relievers, all reported in milligrams. The remainder of each tablet is composed of inactive ingredients such as cellulose (or fiber) and starch.

The recommended adult dose for many of these pain relievers is one or two tablets every 4 to 8 hours (depending on the specific pain reliever). Notice that the extra-strength version of each pain reliever just contains a higher dose of the same compound found in the regular-strength version. For the pain relievers listed, three regular-strength tablets are the equivalent of two extra-strength tablets (and probably cost less).

The dosages given in the table are fairly standard for each drug, regardless of the brand. On most drugstore shelves, there are many different brands of regular-strength ibuprofen, some sold under the generic name and others sold under their brand names (such as Advil). However, if you look closely at the labels, you will find that they all contain the same thing: 200 mg of the compound ibuprofen. There is no difference in the compound or in the amount of the compound. Yet these pain relievers will most likely all have different prices. Choose the least expensive. Why pay more for the same thing?

B2.2 CAN YOU ANSWER THIS? *Convert each of the doses in the table to ounces. Why are drug dosages not listed in ounces?*

Drug Mass per Pill for Common Pain Relievers

Pain Reliever	Mass of Active Ingredient per Pill
aspirin	325 mg
aspirin, extra strength	500 mg
ibuprofen (Advil)	200 mg
ibuprofen, extra strength	300 mg
acetaminophen (Tylenol)	325 mg
acetaminophen, extra strength	500 mg

Enhanced End-of-Chapter Material

CHAPTER REVIEW

Consistent review material at the end of each chapter helps reinforce what you've learned.

Chemical Principles

The left column summarizes the key principles that you should take away from the chapter, and the right column tells why each topic is important for you to understand.

Chemical Principles	Relevance
Uncertainty: Scientists report measured quantities so that the number of digits reflects the certainty in the measurement. Write measured quantities so that every digit is certain except the last, which is estimated.	**Uncertainty:** Measurement is a hallmark of science, and you must communicate the precision of a measurement with the measurement so that others know how reliable the measurement is. When you write or manipulate measured quantities, you must show and retain the precision with which the original measurement was made.
Units: Measured quantities usually have units associated with them. The SI unit for length is the meter; for mass, the kilogram; and for time, the second. Prefix multipliers such as *kilo-* or *milli-* are often used in combination with these basic units. The SI units of volume are units of length raised to the third power; liters or milliliters are often used as well.	**Units:** The units in a measured quantity communicate what the quantity actually is. Without an agreed-on system of units, scientists could not communicate their measurements. Units are also important in calculations, and the tracking of units throughout a calculation is essential.
Density: The density of a substance is its mass divided by its volume, $d = m/V$, and is usually reported in units of grams per cubic centimeter or grams per milliliter. Density is a fundamental property of all substances and generally differs from one substance to another.	**Density:** The density of substances is an important consideration in choosing materials for manufacturing and production. Airplanes, for example, are made of low-density materials, while bridges are made of higher-density materials. Density is important as a conversion factor between mass and volume and vice versa.

NEW! Chemical Skills with Key Learning Outcomes

The left column describes the key skills you should know after reading the chapter, which often correlate to a *Key Learning Outcome* that has been added at the section level. The right column contains a worked example illustrating that skill.

Chemical Skills	Examples
LO: Express very large and very small numbers using scientific notation (Section 2.2). To express a number in scientific notation: • Move the decimal point to obtain a number between 1 and 10. • Write the decimal part multiplied by 10 raised to the number of places you moved the decimal point. • The exponent is positive if you moved the decimal point to the left and negative if you moved the decimal point to the right.	**EXAMPLE 2.18 SCIENTIFIC NOTATION** Express the number 45,000,000 in scientific notation. 45,000,000 7 6 5 4 3 2 1 4.5×10^7

CHAPTER IN REVIEW

Self-Assessment Quiz

Q1. How many atoms are there in 5.8 mol helium?

(a) 23.2 atoms

(b) 9.6×10^{-24} atoms

(c) 5.8×10^{23} atoms

(d) 3.5×10^{24} atoms

Q2. A sample of pure silver has a mass of 155 g. How many moles of silver are in the sample?

(a) 1.44 mol

(b) 1.67×10^4 mol

(c) 0.696 mol

(d) 155 mol

NEW! Chapter Self-Assessment Quiz

The end of each chapter consists of 10–15 multiple-choice questions that are similar to those on other standardized exams and will also be assignable and randomized in MasteringChemistry®.

NEW! *Group-Based* Questions

have been added to the end-of-chapter problems in each chapter, facilitating guided-inquiry learning both inside and outside the classroom. A new *Guided Activity Workbook* (available in the Pearson Custom Library (www.pearsoncustomlibrary.com)) has also been created to use alongside Tro's textbook. A set of interactive *Critical Thinking Questions* that is tailored toward guided learning is also available for instructors at the Instructor Resource Center (www.pearsonhighered.com/irc).

QUESTIONS FOR GROUP WORK

Discuss these questions with the group and record your consensus answer.

121. Complete the following table.

Particle	Mass (amu)	Charge	In the nucleus? (yes/no)	# in ^{32}S atom	# in $^{79}Br^-$ ion
Proton					
Neutron					
Electron					

122. Make a sketch of an oxygen atom. Include the correct number of protons, electrons, and neutrons for the most abundant isotope. Use the following symbols: proton = ●, neutron = o, electron = ●.

123. The table at right includes data similar to that used by Mendeleev when he made the periodic table. Write on a small card the symbol, atomic mass, and a stable compound formed by each element. Arrange your cards in order of increasing atomic mass. Do you observe any repeating patterns? Describe any patterns you observe. (*Hint*: There is one missing element somewhere in the pattern.)

Element	Atomic Mass	Stable Compound	Element	Atomic Mass	Stable Compound
Be	9	$BeCl_2$	O	16	H_2O
S	32	H_2S	Ga	69.7	GaH_3
F	19	F_2	As	75	AsF_3
Ca	40	$CaCl_2$	C	12	CH_4
Li	7	LiCl	K	39	KCl
Si	28	SiH_4	Mg	24.3	$MgCl_2$
Cl	35.4	Cl_2	Se	79	H_2Se
B	10.8	BH_3	Al	27	AlH_3
Ge	72.6	GeH_4	Br	80	Br_2
N	14	NF_3	Na	23	NaCl

124. Arrange the cards from Question 123 so that mass increases from left to right and elements with similar properties are above and below each other. Copy the periodic table you have invented onto a piece of paper. There is one element missing. Predict its mass and a stable compound it might form.

Additional End-of-Chapter Features

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- Cumulative Problems
- Conceptual Problems
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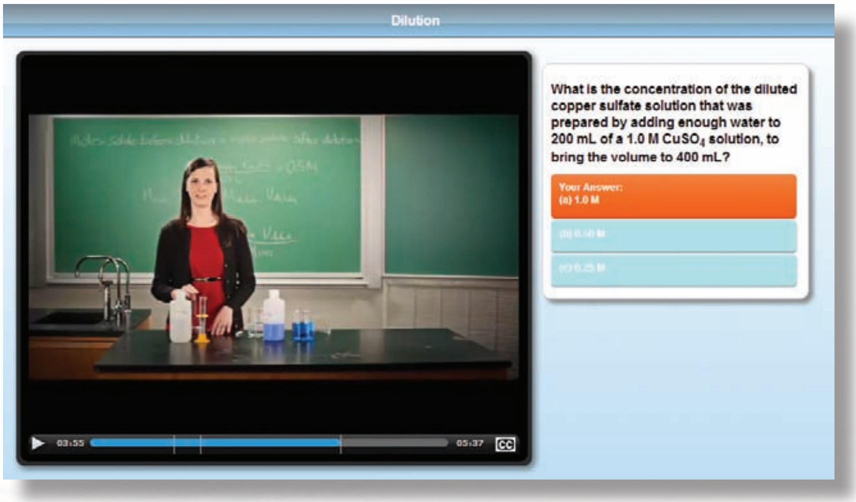

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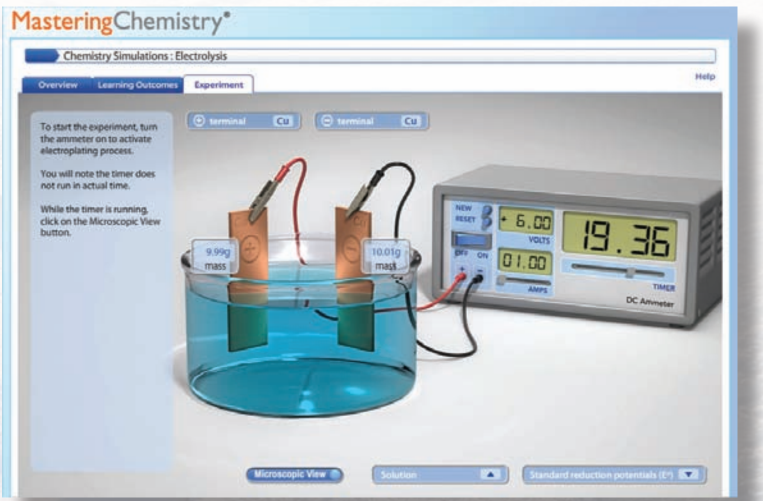

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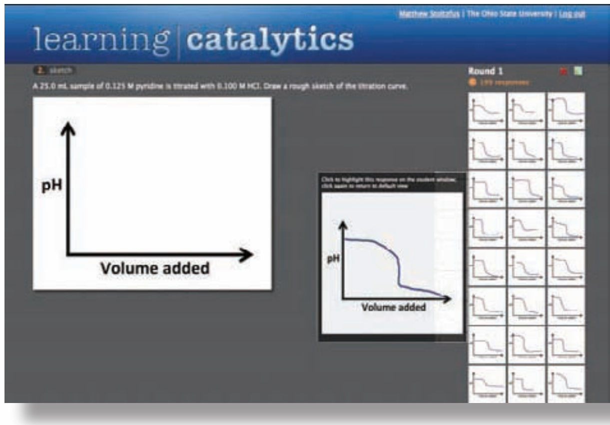

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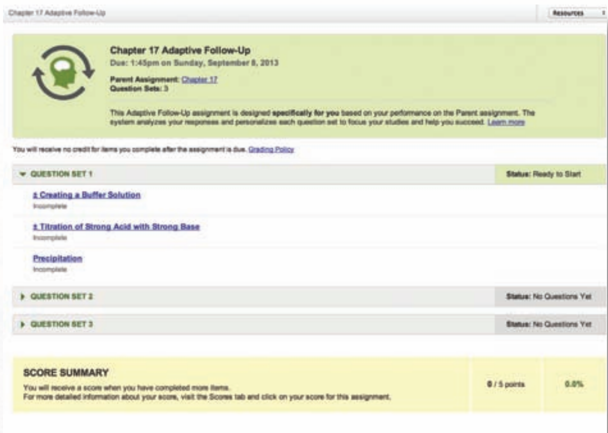

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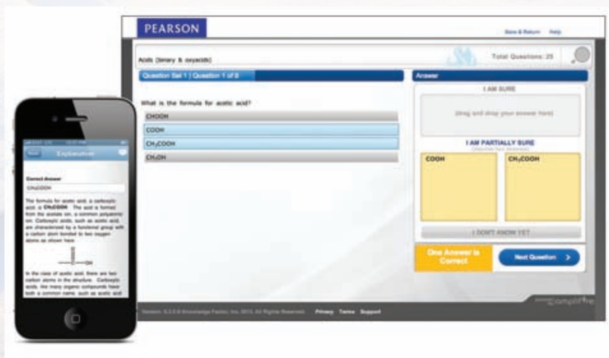

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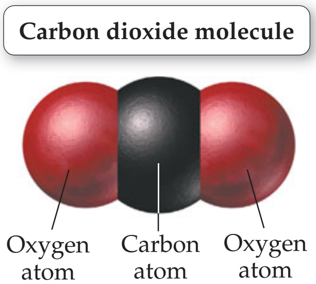
▲ Soda pop is a mixture of carbon dioxide and water and a few other substances that contribute flavor and color. When soda pop is poured into a glass, some of the carbon dioxide molecules come out of the mixture, producing the familiar fizz.

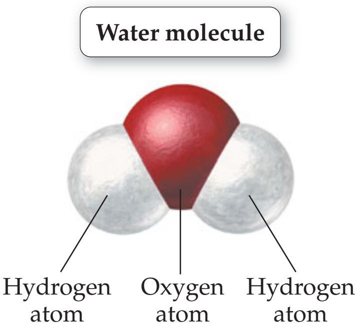
The Chemical World 1

"Imagination is more important than knowledge."—Albert Einstein (1879–1955)

CHAPTER OUTLINE

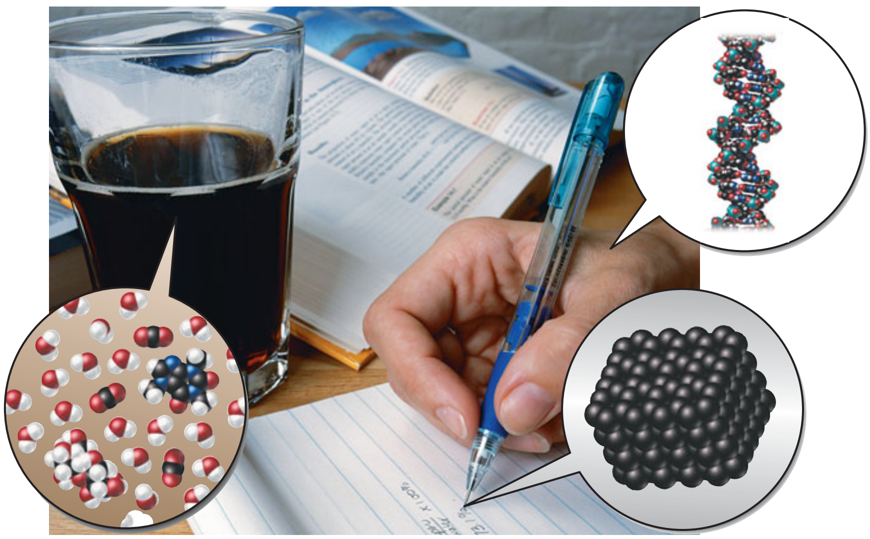
1.1 Soda Pop Fizz





Open a can of soda pop and you hear the familiar "chchchch" of pressure release. Take a sip and you feel the carbon dioxide bubbles on your tongue. If you shake the can before you open it, you are sprayed with the bubbly liquid. A can of soda pop, like most familiar items in our daily lives, is a chemical mixture containing mostly sugar, water, and carbon dioxide. The unique combination of these substances gives soda pop its properties. Have you ever wondered why soda pop tastes sweet? To understand why, you need to understand sugar and solutions of sugar with water. We will learn about solutions in Chapter 13. Have you ever wondered why soda fizzes when you open it? To understand the reason, you need to understand gases and their ability to dissolve in liquids and how that ability varies with changing pressure. We will learn about gases in Chapter 11. And if you want to know why drinking too much soda pop makes you gain weight, you need to understand energy and the production of energy by chemical reactions. We will discuss energy in Chapter 3 and chemical reactions in Chapter 7. You don't need to venture any farther than your own home and your own everyday experiences to encounter chemical questions. Chemicals compose virtually everything in our world: the soda; this book; your pencil; indeed, even your own body.

Chemists are particularly interested in the connections between the properties of substances and the structure of the particles that compose them. For example, why does soda pop fizz? Like all common substances, soda pop is ultimately composed of tiny particles called *atoms*. Atoms are so small that a single drop of soda contains about one billion trillion of them. In soda, as in many substances, these atoms are bound together to form several different types of *molecules*. The molecules important to fizzing are carbon dioxide and water. Carbon dioxide molecules consist of three atoms—one carbon and two oxygen atoms—held together in a straight line by chemical bonds. Water molecules also consist of three atoms—one oxygen and two hydrogen atoms—bonded together, but rather than being straight like carbon dioxide, the water molecule is bent.

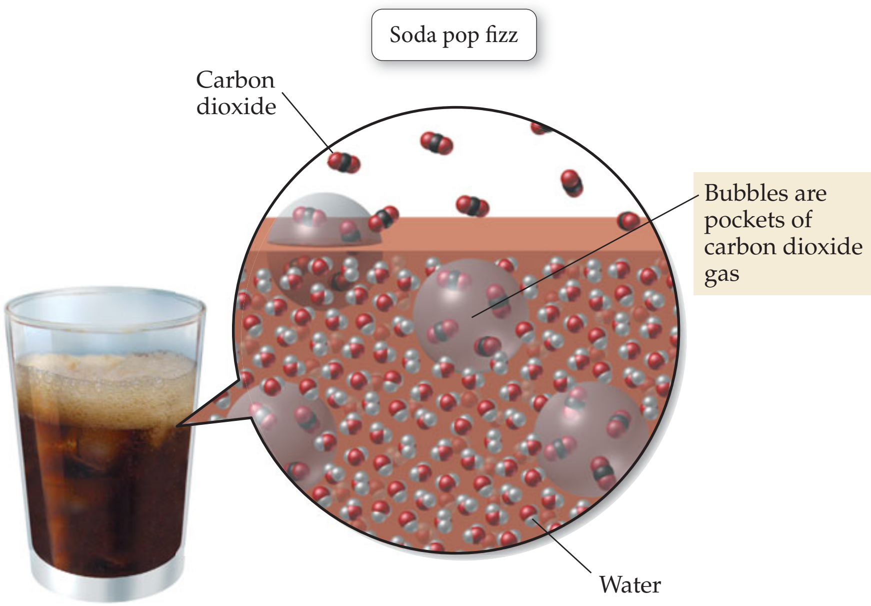


▶ Virtually everything around you is composed of chemicals.

We will explore the nature of atoms, molecules, and chemical bonds more fully in later chapters. For now, think of atoms and molecules as tiny particles that compose all common matter, and chemical bonds as the attachments that hold atoms together.

The details of how atoms bond together to form a molecule—straight, bent, or some other shape—as well as the type of atoms in the molecule, determine *everything* about the substance that the molecule composes. The characteristics of water molecules make water a liquid at room temperature. The characteristics of carbon dioxide molecules make carbon dioxide a gas at room temperature. The characteristics of sugar molecules allow them to interact with our taste buds to produce the sensation of sweetness.

The makers of soda pop use *pressure* (the result of collisions between gaseous molecules and the surfaces around them) to force gaseous carbon dioxide molecules to mix with liquid water molecules. As long as the can of soda is sealed, the carbon dioxide molecules remain mixed with the water molecules, held there by pressure. When the can is opened, the pressure is released and carbon dioxide molecules escape out of the soda mixture (▼ Figure 1.1). As they do, they create bubbles—the familiar fizz of soda pop.



▲ **FIGURE 1.1** **Where the fizz comes from** Bubbles in soda pop are pockets of carbon dioxide gas molecules escaping out of the liquid water.

1.2 Chemicals Compose Ordinary Things

LO: Recognize that chemicals make up virtually everything we come into contact with in our world. *(Note: Most of the sections in the chapters in this book link to a Learning Objective (LO), which is listed at the beginning of the section).*

Is soda pop composed of chemicals? Yes. In fact, nothing that we can hold or touch is *not* made of chemicals. When most people think of chemicals, however, they may envision a can of paint thinner in their garage, or recall a headline about a river polluted by industrial waste. But chemicals compose ordinary things, too. Chemicals compose the air we breathe and the water we drink. They compose toothpaste, Tylenol®, and toilet paper. Chemicals make up virtually everything we come into contact with. Chemistry explains the properties and behavior of chemicals, in the broadest sense, by helping us understand the molecules that compose them.

▲ People often have a very narrow view of chemicals, thinking of them only as dangerous poisons or pollutants.

▲ Chemists are interested in knowing why ordinary things, such as water, are the way they are. When a chemist sees a pitcher of water, she thinks of the molecules that compose the liquid and how those molecules determine its properties.

As you experience the world around you, molecules are interacting to create your experience. Imagine watching a sunset. Molecules are involved in every step. Molecules in air interact with light from the sun, scattering away the blue and green light and leaving the red and orange light to create the color you see. Molecules in your eyes absorb that light and as a result are altered in a way that sends a signal to your brain. Molecules in your brain then interpret the signal to produce images and emotions. This whole process—mediated by molecules—creates the evocative experience of seeing a sunset.

Chemists are interested in why ordinary substances are the way they are. Why is water a liquid? Why is salt a solid? Why does soda fizz? Why is a sunset red? Throughout this book, you will learn the answers to these questions and many others. *You will learn the connections between the behavior of matter and the structure of the particles that compose it.*

1.3 All Things Are Made of Atoms and Molecules

LO: Recognize that all things are made of atoms and molecules.

Nobel laureate Richard Feynman, in a lecture to first-year physics students at the California Institute of Technology, said that the most important idea in all human knowledge is that *all things are made of atoms*. Since atoms are usually bound together to form molecules, however, a chemist might add the concept of *molecules* to Feynman's bold assertion. This simple idea—that all things are made of atoms and molecules—explains much about our world and our experience of it. Atoms and molecules determine how matter behaves—if they were different, matter would be different. The nature of water molecules, for example, determines how water behaves. The nature of sugar molecules determines how sugar behaves, and the molecules that compose humans determine much about how our bodies behave.

◀ Richard Feynman (1918–1988), Nobel Prize–winning physicist and popular professor at California Institute of Technology.

There is a direct connection between the world of atoms and molecules and the world we experience every day. Chemists explore this connection. They seek to understand it. A good, simple definition of **chemistry** is *the science that tries to understand how matter behaves by studying how atoms and molecules behave*.

1.4 The Scientific Method: How Chemists Think

LO: Identify and understand the key characteristics of the scientific method: observation, the formulation of hypotheses, the testing of hypotheses by experiment, and the formulation of laws and theories.

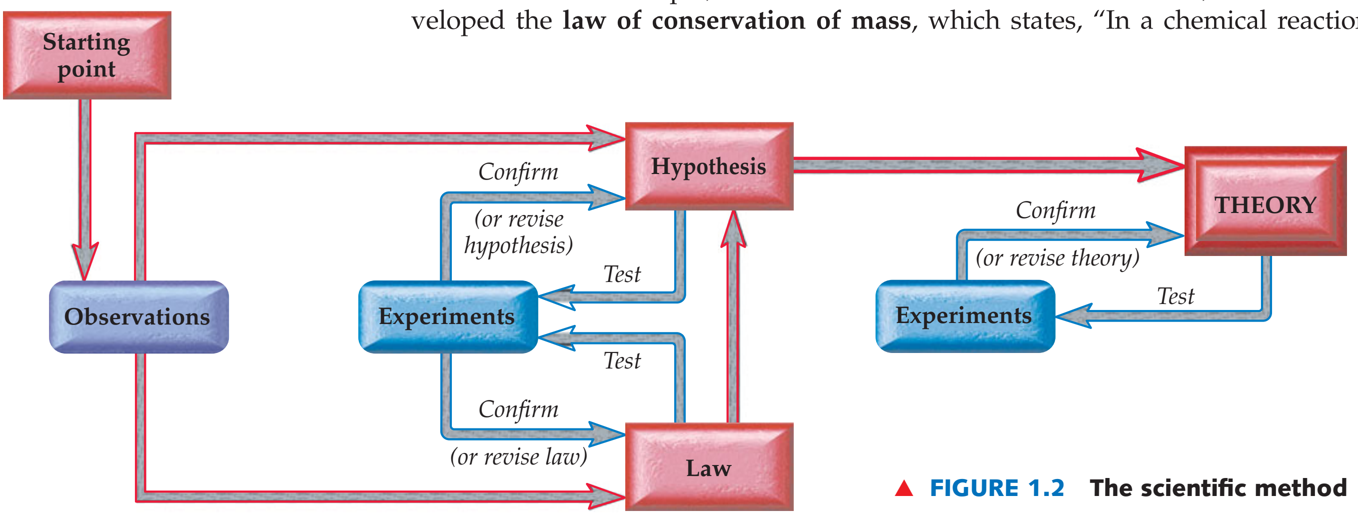
Chemists use the **scientific method**—a way of learning that emphasizes observation and experimentation—to understand the world. The scientific method stands in contrast to ancient Greek philosophies that emphasized *reason* as the way to understand the world. Although the scientific method is not a rigid procedure that automatically leads to a definitive answer, it does have key characteristics that distinguish it from other ways of acquiring knowledge. These key characteristics include observation, the formulation of hypotheses, the testing of hypotheses by experiment, and the formulation of laws and theories.

The first step in acquiring scientific knowledge (▼ Figure 1.2) is often the **observation** or measurement of some aspect of nature. Some observations are simple, requiring nothing more than the naked eye. Other observations rely on the use of sensitive instrumentation. Occasionally, an important observation happens entirely by chance. Alexander Fleming (1881–1955), for example, discovered penicillin when he observed a bacteria-free circle around a certain mold that had accidentally grown on a culture plate. Regardless of how these observations occur, they usually involve the measurement or description of some aspect of the physical world. For example, Antoine Lavoisier (1743–1794), a French chemist who studied *combustion*, burned substances in closed containers. He carefully measured the mass of each container and its contents before and after burning the substance inside, noting that there was no change in the mass during combustion. Lavoisier made an *observation* about the physical world.

Combustion means burning. The mass of an object is a measure of the quantity of matter within it.

Observations often lead scientists to formulate a **hypothesis**, a tentative interpretation or explanation of the observations. Lavoisier explained his observations on combustion by hypothesizing that combustion involved the combination of a substance with a component of air. A good hypothesis is *falsifiable*, which means that further testing has the potential to prove it wrong. Hypotheses are tested by **experiments**, highly controlled observations designed to validate or invalidate hypotheses. The results of an experiment may confirm a hypothesis or show the hypothesis to be mistaken in some way. In the latter case, the hypothesis may have to be modified, or even discarded and replaced by an alternative hypothesis. Either way, the new or revised hypothesis must also be tested through further experimentation.

Sometimes a number of similar observations lead to the development of a **scientific law**, a brief statement that summarizes past observations and predicts future ones. For example, based on his observations of combustion, Lavoisier developed the **law of conservation of mass**, which states, "In a chemical reaction



▲ **FIGURE 1.2 The scientific method**

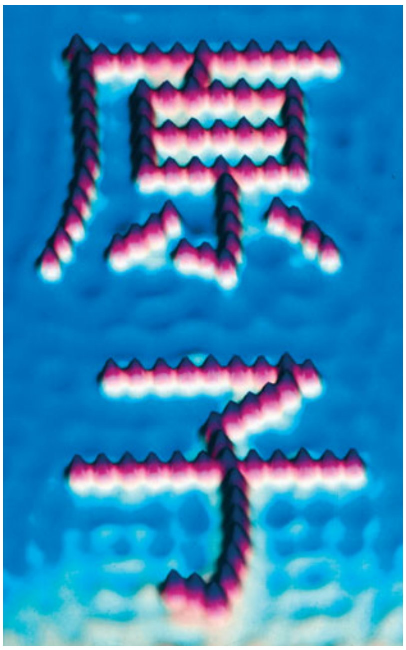
▶ (Right) Painting of the French chemist Antoine Lavoisier and his wife, Marie, who helped him in his work by illustrating his experiments, recording results, and translating scientific articles from English. [*Source:* Jacques Louis David (French, 1748–1825). "Antoine-Laurent Lavoisier (1743–1794) and His Wife (Marie-Anne-Pierrette Paulze, 1758–1836)," 1788, oil on canvas, H. 102-1/4 in. W. 76-5/8 in. (259.7 × 194.6 cm). The Metropolitan Museum of Art, Purchase, Mr. and Mrs. Charles Wrightsman Gift, in honor of Everett Fahy, 1977. (1977.10) Image copyright © The Metropolitan Museum of Art.] (Far right) John Dalton, the English chemist who formulated the atomic theory.

matter is neither created nor destroyed." This statement grew out of Lavoisier's observations, and it predicted the outcome of similar experiments on *any* chemical reaction. Laws are also subject to experiments, which can prove them wrong or validate them.

Scientific theories are also called *models*.

One or more well-established hypotheses may form the basis for a scientific **theory**. Theories provide a broader and deeper explanation for observations and laws. They are models of the way nature is, and they often predict behavior that extends well beyond the observations and laws on which they are founded. A good example of a theory is the **atomic theory** of John Dalton (1766–1844). Dalton explained the law of conservation of mass, as well as other laws and observations, by proposing that all matter was composed of small, indestructible particles called atoms. Dalton's theory was a model of the physical world—it went beyond the laws and observations of the time to explain these laws and observations.

Theories are also tested and validated by experiments. Notice that the scientific method begins with observation, and then laws, hypotheses, and theories are developed based on those observations. Experiments, which are carefully controlled observations, determine the validity of laws, hypotheses, or theories. If a law, hypothesis, or theory is inconsistent with the findings of an experiment, it must be revised and new experiments must be conducted to test the revisions. Over time, scientists eliminate poor theories, and good theories—those consistent with experiments—remain. Established theories with strong experimental support are the most powerful pieces of scientific knowledge. People unfamiliar with science sometimes say, "That is just a theory," as if theories were mere speculations. However, well-tested theories are as close to truth as we get in science. For example, the idea that all matter is made of atoms is "just a theory," but it is a theory with 200 years of experimental evidence to support it, including the recent imaging of atoms themselves (◀ Figure 1.3). Established theories should not be taken lightly—they are the pinnacle of scientific understanding.



▲ **FIGURE 1.3 Are atoms real?** The atomic theory has 200 years of experimental evidence to support it, including recent images, such as this one, of atoms themselves. This image shows the Kanji (a system of Japanese writing using Chinese characters) for "atom" written with individual iron atoms on top of a copper surface.

CONCEPTUAL CHECKPOINT 1.1

Which statement most resembles a scientific theory?

(a) When the pressure on a sample of oxygen gas is increased 10%, the volume of the gas decreases by 10%.

(b) The volume of a gas is inversely proportional to its pressure.

(c) A gas is composed of small particles in constant motion.

(d) A gas sample has a mass of 15.8 g and a volume of 10.5 L.

Note: The answers to all Conceptual Checkpoints appear at the end of the chapter.

EVERYDAY CHEMISTRY

▶ Combustion and the Scientific Method

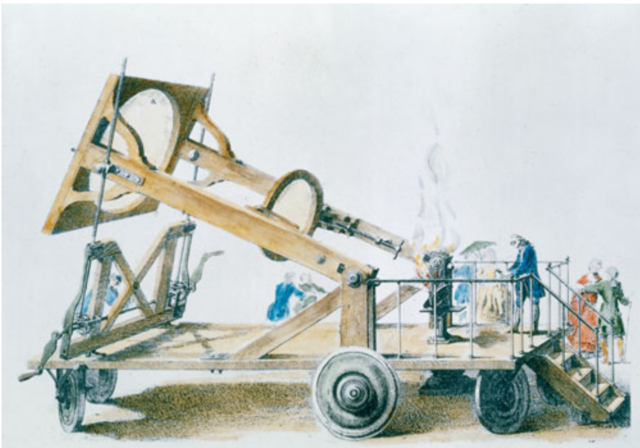
Early chemical theories attempted to explain common phenomena such as combustion. Why did things burn? What was happening to a substance when it burned? Could something that was burned be unburned? Early chemists burned different substances and made observations to try to answer these questions. They observed that substances stop burning when placed in a closed container. They found that many metals burn to form a white powder that they called a *calx* (now we know that these white powders are oxides of the metal) and that the metal could be recovered from the calx, or unburned, by combining the calx with charcoal and heating it.

Chemists in the first part of the eighteenth century formed a theory about combustion to explain these observations. In this theory, combustion involved a fundamental substance that they called *phlogiston*. This substance was present in anything that burned and was released during combustion. Flammable objects were flammable because they contained phlogiston. When things burned in a closed container, they didn't burn for very long because the space within the container became saturated with phlogiston. When things burned in the open, they continued to burn until all of the phlogiston within them was gone. This theory also explained how metals that had burned could be unburned. Charcoal was a phlogiston-rich material—they knew this because it burned so well—and when it was combined with a calx, which was a metal that had been emptied of its phlogiston, it transferred some of its phlogiston into the calx, converting the calx back into the unburned form of the metal. The phlogiston theory was consistent with all of the observations of the time and was widely accepted as valid.

Like any theory, the phlogiston theory was tested continually by experiment. One set of experiments, conducted in the mid–eighteenth century by Louis-Bernard Guyton de Morveau (1737–1816), consisted of weighing metals before and after burning them. In every case the metals *gained* weight when they were burned. This observation is inconsistent with the phlogiston theory, which predicted that metals should *lose* weight because phlogiston was supposed to be lost during combustion. Clearly, the phlogiston theory needed modification.

The first modification was that phlogiston was a very light substance so that it actually "buoyed up" the materials that contained it. Thus when phlogiston was released, the material became heavier. Such a modification seemed to fit the observations but also seemed far-fetched. Antoine Lavoisier developed a more likely explanation by devising a completely new theory of combustion. Lavoisier proposed that, when a substance burned, it actually took something *out* of the air, and when it unburned, it released something back into the air. Lavoisier said that burning objects *fixed* (attached or bonded) the air and that the *fixed* air was released during unburning. In a confirming experiment (▼ Figure 1.4), Lavoisier roasted a mixture of calx and charcoal with the aid of sunlight focused by a giant burning lens, and found that a huge volume of "fixed air" was released in the process. The scientific method worked. The phlogiston theory was proven wrong, and a new theory of combustion took its place—a theory that, with a few refinements, is still valid today.

B1.1 CAN YOU ANSWER THIS? *What is the difference between a law and a theory? How does the example of the phlogiston theory demonstrate this difference?*

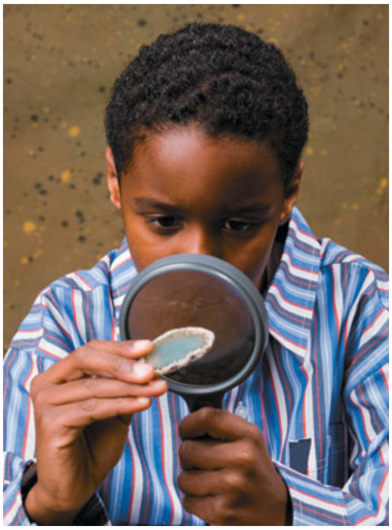


▲ **FIGURE 1.4 Focusing on combustion** The great burning lens belonging to the Academy of Sciences. Lavoisier used a similar lens in 1777 to show that a mixture of *calx* (metal oxide) and charcoal released a large volume of *fixed air* when heated.

1.5 A Beginning Chemist: How to Succeed

You are a beginning chemist. This may be your first chemistry course, but it may not be your last. To succeed as a beginning chemist, keep the following ideas in mind. First, chemistry requires curiosity and imagination. If you are content knowing that the sky is blue, but don't care *why* it is blue, then you may have to rediscover your curiosity. I say "rediscover" because even children—or better, *especially* children—have this kind of curiosity. To succeed as a chemist, you must have the curiosity and imagination of a child—*you must want to know the why of things.*

Second, chemistry requires calculation. Throughout this course, you will be asked to calculate answers and quantify information. *Quantification* involves



▲ To succeed as a scientist, you must have the curiosity of a child.

measurement as part of observation—it is one of the most important tools in science. Quantification allows you to go beyond merely saying that this object is hot and that one is cold or that this one is large and that one is small. It allows you to specify the difference precisely. For example, two samples of water may feel equally hot to your hand, but when you measure their temperatures, you may find that one is 40 °C and the other is 44 °C. Even small differences can be important in a calculation or experiment, so assigning numbers to observations and manipulating those numbers become very important in chemistry.

Lastly, chemistry requires commitment. To succeed in this course, you must commit to learning chemistry. Roald Hoffman, winner of the 1981 Nobel Prize for chemistry, said,

> *I like the idea that human beings can do anything they want to. They need to be trained sometimes. They need a teacher to awaken the intelligence within them. But to be a chemist requires no special talent, I'm glad to say. Anyone can do it, with hard work.*

Professor Hoffman is right. The key to success in this course is hard work—that requires commitment. You must do your work regularly and carefully. If you do, you will succeed, and you will be rewarded by seeing a whole new world—the world of molecules and atoms. This world exists beneath the surface of nearly everything you encounter. I welcome you to this world and consider it a privilege, together with your professor, to be your guide.

CHAPTER IN REVIEW

Self-Assessment Quiz

Q1. Where can you find chemicals?
- **(a)** In a hardware store
- **(b)** In a chemical stockroom
- **(c)** All around you and even inside of you
- **(d)** All of the above

Q2. Which statement best defines chemistry?
- **(a)** The science that studies solvents, drugs, and insecticides
- **(b)** The science that studies the connections between the properties of matter and the particles that compose that matter
- **(c)** The science that studies air and water pollution
- **(d)** The science that seeks to understand processes that occur only in chemical laboratories

Q3. According to the scientific method, what is a law?
- **(a)** A short statement that summarizes a large number of observations
- **(b)** A fact that can never be refuted
- **(c)** A model that gives insight into how nature is
- **(d)** An initial guess with explanatory power

Q4. Which statement is an example of an observation?
- **(a)** In a chemical reaction, matter is conserved.
- **(b)** All matter is made of atoms.
- **(c)** When a given sample of gasoline is burned in a closed container, the mass of the container and its contents does not change.
- **(d)** Atoms bond to one another by sharing electrons.

Q5. Which characteristic is necessary for success in understanding chemistry?
- **(a)** Curiosity
- **(b)** Calculation
- **(c)** Commitment
- **(d)** All of the above

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

Chemical Principles

Matter and Molecules: Chemists are interested in all matter, even ordinary matter such as water or air. You don't need to go to a chemical storeroom to find chemicals because they are all around you. Chemistry is the science that studies the connections between the properties of matter and the particles that compose that matter.

Relevance

Matter and Molecules: Chemists want to understand matter for several reasons. First, chemists are simply curious—they want to know why. Why are some substances reactive and others not? Why are some substances gases, some liquids, and others solids? Chemists are also practical; they want to understand matter so that they can control it and produce substances that are useful to society and to humankind.