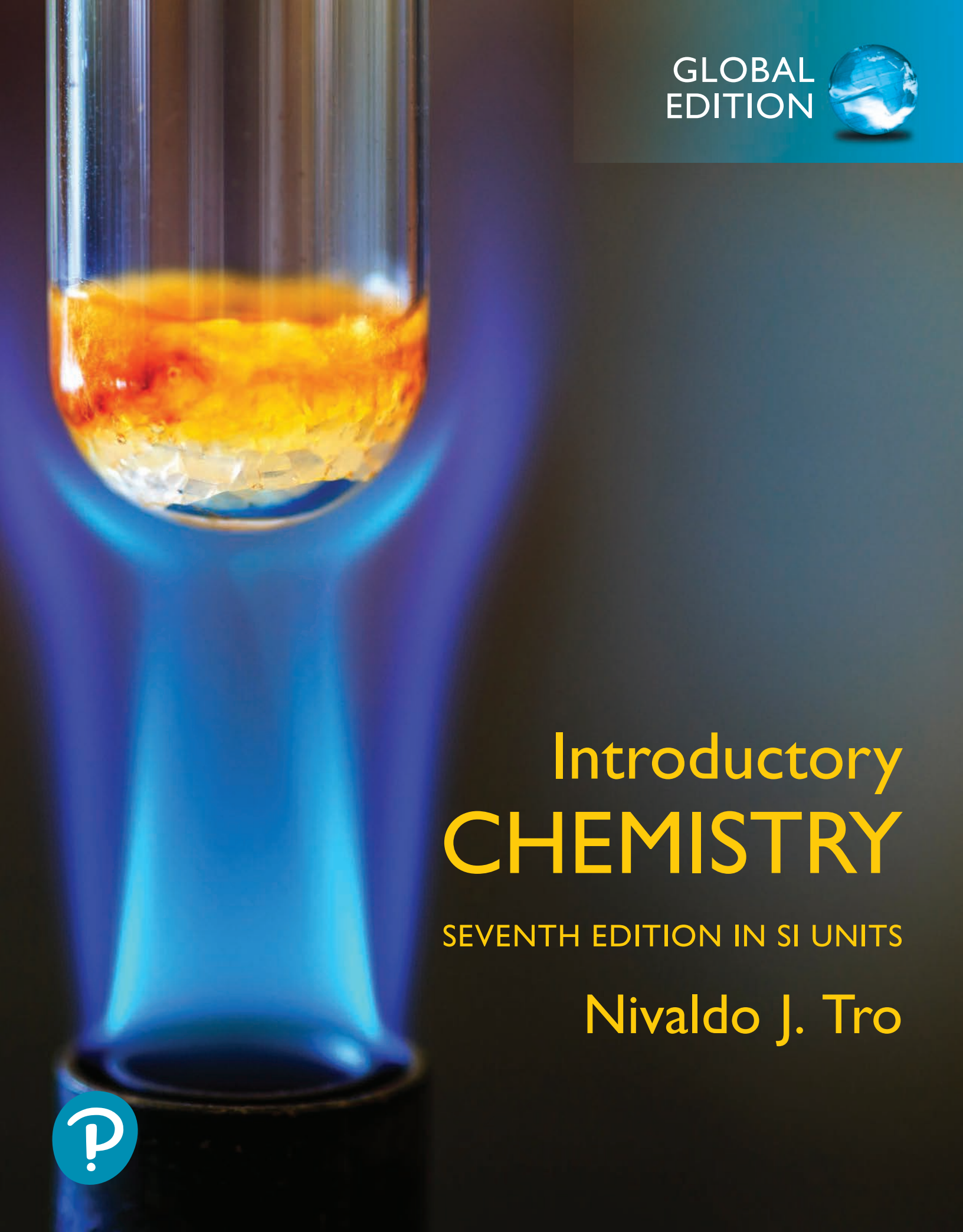
GLOBAL
EDITION
Introductory
CHEMISTRY
SEVENTH EDITION IN SI UNITS
Nivaldo J. Tro

# INTRODUCTORY CHEMISTRY

SEVENTH EDITION IN SI UNITS

Nivaldo J. Tro



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# About the Author

**Nivaldo Tro** has been teaching college chemistry since 1990 and is currently teaching at Santa Barbara City College. He received his Ph.D. in chemistry from Stanford University for work on developing and using optical techniques to study the adsorption and desorption of molecules to and from surfaces in ultrahigh vacuum. He then went on to the University of California at Berkeley, where he did postdoctoral research on ultrafast reaction dynamics in solution. Professor Tro has been awarded grants from the American Chemical Society Petroleum Research Fund, from the Research Corporation, and from the National Science Foundation to study the dynamics of various processes occurring in thin adlayer films adsorbed on dielectric surfaces. Professor Tro lives in Santa Barbara with his wife, Ann. In his leisure time, Professor Tro enjoys cycling, surfing, and being outdoors.

*To Annie*

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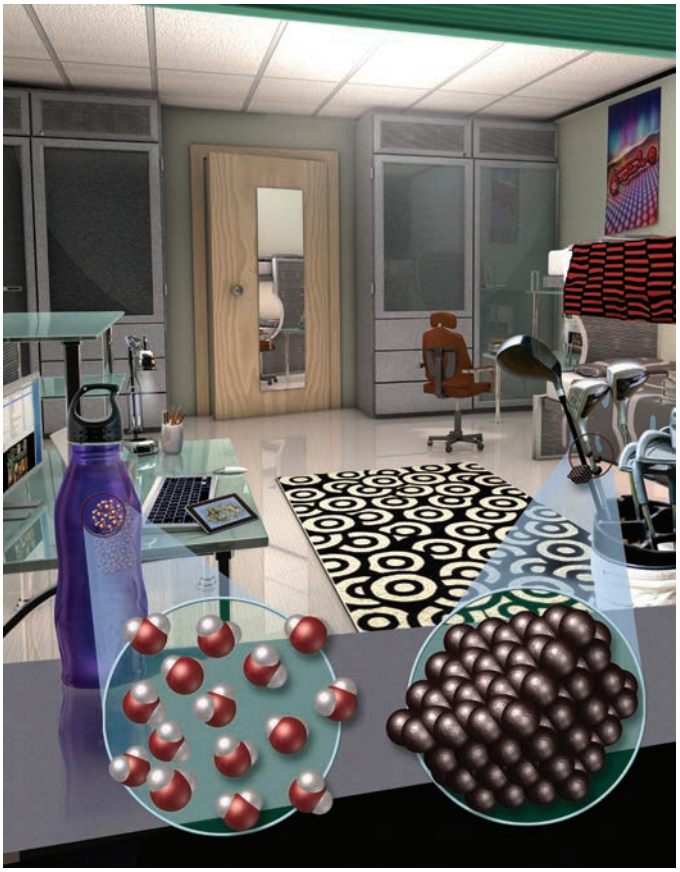
# Contents





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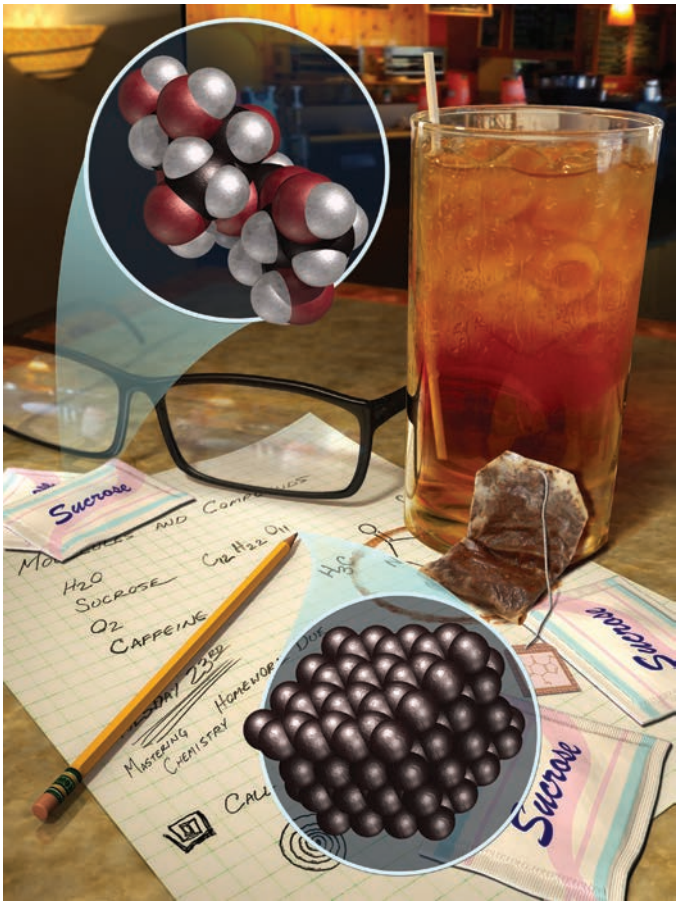

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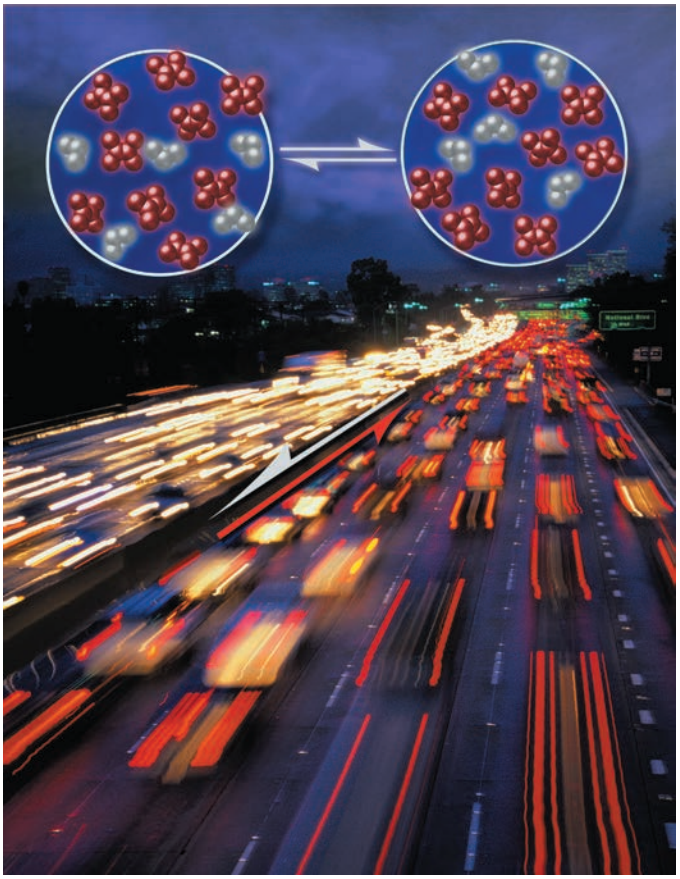

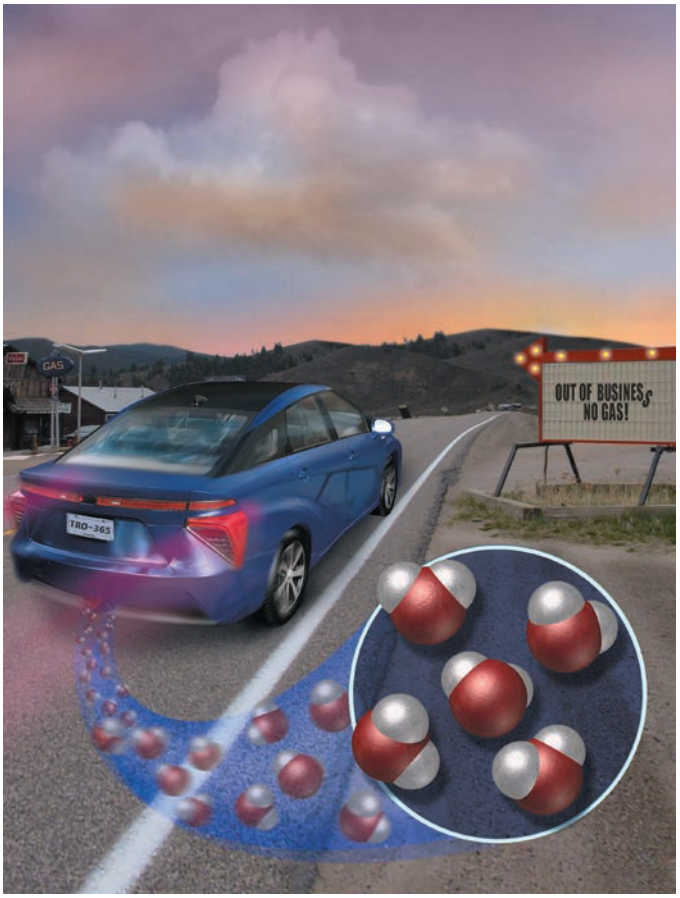


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## Three-Column Problem-Solving Strategies

# Interactive Media Contents

This icon indicates that this feature is embedded and interactive in the eTextbook.

## Key Concept Videos



## Key Concept Interactives

## Interactive Worked Examples

# To the Student

This book is for *you*, and every text feature is meant to help you learn and succeed in your chemistry course. I wrote this book with two main goals for you in mind: 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. Several outstanding artists have helped me 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 one-size-fits-all formula for problem solving, but I can and do give you strategies that will help you develop the *chemical intuition* you need to understand chemical reasoning.

Look for several recurring features 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 develop a problem-solving approach; (2) the solution map, a visual aid that helps you navigate your way through problems; (3) 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) three-column Examples, which describe a problem-solving procedure while demonstrating how it is applied to two different Examples. In addition, the For More Practice feature at the end of each worked Example directs you to the end-of-chapter Problems that provide more opportunity to practice the skill(s) covered in each Example. In addition, Interactive Worked Examples are digital versions of select worked Examples from the text that help you break down problems using the book's "Sort, Strategize, Solve, and Check" technique.

Recent research has demonstrated that you will do better on your exams if you take a multiple-choice pre-exam before your actual exam. At the end of each chapter, you will find a Self-Assessment Quiz to help you check your understanding of the material in that chapter. You can string these together to make a pre-exam. For example, if your exam covers Chapters 5–7, complete the Self-Assessment Quizzes for those chapters as part of your preparation for the exam. The questions you miss on the quiz will reveal the areas you need to spend the most time studying. Studies show that if you do this, you will do better on the actual exam.

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
nivatro@gmail.com

# To the Instructor

I thank all of you who have used any of the first six editions of *Introductory Chemistry*—you have made this book the best-selling book in its market, and for that I am extremely grateful. The preparation of the seventh 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 use 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 seventh edition, making the visual impact sharper and more targeted to student learning. For example, many images now include blue annotations that represent the author voice. These annotations put the narrative closest to its point of relevance instead of being lost in the figure caption. My intent is to create an art program that teaches and 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). Students can begin to see the connections between the macroscopic world, the molecular world, and the representation of the molecular world with symbols and formulas.

The problem-solving pedagogy employs four steps as it has done in the previous six editions: Sort, Strategize, Solve, and Check. This four-step procedure guides students as they learn chemical problem solving. Students will also encounter extensive flowcharts throughout the book, allowing them to better visualize the organization of chemical ideas and concepts.

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 told me that you use a similar technique in lecture and office hours. Since students have specifically asked for connections between worked Examples and end-of-chapter Problems, I include a For More Practice feature at the end of each worked Example that lists the end-of-chapter review Examples and end-of-chapter Problems that provide additional opportunities to practice the skill(s) covered in the example. Also in this edition, we have 78 Interactive Worked Examples, which can be accessed in the eText or through Mastering™ Chemistry.

A successful feature of previous editions is 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. For this edition, all Conceptual Checkpoints are embedded in the eText. Emphasizing understanding rather than calculation, they are designed to encourage active learning even while reading.

In my own teaching, I have been influenced by two studies. The first one is a mega analysis of the effect of active learning on student learning in STEM disciplines.[1] In this study, Freeman and his coworkers convincingly demonstrate that students learn better when they are active in the process. The second study focuses on the effect of multiple-choice pretests on student exam performance.[2] Here, Pyburn and his coworkers show that students who take a multiple-choice pretest do better on exams than those who do not. Even more interesting, the enhancement is greater for lower performing students. In my courses, I have implemented both active learning and multiple-choice pretesting with good results. In my books, I have developed tools to allow you to incorporate these techniques as well.

To help you with active learning, I now have 45 Key Concept Videos that accompany this book. These three- to five-minute videos each introduce a key concept from the chapter. They are themselves interactive because every video has an embedded question posed to the student to test understanding. In addition, there are now 78 Interactive Worked Example videos in the media package. This means that you now have a library of 123 interactive videos to enhance your course. In addition, I have created new digital content called Key Concept Interactives described in more detail below in the section entitled "New to This Edition."

In my courses, I use these videos and interactives in conjunction with the book to implement a *before, during, after* strategy for my students. My goal is simple: *Engage students in active learning before class, during class, and after class.* To that end, I assign a video or interactive *before* most class sessions. All videos and interactives are embedded in the eText, allowing students to review and test their understanding in real time. The video or interactive introduces students to a concept or problem that I will cover in the lecture. *During* class, I expand on the concept or problem using *Learning Catalytics*™ to question my students. Instead of simply passively listening to a lecture, they are interacting with the concepts through questions that I pose. Sometimes I ask my students to answer individually, other times in pairs or even groups. This approach has changed my classroom. Students engage in the material in new ways. They are actively learning and have to think and process and interact. Finally, *after* class, I give them another assignment, usually a short follow-up question, problem, or video. At this point, they must apply what they have learned to solve a problem.

To help you with multiple-choice pretesting, each chapter contains a Self-Assessment Quiz, which is also embedded in the eText. 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 pretest on the core material that will be on the exam.

My goal with this edition is to continue to help you make learning a more active (rather than passive) process for your students. I hope the tools that I have provided here continue to aid you in teaching your students better and more effectively. Please feel free to email 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
nivatro@gmail.com

---

[1] Freeman, Scott; Eddy, Sarah L.; McDonough, Miles; Smith, Michelle K.; Okoroafor, Nnadozie; Jordt, Hannah; and Wenderoth, Mary Pat. Active learning increases student performance in science, engineering, and mathematics, 2014, *Proc. Natl. Acad. Sci.*

[2] Pyburn, Daniel T.; Pazicni, Samuel; Benassi, Victor A.; and Tappin, Elizabeth M. The testing effect: An intervention on behalf of low-skilled comprehenders in general chemistry, *J. Chem. Educ.*, 2014, 91 (12), pp. 2045–2057.

# Preface

## 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; 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.

## Acknowledgments

This book has been a group effort, and I am grateful for all of those who helped me. First and foremost, I would like to thank my editors on this edition, Jessica Moro and Elizabeth Ellsworth Bell. I have known and worked with both of them for many years and in various roles, and am grateful to have them as my editors. I am also deeply grateful to Edward Dodd, my development editor. Ed is an author's dream editor. He is thorough, detail-oriented, creative, and incredibly organized. However, Ed is also gracious, generous, and a joy to work with. Thanks, Ed, for your unending efforts on this revision. Thanks also to my content producer Beth Sweeten. Beth has managed the many details and moving parts of producing this book with care and precision. I appreciate her steady hand, attention to detail, and hard work. Thanks also to my media developer Jackie Jacob. Jackie and I have been working together for many years to produce innovative media pieces that are pedagogically sound and easy to use. She is simply the best in the business, and I am lucky to get to work with her. I am also grateful to my media editor Chloe Veylit who has helped tremendously with the development of the new Key Concept Videos, Interactive Worked Examples, Key Concept Interactives, and other media elements. Chloe is creative, organized, and a great colleague.

Thanks also to Adam Jaworski, who oversees product management in Science at Pearson. I am grateful to have his wise and steady, yet innovative, hand at the wheel, especially during the many changes that are happening within educational publishing. I am also grateful to Gary Hespeheide for his creativity and hard work in crafting the design of this text. I also thank Francesca Monaco and her

coworkers at Straive. I am a picky author and Francesca is endlessly patient and a true professional. I am also greatly indebted to my copy editor, Betty Pessagno, for her dedication and professionalism over many projects.

I am also grateful to those who have supported me personally while working on this book. First on that list is my wife, Ann. Her patience and love for me are beyond description, and without her, this book would never have been written. I am also indebted to my children, Michael, Ali, Kyle, and Kaden, whose smiling faces and love of life always inspire me. I come from a large Cuban family whose closeness and support most people would envy. Thanks to my parents, Nivaldo and Sara; my siblings, Sarita, Mary, and Jorge; my siblings-in-law, Nachy, Karen, and John; and my nephews and nieces, Germain, Danny, Lisette, Sara, and Kenny. These are the people with whom I celebrate life.

I am especially grateful to Kyle Tro, who put in many hours proofreading changes in the manuscript, working problems, and organizing appendices. Kyle, you are an amazing person—it is my privilege to have you work with me on this project.

Lastly, I am indebted to the many reviewers, listed next, whose ideas are found 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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## Acknowledgments for the Seventh Edition in SI Units

Pearson would like to acknowledge and thank the following people for their contributions.

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Katherine G. Stevens
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### Reviewers

Kenneth Ozoemena
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Katherine G. Stevens
*Utrecht University*

Yin Yin Teo
*Universiti Malaya*

# New to This Edition

The book has been extensively revised and contains more small changes than can be detailed here. The most significant changes to the book and its supplements are listed below:

## New Key Concept Interactives

15 new *Key Concept Interactives* (*KCIs*) have been added to the eTextbook and are assignable in Mastering Chemistry. Each interactive guides a student through a key topic as they navigate through a series of interactive screens. As they work through the KCI, they are presented with questions that must be answered to progress. Wrong answers result in feedback to guide them toward success.

## New Interactive Videos

33 new *Key Concept Videos* (*KCVs*) and 39 new *Interactive Worked Examples* (*IWEs*) have been added to the media package that accompanies the book. All videos are available within the eTextbook and are assignable in Mastering Chemistry. *The video library now contains over 120 interactive videos*. These tools are designed to help professors engage their students in active learning.

## New and Revised End-of-Chapter Problems

48 New End-of-Chapter questions have been added throughout the book, and 83 have been revised. Many new End-of-Chapter questions involve the interpretation of graphs and data. All new End-of-Chapter questions are assignable in Mastering Chemistry.

## Updated Conceptual Connections

The Conceptual Connections feature within the eTextbook has been updated to allow students to answer the question and receive feedback, written by the author, on their response.

## Predict

This feature asks students to predict the outcome of the topic they are about to read. After the student reads the section, *Predict Follow-up* confirms whether the student predicted correctly or incorrectly and why. Education research has demonstrated that students learn a topic better if they make a prediction about the topic before learning it (even if the prediction is wrong).

## Accessibility

All the art throughout the text has been updated with color contrast and accessibility in mind.

## Diversity, Equity, and Inclusion Review

As mentioned previously, the entire book went through a detailed review to ensure the content reflects the rich diversity of our learners and is inclusive of their lived experiences.

# Teaching and Learning Resources

It is increasingly true today that as valuable as a good textbook is, it is still only one element of a comprehensive learning package. The teaching and learning package that accompanies *Introductory Chemistry*, 7th Edition in SI Units is the most comprehensive and integrated on the market. We have made every effort to provide high-quality instructor resources that will save you preparation time and will enhance the time you spend in the classroom.

## Mastering Chemistry

Mastering Chemistry is the most effective and widely used online homework, tutorial, and assessment system for the sciences. It delivers self-paced tutorials that focus on your course objectives, provides individualized coaching, and responds to each student's progress. The Mastering system helps teachers maximize class time with easy-to assign, customizable, and automatically graded assessments that motivate students to learn.

## Mastering Chemistry is a Learning Platform Designed with You in Mind

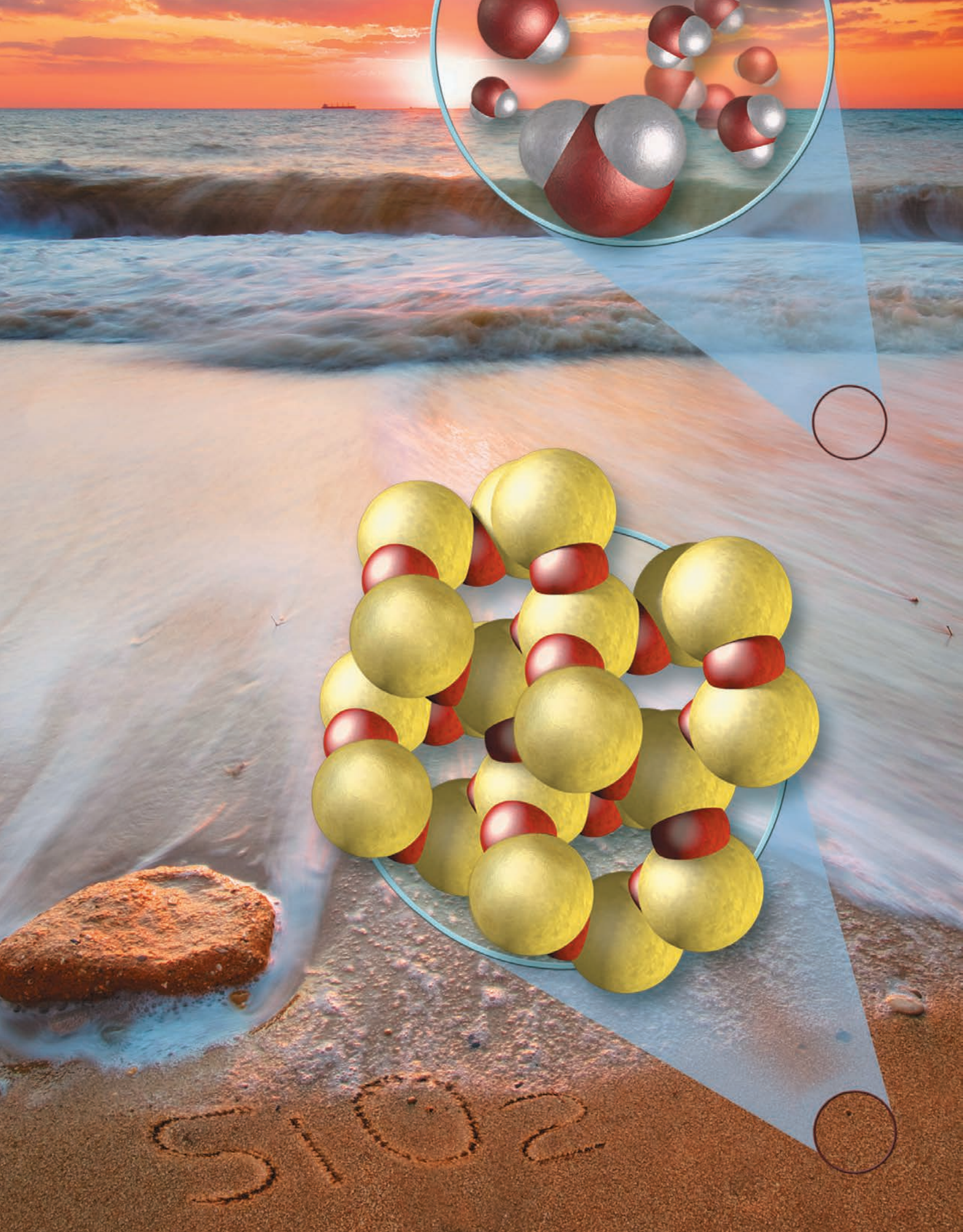
New resources in Mastering Chemistry are designed to help students learn and provide more effective instruction for teachers.

- A complete eText! More than a PDF, the Pearson eText includes embedded videos, interactive self-assessments, and more—all offline accessible via the Pearson+ app for eText.
- A new Study Area with resources designed to help students master the toughest topics in chemistry.
- Numerous opportunities for students to practice problem solving skills, with feedback right when you need it.
- Teachers can assign hundreds of activities and problems that can be tailored to specific instructional goals.
- Teachers have access to a library of extensively tested end-of-chapter problems and comprehensive tutorials that incorporate a wide variety of answer types; wrong-answer feedback; and individualized help, including hints or simpler sub-problems.
- Teachers can develop pre-class and post-class diagnostic tests that are automatically graded, and they can create weekly homework assignments and exams of appropriate difficulty, duration, and content coverage.

## Instructor Resources

A robust set of instructor resources and multimedia accompanies the text and can be accessed through Mastering Chemistry and the Instructor Resource Center.

- All of the figures, photos, and tables from the text in JPEG and PowerPoint.
- Customizable PowerPoint. Lecture outlines save valuable class prep time.
- An Instructor Solution Manual.
- Test Bank provides a wide variety of customizable questions and is available in Microsoft Word, PDF, and TestGen. formats.
- An Instructor Manual.



# 1 The Chemical World

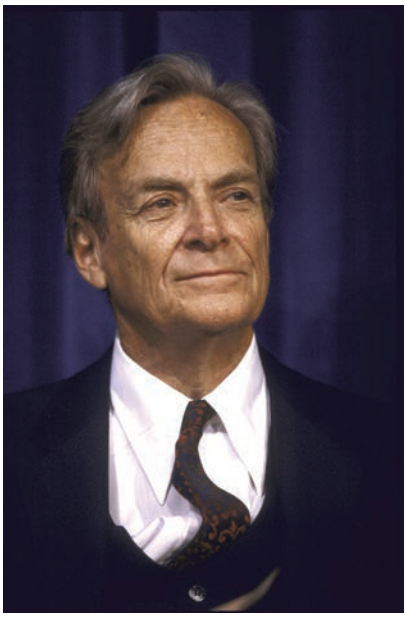
*"Imagination is more important than knowledge."*
—Albert Einstein (1879–1955)

## CHAPTER OUTLINE



## 1.1 Sand and Water

WATCH NOW! Key Concept Video 1.1
Welcome to the Molecular World
This icon indicates that this feature is embedded and interactive in the eTextbook.



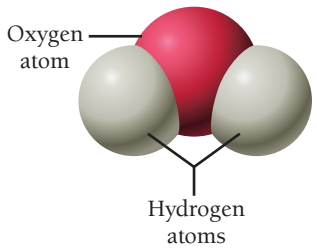
▲ Richard Feynman (1918–1988), Nobel Prize–winning physicist and popular professor at California Institute of Technology.

I love the beach but hate sand. Sand gets everywhere and even comes home with you. Sand is annoying because sand particles are so small. They stick to your hands, to your feet, and to any food you might be trying to eat for lunch. But the smallness of sand particles pales in comparison to the smallness of the particles that compose them. Sand—like all other kinds of ordinary matter—is composed of atoms. Atoms are unimaginably small. A single sand grain contains more atoms than there are sand grains on the largest of beaches.

The idea that matter is composed of tiny particles is among the greatest discoveries of humankind. Nobel laureate Richard Feynman (1918–1988), 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*. Why is this idea so important? Because it establishes how we should go about understanding the properties of the things around us. If we want to understand how matter behaves, we must understand how the particles that compose that matter behave.

Atoms, and the molecules they compose, determine how matter behaves—if they were different, matter would be different. The nature of water molecules, for example, determines how water behaves. If water molecules were different—even in a small way—then water would be a different sort of substance. For example, we know that a water molecule is composed of two hydrogen atoms bonded to an oxygen atom with a shape that looks like this:

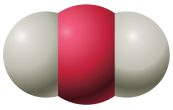
**Water molecule**




◀ A single grain of sand on a large beach contains more atoms than there are grains of sand on the entire beach.

How would water be different if the shape of the water molecule was different? What if the hydrogen atoms bonded to oxygen to form a linear molecule instead of a bent one?

**Hypothetical linear water molecule**



The answer to this question is not altogether simple. We don't know exactly how our hypothetical linear water would behave, but we do know it would be much different than ordinary water. For example, linear water would probably have a much lower boiling point than ordinary water. In fact, it may even be a gas (instead of a liquid) at room temperature. Imagine what our world would be like if water was a gas at room temperature. There would be no rivers, no lakes, no oceans, and probably no people (since liquid water is such an important part of what composes us).

There is a direct connection between the world of atoms and molecules and the world we experience every day (▼ **FIGURE 1.1**). 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*.

▲ **FIGURE 1.1 Virtually everything around you is composed of chemicals.**

# 1.2 Chemicals Compose Ordinary Things

▶ 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.)*

We just saw how chemists are interested in substances such as sand and water. But are these substances chemicals? Yes. In fact, everything that we can hold or touch is 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 with which we come into contact. Chemistry explains the properties and behavior of chemicals, in the broadest sense, by helping us understand the molecules that compose them.