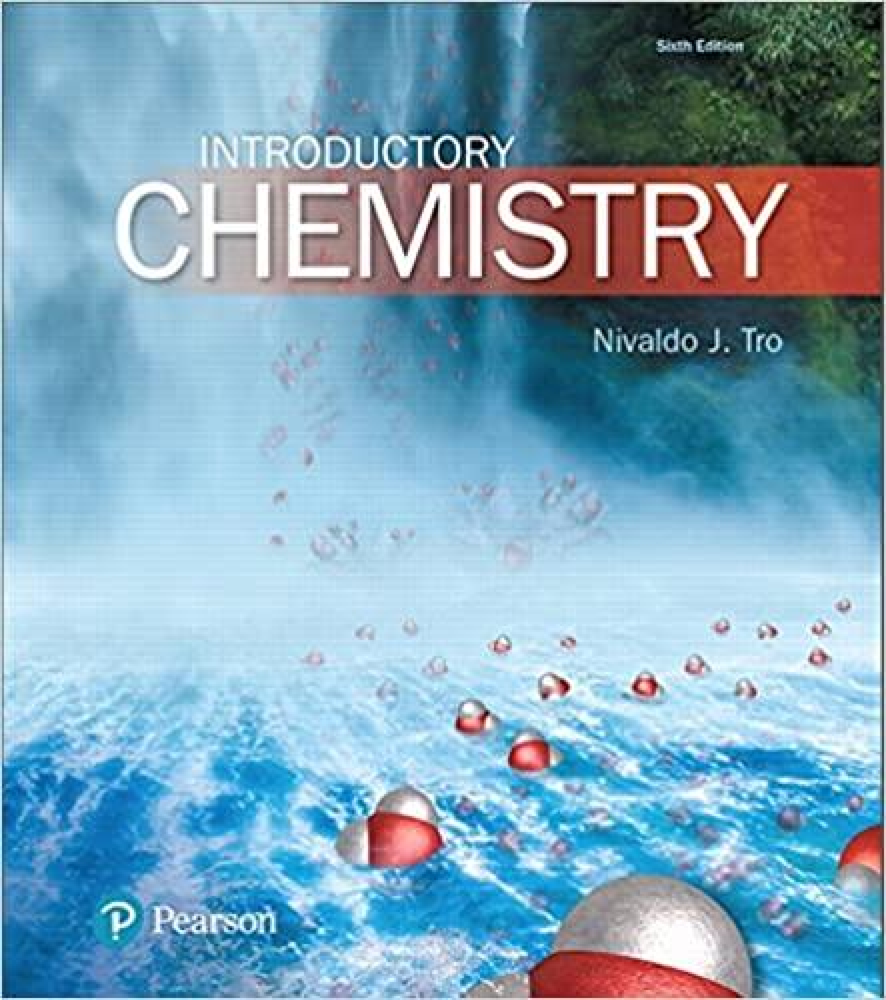
Sixth Edition
INTRODUCTORY
CHEMISTRY
Nivaldo J. Tro
Pearson

About the Author

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

To Annie

Brief Contents

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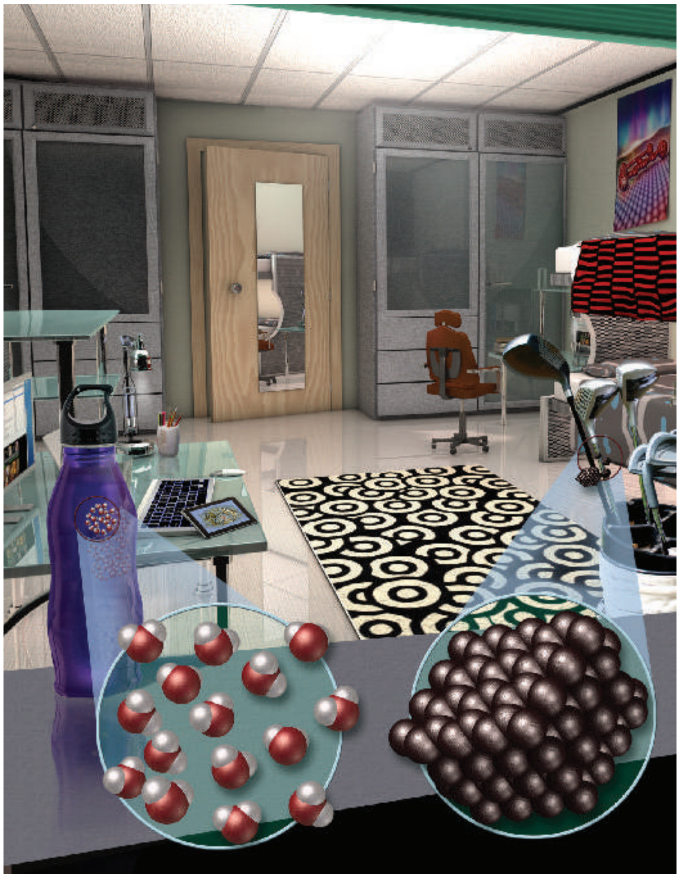

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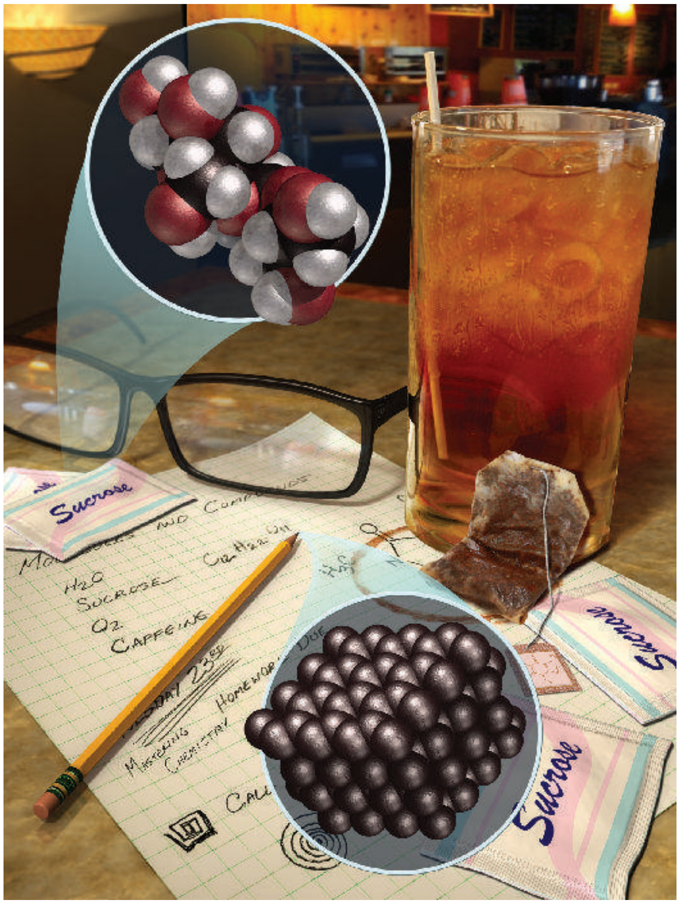

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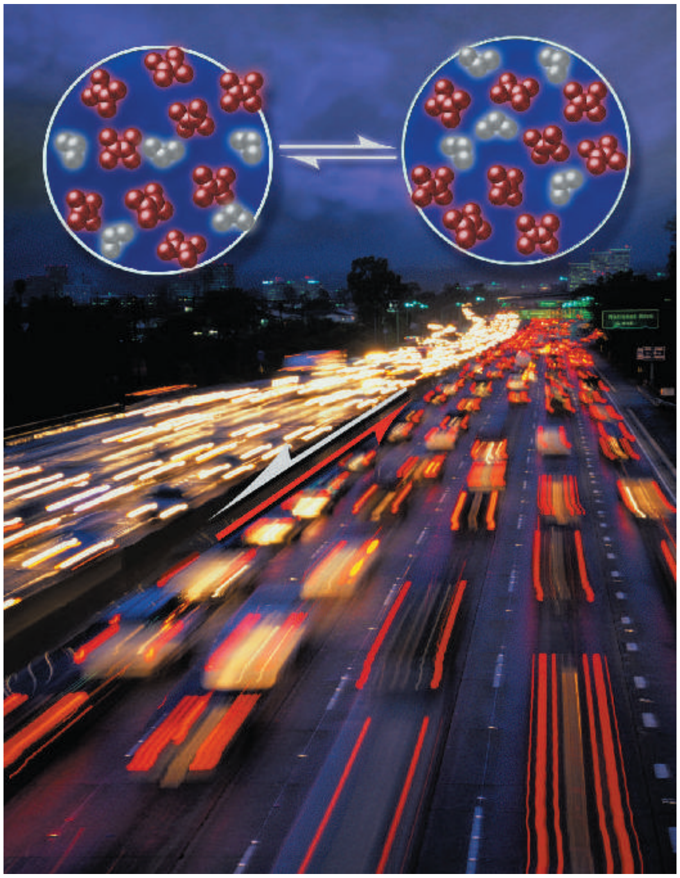

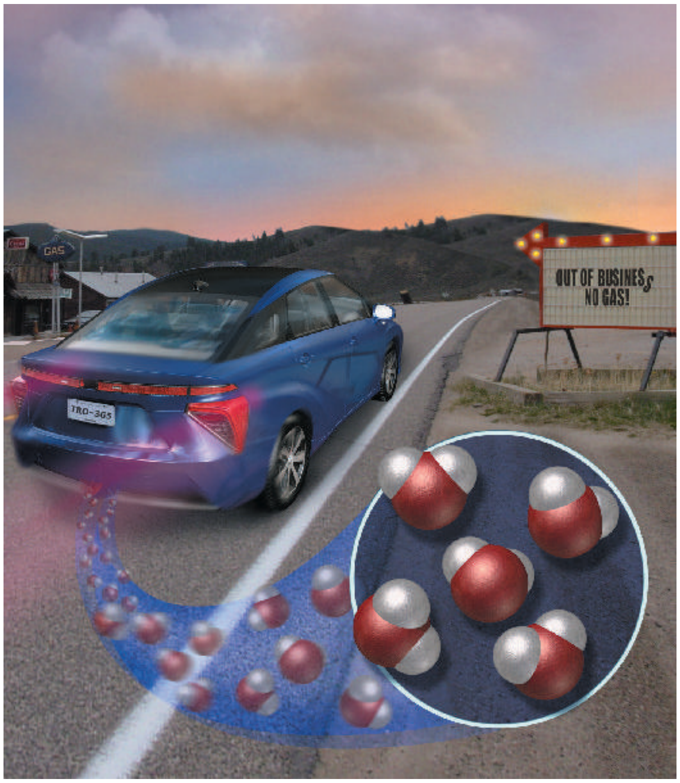

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The eText 2.0 icon indicates that this feature is embedded and interactive in the eText.

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. Interactive Worked Examples can be found in the eText 2.0 and can be accessed directly at: https://media.pearsoncmg.com/ph/esm/esm_tro_intro_6/media/index.html.

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
tro@westmont.edu

To the Instructor

I thank all of you who have used any of the first five 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 sixth 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 sixth edition, making the visual impact sharper and more targeted to student learning. For example, I have continued to expand and refine a hierarchical system of labeling in many of the images: the white-boxed labels are the most important, the tan boxes are second in importance, and the unboxed labels are the third most important. In many cases, this system allows information to be placed closest to its point of relevance, instead of being lumped together in the caption. In addition, 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 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 five 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 39 Interactive Worked Examples, which can be accessed in the eText 2.0.

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 eText 2.0. Emphasizing understanding rather than calculation, they are designed to encourage active learning even while reading. Your continued embrace of this feature prompted me to add more of these to the sixth edition.

In this edition, I have also added a new category of End-of-Chapter Questions called *Data Interpretation and Analysis*. These questions present real data in real-life situations and ask students to analyze and interpret that data. They are designed to give students much needed practice in reading graphs, understanding tables, and making data-driven decisions.

In my own teaching, I have been influenced by two studies published in the last few years. 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 have added 12 Key Concept Videos to the media package that accompanies 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 19 new Interactive Worked Examples adding to a total of 39 new and revised Interactive Worked Example videos in the media package. This means that you now have a library of 31 new interactive videos and a total of 51 new and revised interactive videos to enhance your course.

In my courses, I use these videos 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 *before* most class sessions. All Key Concept Videos and Interactive Worked Examples are embedded and interactive in eText 2.0, allowing students to review and test their understanding in real-time. The video 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 or problem. 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. Like the Conceptual Checkpoints and the videos, these quizzes are embedded in eText 2.0. 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 new 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
tro@westmont.edu

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[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] Daniel T. Pyburn, Samuel Pazicni, Victor A. Benassi, and Elizabeth M. Tappin *J. Chem. Educ.*, 2014, 91 (12), pp. 2045–2057.

Preface

What's New in 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.

- I have added a new category of end-of-chapter questions called *Data Interpretation and Analysis*. These questions present real data in real-life situations and ask students to analyze that data. They give students much needed practice in reading graphs, digesting tables, and making data-driven decisions. A new section (Section 1.4), including a new in-chapter worked Example (Example 1.4), introduces these skills.
- There are 12 new Key Concept Videos and 19 new Interactive Worked Examples to accompany the book. That means there are 31 new videos and 51 total new and revised interactive videos to accompany the material in the sixth edition. All Key Concept Videos and Interactive Worked Examples are embedded and interactive in eText 2.0, allowing students to review and test their understanding in real-time. These tools are designed to help professors engage their students in active learning. Recent research has conclusively demonstrated that students learn better when they are active in the learning process, as opposed to passively listening and simply taking in content. The Key Concept Videos are brief (three to five minutes), and each introduces and explains a key concept from a chapter. The student does not just passively listen to the video; the video stops in the middle and poses a question to the student. The student must answer the question before the video continues. Each video also includes a follow-up question that is assignable in MasteringChemistry™. The Interactive Worked Examples are similar in concept, but instead of explaining a key concept, they walk the student through one of the in-chapter worked examples from the book. Like the Key Concept Videos, Interactive Worked Examples stop in the middle and force the student to interact by completing a step in the example. The examples also have a follow-up question that is assignable in MasteringChemistry™. The power of interactivity to make connections in problem solving is immense. I did not quite realize this power until we started making the Interactive Worked Examples and I saw how I could use the animations to make connections that are just not possible on the static page.
- All chapter-ending Self-Assesment Quizzes are embedded in eText 2.0.
- I have added 13 new Conceptual Checkpoint questions throughout the book. For this edition, all Conceptual Checkpoints are embedded in eText 2.0.
- I have updated the data throughout the book to reflect the most recent measurements and developments available. I changed the half-life of carbon-14 to 5715 years in Table 17.2 and throughout Chapter 17 to reflect the current accepted value, and I also added new information about *thermoluminescent dosimeters* (and deleted the information on film badge dosimeters) to Section 17.4. Other updates include changes to Figure 8.2, *Climate change*; Section 10.1, *Bonding Models and AIDS Drugs*; Table 11.5, *Changes in Pollutant Levels for Major U.S. Cities, 1980–2014*; the *Chemistry in the Environment* box in Section 12.8, *Water: A Remarkable Molecule*; and Section 17.8, *Nuclear Power: Using Fission to Generate Electricity*.

- Several chapter-opening sections and (or) the corresponding art, including Sections 1.1, 2.1, 12.1, and 16.1, have been replaced or significantly modified.
- I added a new section (Section 2.8) and new worked example (Example 2.12) as well as new end-of-chapter Problems to address conversions involving quantities with combined units such as mL/kg or km/hr.
- I have extensively modified the art program to move information from the captions and into the art itself. This allows relevant information to be placed right where it is most needed and makes the art a more accessible study and review tool. I have modified 70 figures in this way.
- I have modified end-of-chapter Problems that were showing low levels of student success when assigned in MasteringChemistry™.
- I have added temporary symbols for elements 113, 115, 117, and 118 (Uut, Uup, Uus, and Uuo, respectively) to all periodic tables.
- In all chapters, chapter text was edited for clarity and to limit use of passive voice and extraneous words and phrases.

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. 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

Instructor and Student Supplements	
0134564057 / 9780134564050	Instructor Resource Manual with Complete Solutions
013455342X / 9780134553429	TestGen Test Bank (Download only)
0134553446 / 9780134553443	Instructor Resource Materials (Download only)
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0134564065 / 9780134564067	Student Selected Solutions Manual
0134555554 / 9780134555553	Modified MasteringChemistry™ with Pearson eText–Instant Access
0134555570 / 9780134555577	MasteringChemistry™ with Pearson eText–Instant Access

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 editor Scott Dustan. I have known Scott for many years and in various roles, and am grateful to have him as my editor. I appreciate his straightforward style, constant support, and commitment to my work. I am also in a continual state of awe and gratitude to Erin Mulligan, my development editor and friend. Thanks, Erin, for all your outstanding help and advice. Thanks also to Jackie Jakob, media editor extraordinaire. Jackie is the force behind the media elements that accompany this book, and I am grateful for her vision, guidance, and friendship. Thanks also to Jennifer Hart, with whom I have now worked for over a decade. Thanks Jennifer for your constant attention, guidance, and wisdom on all of my projects at Pearson. I am also grateful for Jeanne Zalesky, Adam Jaworski, Paul Corey and the rest of Pearson leadership. You have supported my projects and my vision from the beginning, and I am privileged to work with you.

I would also like to thank Elizabeth Ellsworth, my marketing manager, whose creativity in describing and promoting the book is without equal. I am also grateful to Coleen Morrison, whose help with editing and manuscript preparation was invaluable. Thanks also to the MasteringChemistry™ team who continue to provide and promote the best online homework system on the planet. I also appreciate the expertise and professionalism of my copy editor, Betty Pessagno, as well as the skill and diligence of Francesca Monaco and her colleagues at codeMantra. I am a picky author, and they always accommodated my seemingly endless requests. Thank you, Francesca. Thanks as well to my content producer, Chandrika Madhavan and the rest of the Pearson editorial and production team—they are part of a

first-class operation. This text has benefited immeasurably from their talents and hard work. I owe a special debt of gratitude to Quade Paul, who continues to make my ideas come alive in his chapter-opener and cover art.

I am grateful for the assistance of my colleagues, Allan Nishimura, David Marten, Stephen Contakes, Kristi Lazar, Carrie Hill, Michael Everest, Amanda Silberstein, and Heidi Henes-Vanbergen, who have supported me in my department while I worked on this book. I owe a special debt of gratitude to Michael Tro. He has been helping me with manuscript preparation, proofreading, organizing art manuscripts, and tracking changes in end-of-chapter material for the past six years. Michael has been reliable, accurate, and invaluable. Thanks Mikee! I also owe a special thanks to my colleagues Michael Everest and Tom Greenbowe, who collaborated with me in creating some of the end of chapter questions.

I am grateful to those who have given so much to me personally while writing this book. First on that list is my wife, Ann. Her patience and love for me are beyond description. I also thank 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, Jeff, Nachy, Karen, and John; my nephews and nieces, Germain, Danny, Lisette, Sara, and Kenny. These are the people with whom I celebrate life.

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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Help students develop 21st-century skills to succeed in chemistry courses, future careers, and beyond.

Nivaldo Tro's approach introduces students to 21st-century skills, encouraging them to think critically when they encounter complex information and real-world problems.

NEW! Data Interpretation and Analysis Questions at the end of each chapter allow students to work with real data to develop 21st-century problem-solving skills. These questions ask students to sort, analyze and interpret actual data from real-life situations. Students practice reading graphs, digesting tables, and making data-driven decisions.

Data Interpretation and Analysis

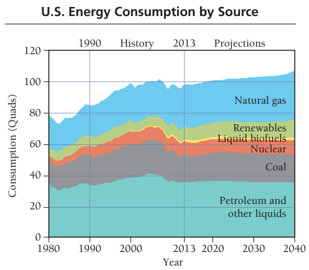
124. The graph at right shows U.S. energy consumption by source from 1980 to 2040 (based on projections). The consumption is measured in quadrillion BTUs or quads (1 quad $= 1.055 \times 10^{18}$ J).

(a) What were the three largest sources of U.S. energy in 2013 in descending order? What total percent of U.S. energy do these three sources provide?

(b) What percent of total U.S. energy is provided by renewables in 2013?

(c) Which two sources of U.S. energy decline as a percentage of total energy use between 1989 and 2040 (based on projections)?

(d) How much U.S. energy (in joules) was produced by nuclear power in 1990?



A new section (Section 1.4), which includes a new in-chapter worked example (Example 1.1), introduces data interpretation and analysis skills and emphasizes their importance in student success.

All Data Interpretation and Analysis Questions are assignable in MasteringChemistry™

1.4 Analyzing and Interpreting Data

▶ Identify patterns in data and interpret graphs.

We just learned how early scientists such as Lavoisier and Dalton saw patterns in a series of related measurements. Sets of measurements constitute scientific *data*, and learning to analyze and interpret data is an important scientific skill.

Identifying Patterns in Data

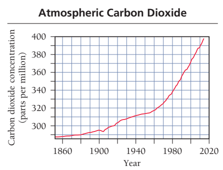
Suppose you are an early chemist trying to understand the composition of water. You know that water is composed of the elements hydrogen and oxygen. You do several experiments in which you decompose different samples of water into hydrogen and oxygen, and you get the following results:

Sample	Mass of Water Sample	Mass of Hydrogen Formed	Mass of Oxygen Formed
A	20.0 g	2.2 g	17.8 g
B	50.0 g	5.6 g	44.4 g
C	100.0 g	11.1 g	88.9 g

Do you notice any patterns in this data? The first and easiest pattern to see is that the sum of the masses of oxygen and hydrogen always sums to the mass of the water sample. For example, for the first water sample, 2.2 g hydrogen + 17.8 g oxygen = 20.0 g water. The same is true for the other samples. Another pattern, which is a bit more difficult to see, is that the ratio of the masses of oxygen and hydrogen is the same for each sample.

Sample	Mass of Hydrogen Formed	Mass of Oxygen Formed	$\frac{\text{Mass Oxygen}}{\text{Mass Hydrogen}}$
A	2.2 g	17.8 g	8.1
B	5.6 g	44.4 g	7.9
C	11.1 g	88.9 g	8.01

The ratio is 8—the small variations are due to experimental error, which is common in all measurements and observations.



▲ **FIGURE 1.5 Atmospheric carbon dioxide levels from 1860 to present.**

Seeing patterns in data is a creative process that requires you to not just merely tabulate laboratory measurements, but to see relationships that may not always be obvious. The best scientists see patterns that others have missed. As you learn to interpret data in this course, be creative and try looking at data in new ways.

Interpreting Graphs

Data is often visualized using graphs or images, and scientists must constantly analyze and interpret graphs. For example, the graph in ◀ **FIGURE 1.5** shows the concentration of carbon dioxide in Earth's atmosphere as a function of time. Carbon dioxide is a greenhouse gas that has been rising as result of the burning of fossil fuels (such as gasoline and coal). When you look at a graph such as this one, you should first examine the x and y axes and make sure you understand what each axis represents. You should also examine the numerical range of the axes. In Figure 1.5, the y axis does not begin at zero in order to better display the change that is occurring. How would this graph look different if the y axis began at zero instead of at 290? Notice also that, in this graph, the increase in carbon dioxide has not been constant over time. The rate of increase—represented by the slope of the line—has intensified since about 1960.

EXAMPLE 1.1 Interpreting Graphs

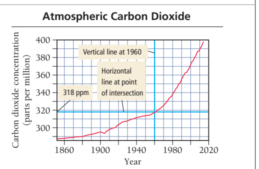
Examine the graph in Figure 1.5 and answer each question.

(a) What was the concentration of carbon dioxide in 1960?
(b) What was the concentration in 2000?
(c) How much did the concentration increase between 1960 and 2000?
(d) What is the average rate of increase over this time?
(e) If the average rate of increase remains constant, estimate the carbon dioxide concentration in 2030.

SOLUTION

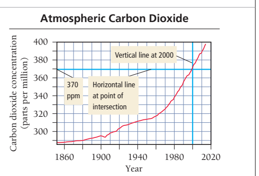
a) What was the concentration of carbon dioxide in 1960?

To determine the concentration of carbon dioxide in 1960, draw a vertical line at the year 1960. At the point where the vertical line intersects the carbon dioxide concentration curve, draw a horizontal line. The point where the horizontal line intercepts the y axis represents the concentration in 1960. So, the concentration in 1960 was 318 ppm.



b) What was the concentration in 2000?

Apply the same procedure as in part a, but now shift the vertical line to the year 2000. The concentration in the year 2000 was 370 ppm.

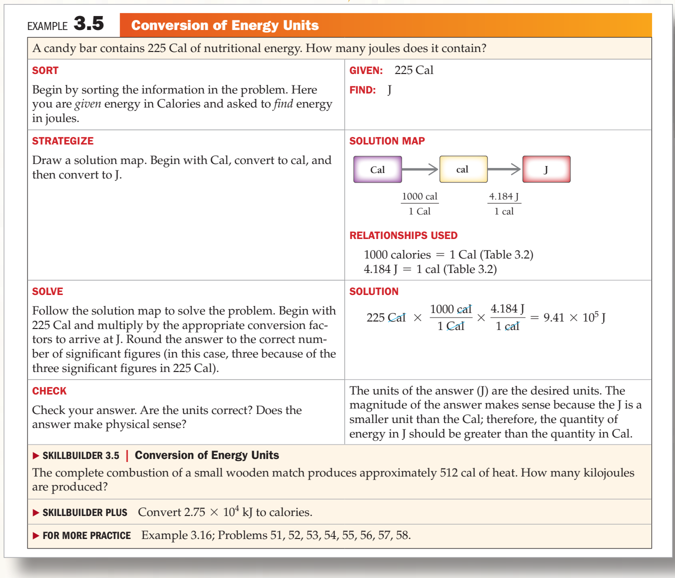


continued on page 10 ▶

Students build a framework for solving problems.

Nivaldo Tro's unique problem-solving technique, "Sort, Strategize, Solve, and Check," teaches students how to successfully approach, set up, and solve the problems they encounter in their introductory chemistry course. Solution maps visually walk students through problems and help them learn how to organize and use given information to successfully solve problems.

Two- and three-column example formats help students break down the steps of each problem and learn and practice problem-solving techniques they can apply in other assignments.



EXAMPLE **3.5** **Conversion of Energy Units**

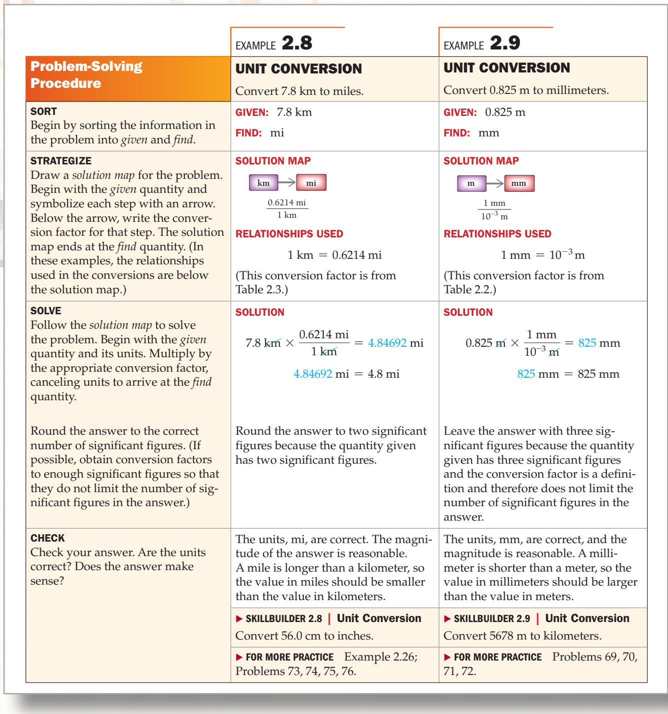
A candy bar contains 225 Cal of nutritional energy. How many joules does it contain?

SORT Begin by sorting the information in the problem. Here you are *given* energy in Calories and asked to *find* energy in joules.	**GIVEN:** 225 Cal **FIND:** J
STRATEGIZE Draw a solution map. Begin with Cal, convert to cal, and then convert to J.	**SOLUTION MAP** Cal → cal → J; $\frac{1000\ cal}{1\ Cal}$, $\frac{4.184\ J}{1\ cal}$ **RELATIONSHIPS USED** 1000 calories = 1 Cal (Table 3.2); 4.184 J = 1 cal (Table 3.2)
SOLVE Follow the solution map to solve the problem. Begin with 225 Cal and multiply by the appropriate conversion factors to arrive at J. Round the answer to the correct number of significant figures (in this case, three because of the three significant figures in 225 Cal).	**SOLUTION** $225\ Cal \times \frac{1000\ cal}{1\ Cal} \times \frac{4.184\ J}{1\ cal} = 9.41 \times 10^5\ J$
CHECK Check your answer. Are the units correct? Does the answer make physical sense?	The units of the answer (J) are the desired units. The magnitude of the answer makes sense because the J is a smaller unit than the Cal; therefore, the quantity of energy in J should be greater than the quantity in Cal.

▶ **SKILLBUILDER 3.5** | **Conversion of Energy Units**
The complete combustion of a small wooden match produces approximately 512 cal of heat. How many kilojoules are produced?

▶ **SKILLBUILDER PLUS** Convert 2.75×10^4 kJ to calories.

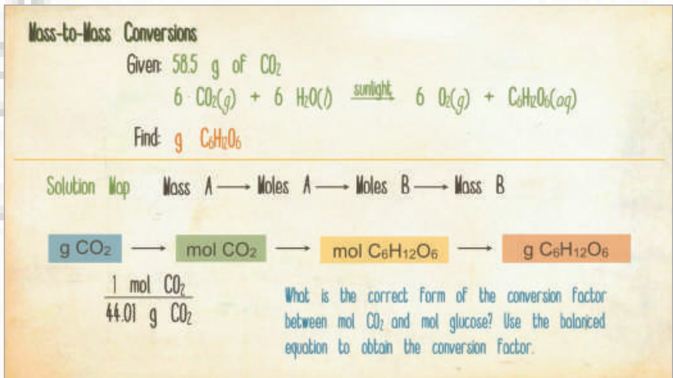
▶ **FOR MORE PRACTICE** Example 3.16; Problems 51, 52, 53, 54, 55, 56, 57, 58.



Problem-Solving Procedure	EXAMPLE **2.8** UNIT CONVERSION Convert 7.8 km to miles.	EXAMPLE **2.9** UNIT CONVERSION Convert 0.825 m to millimeters.
SORT Begin by sorting the information in the problem into *given* and *find*.	**GIVEN:** 7.8 km **FIND:** mi	**GIVEN:** 0.825 m **FIND:** mm
STRATEGIZE Draw a *solution map* for the problem. Begin with the *given* quantity and symbolize each step with an arrow. Below the arrow, write the conversion factor for that step. The solution map ends at the *find* quantity. (In these examples, the relationships used in the conversions are below the solution map.)	**SOLUTION MAP** km → mi; $\frac{0.6214\ mi}{1\ km}$ **RELATIONSHIPS USED** 1 km = 0.6214 mi (This conversion factor is from Table 2.3.)	**SOLUTION MAP** m → mm; $\frac{1\ mm}{10^{-3}\ m}$ **RELATIONSHIPS USED** $1\ mm = 10^{-3}\ m$ (This conversion factor is from Table 2.2.)
SOLVE Follow the *solution map* to solve the problem. Begin with the *given* quantity and its units. Multiply by the appropriate conversion factor, canceling units to arrive at the *find* quantity.	**SOLUTION** $7.8\ km \times \frac{0.6214\ mi}{1\ km} = 4.84692\ mi$ 4.84692 mi = 4.8 mi	**SOLUTION** $0.825\ m \times \frac{1\ mm}{10^{-3}\ m} = 825\ mm$ 825 mm = 825 mm
Round the answer to the correct number of significant figures. (If possible, obtain conversion factors to enough significant figures so that they do not limit the number of significant figures in the answer.)	Round the answer to two significant figures because the quantity given has two significant figures.	Leave the answer with three significant figures because the quantity given has three significant figures and the conversion factor is a definition and therefore does not limit the number of significant figures in the answer.
CHECK Check your answer. Are the units correct? Does the answer make sense?	The units, mi, are correct. The magnitude of the answer is reasonable. A mile is longer than a kilometer, so the value in miles should be smaller than the value in kilometers.	The units, mm, are correct, and the magnitude is reasonable. A millimeter is shorter than a meter, so the value in millimeters should be larger than the value in meters.
	▶ **SKILLBUILDER 2.8** | **Unit Conversion** Convert 56.0 cm to inches.	▶ **SKILLBUILDER 2.9** | **Unit Conversion** Convert 5678 m to kilometers.
	▶ **FOR MORE PRACTICE** Example 2.26; Problems 73, 74, 75, 76.	▶ **FOR MORE PRACTICE** Problems 69, 70, 71, 72.

PEARSON eText 2.0

NEW! and UPDATED! Interactive Worked Examples are digital versions of select worked examples from the text that make Nivaldo Tro's unique problem-solving strategies interactive. In these digital versions the author walks students through the problem-solving process, asking them to pause and answer questions along the way. Worked example videos are embedded in eText 2.0 and assignable in MasteringChemistry™.



Students learn to think critically about information in the classroom and in everyday life.

NEW! Key Concept Videos combine artwork from the textbook with 2D and 3D animations to create a dynamic on-screen viewing experience and help students understand and apply important concepts throughout the text. Key Concept Videos are embedded in eText 2.0 and are assignable in MasteringChemistry™.

PEARSON eText 2.0

These short (3–5 minutes) videos combine animation and live-action clips of author Nivaldo Tro explaining the key concept of each chapter. Embedded questions in each video increase engagement and test student understanding. Follow-up questions are assignable in MasteringChemistry™.

UPDATED! Chapter-in-Review Exercises and Self-Assessment Quizzes have been revised using MasteringChemistry™ metadata to identify questions that students struggled with in previous editions. In addition to a full complement of end-of-chapter questions, each chapter features a 10–15 multiple-choice question quiz that help students assess their understanding of chapter content, building critical thinking skills and reinforcing key concepts.

Chapter 3 in Review

MasteringChemistry™ provides end-of-chapter exercises, feedback-enriched tutorial problems, animations, and interactive activities to encourage problem solving practice and deeper understanding of key concepts and topics.

Self-Assessment Quiz

PEARSON eText 2.0

Q1. Which substance is a pure compound?
(a) Gold **(b)** Water
(c) Milk **(d)** Fruit cake

Q2. Which property of trinitrotoluene (TNT) is most likely a chemical property?
(a) Yellow color
(b) Melting point is 80.1 °C
(c) Explosive
(d) None of the above

Q3. Which change is a chemical change?
(a) The condensation of dew on a cold night
(b) A forest fire
(c) The smoothening of rocks by ocean waves
(d) None of the above

Q4. Which process is endothermic?
(a) The burning of natural gas in a stove
(b) The metabolism of glucose by your body
(c) The melting of ice in a soft drink
(d) None of the above

Q5. A 35-g sample of potassium completely reacts with chlorine to form 67 g of potassium chloride. How many grams of chlorine must have reacted?
(a) 67 g **(b)** 35 g **(c)** 32 g **(d)** 12 g

Q6. A runner burns 2.56×10^3 kJ during a five-mile run. How many nutritional Calories did the runner burn?
(a) 1.07×10^1 Cal **(b)** 612 Cal
(c) 6.12×10^5 Cal **(d)** 1.07×10^4 Cal

Q7. Convert the boiling point of water (100.00 °C) to K.
(a) −173.15 K
(b) 0 K
(c) 100.00 K
(d) 373.15 K

Q8. A European doctor reports that you have a fever of 39.2 °C. What is your fever in degrees Fahrenheit?
(a) 102.6 °F **(b)** 128.26 °F
(c) 71.2 °F **(d)** 4 °F

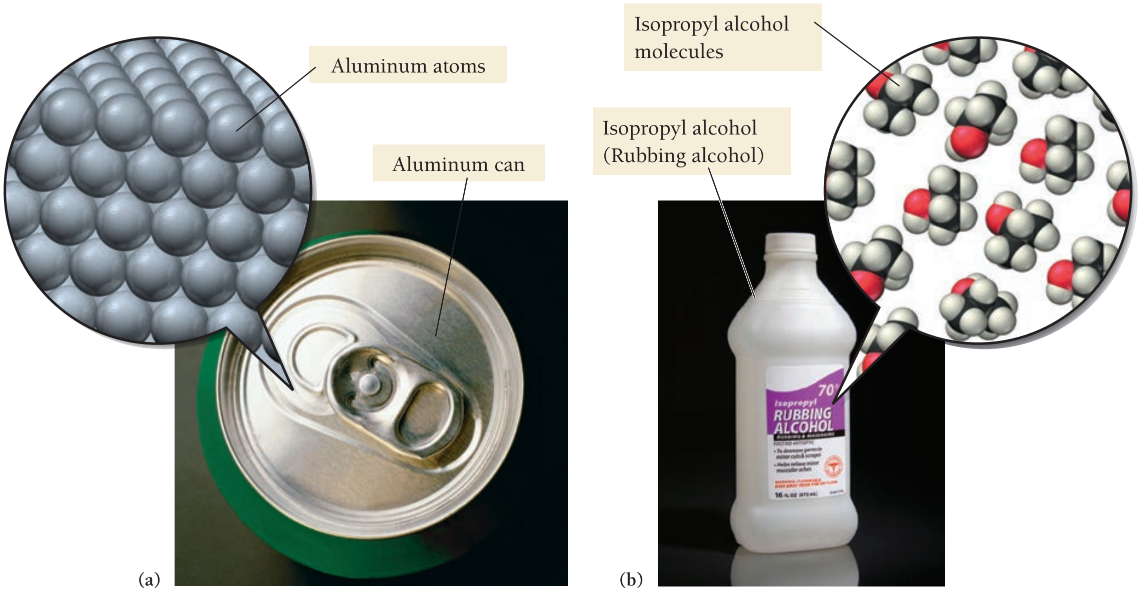
Q9. How much heat must be absorbed by 125 g of ethanol to change its temperature from 21.5 °C to 34.8 °C?
(a) 6.95 kJ
(b) 4.02×10^3 kJ
(c) 86.6 kJ
(d) 4.02 kJ

Q10. Substance A has a heat capacity that is much greater than that of substance B. If 10.0 g of substance A initially at 25.0 °C is brought into thermal contact with 10.0 g of B initially at 75.0 °C, what can you conclude about the final temperature of the two substances once the exchange of heat between the substances is complete?
(a) The final temperature will be between 25.0 °C and 50.0 °C.
(b) The final temperature will be between 50.0 °C and 75.0 °C.
(c) The final temperature will be 50.0 °C.
(d) You can conclude nothing about the final temperature without more information.

Answers: 1:b, 2:c, 3:b, 4:c, 5:c, 6:b, 7:d, 8:a, 9:d, 10:a

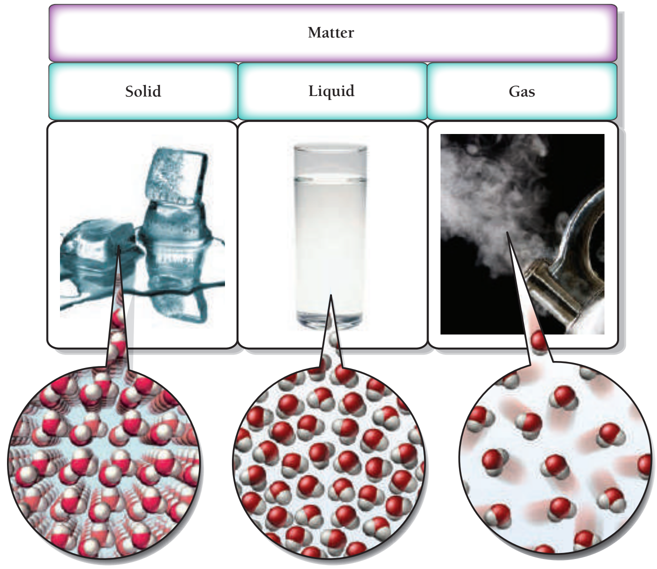
Multipart macroscopic and molecular images engage students in chemistry.

Multipart images allow students to see the relationship between the formulas they write down on paper (symbolic), the world they see around them (macroscopic), and the atoms and molecules that compose the world (molecular).



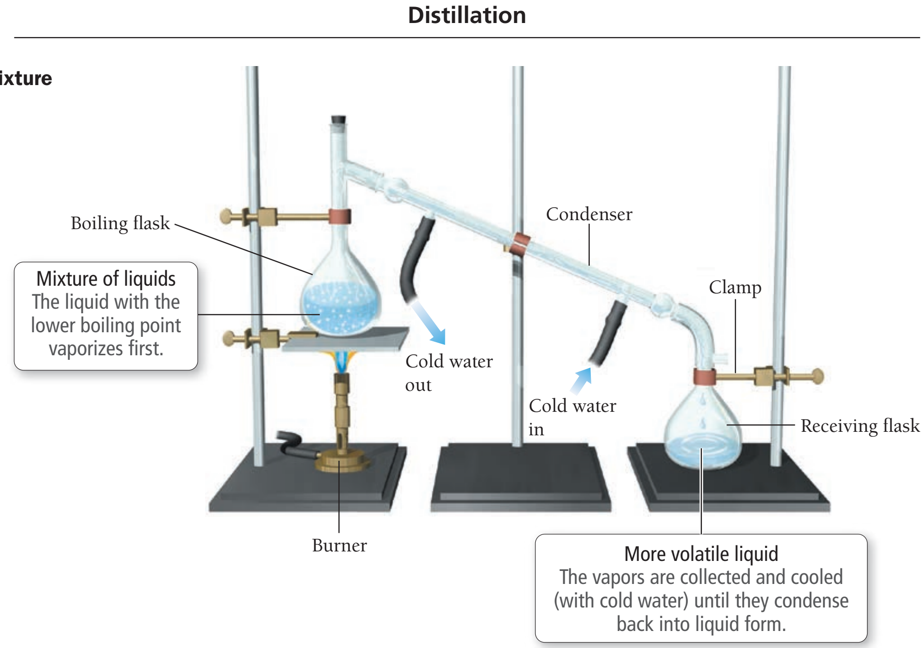
▲ **FIGURE 3.1 Atoms and molecules** All matter is ultimately composed of atoms. (**a**) In some substances, such as aluminum, the atoms exist as independent particles. (**b**) In other substances, such as rubbing alcohol, several atoms bond together in well-defined structures called molecules.

Abundant molecular-level views show students the connection between everyday processes that are visible to the eye and the behavior of atoms and molecules.

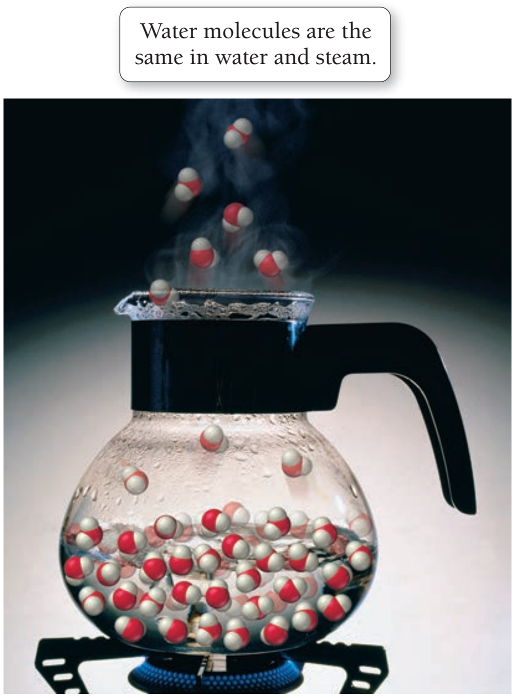


► **FIGURE 3.4 Three states of matter** Water exists as ice (solid), water (liquid), and steam (gas). In ice, the water molecules are closely spaced and, although they vibrate about a fixed point, they do not generally move relative to one another. In liquid water, the water molecules are also closely spaced but are free to move around and past each other. In steam, water molecules are separated by large distances and do not interact significantly with one another.

A revised art program helps students make connections and see that chemistry is all around them.



▶ **FIGURE 3.13 Separating a mixture of two liquids by distillation**



▲ **FIGURE 3.9 A physical property** The boiling point of water is a physical property, and boiling is a physical change. When water boils, it turns into a gas, but the water molecules are the same in both the liquid water and the gaseous steam.

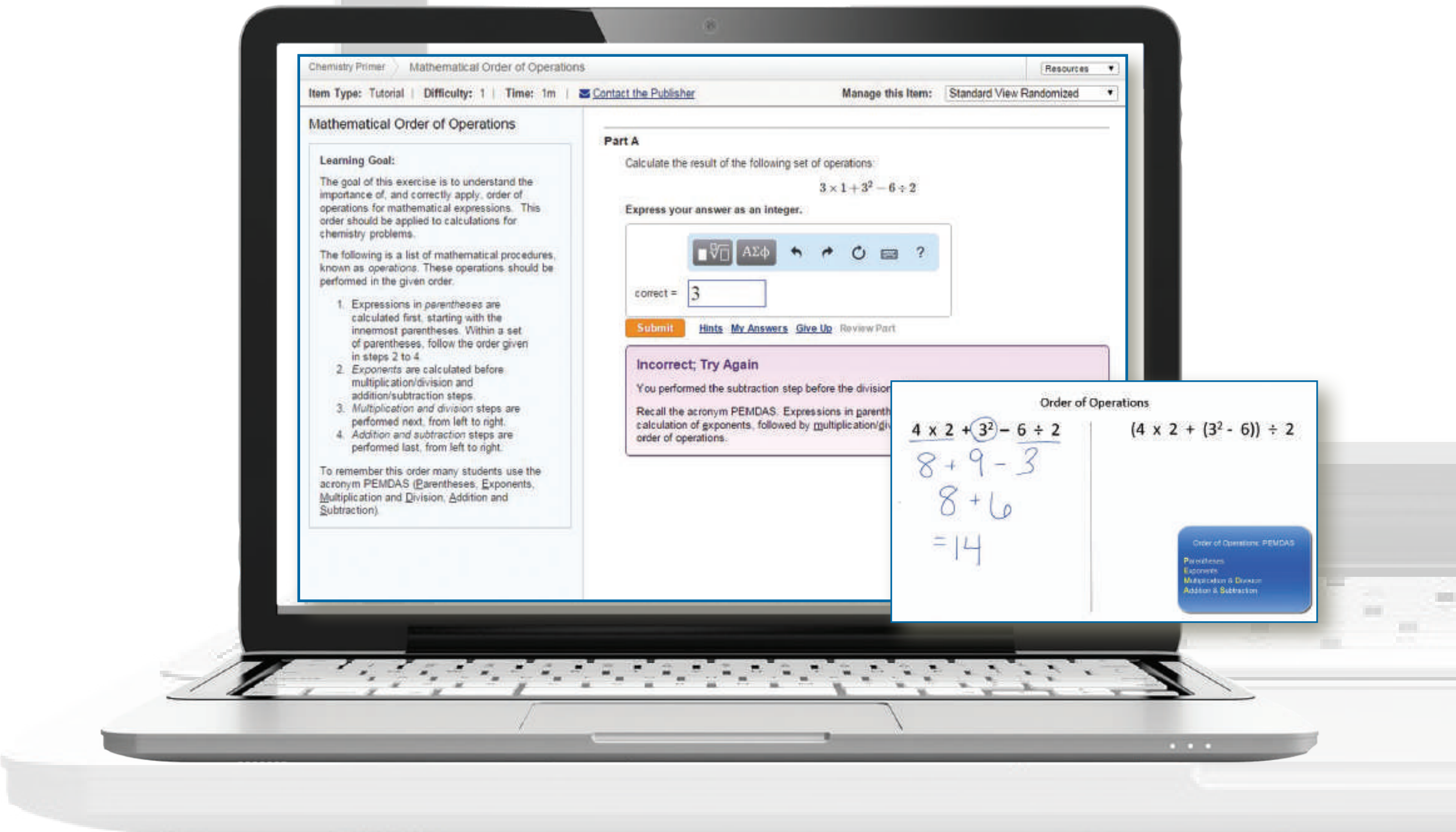
NEW and UPDATED! Illustrations include extensive labels and annotations to direct student attention to key elements in the art and promote understanding of the processes depicted. Numerous figures in the sixth edition have updated labels and annotations to focus readers on key concepts. Relevant information is placed where it is most needed and makes the art a vital study and review tool.

Dynamic Study Modules and the **Chemistry Primer** help students come to class prepared.

66 Dynamic Study Modules adapt to students' individual levels of understanding and help them study effectively on their own. Dynamic Study Modules continuously assess student activity and performance in real time. These are available as graded assignments prior to class and are accessible on smartphones, tablets, and computers.

Topics include key math skills and general chemistry concepts such as phases of matter, redox reactions, acids and bases, solutions, and chemical equilibrium.

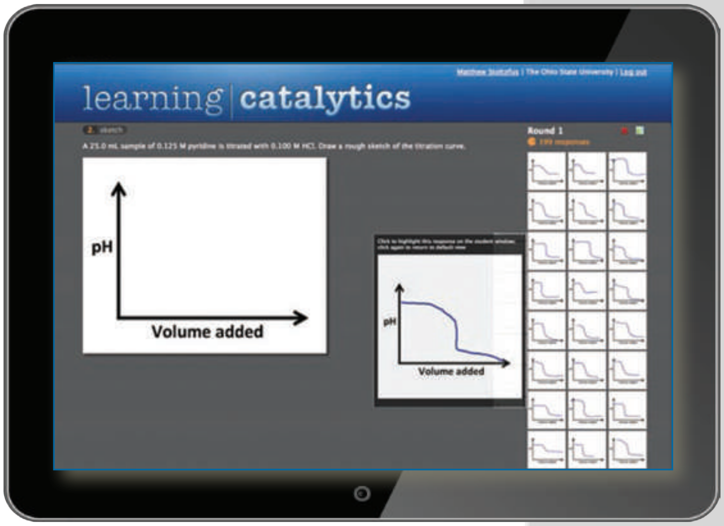
The Chemistry Primer's pre-built diagnostic assignments get students up-to-speed at the beginning of the course, addressing topics such as math in the context of chemistry, basic chemical literacy, balancing chemical equations, mole theory, and stoichiometry. The Chemistry Primer scales to students' needs – remediation is only suggested to students that perform poorly on initial assessment, and involves Tutorials, Wrong-Answer Specific Feedback, Video Instruction, and Step-Wise Scaffolding to build student understanding.



MasteringChemistry™ ensures student engagement before, during, and after class.

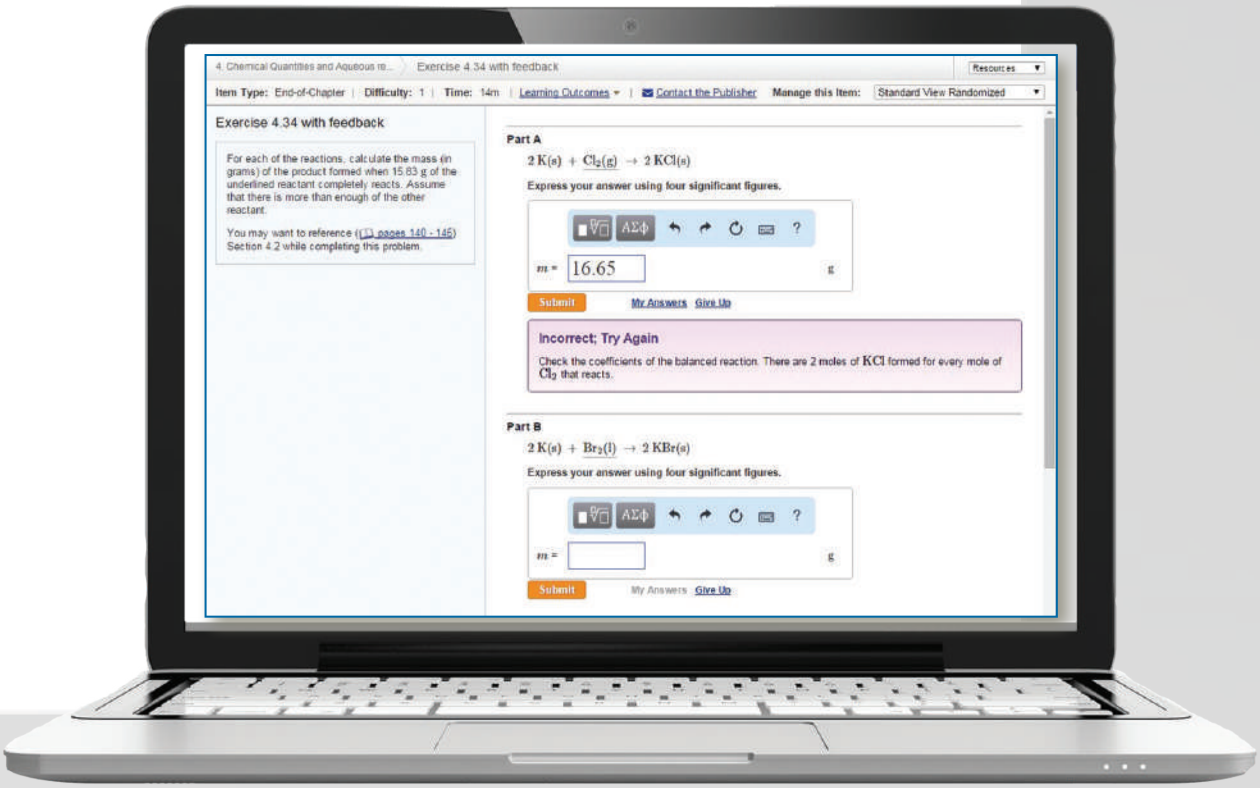
With questions specific to Tro's Introductory Chemistry, **Learning Catalytics™** generates class discussion, guides lecture, and promotes peer-to-peer learning with real-time analytics. Instructors can:

- **NEW!** Upload a full PowerPoint® deck for easy creation of slide questions
- Help students develop critical thinking skills
- Monitor responses to find out where students are struggling
- Adjust teaching strategy with real-time data
- Automatically group students for discussion, team-work, and peer-to-peer learning



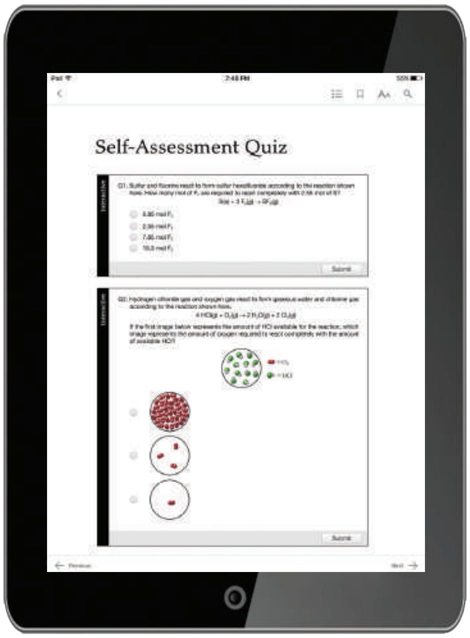
UPDATED! MasteringChemistry™ offers a wide variety of problems, ranging from multi-step tutorials with extensive hints and feedback to multiple-choice End-of-Chapter Problems and Test Bank questions.

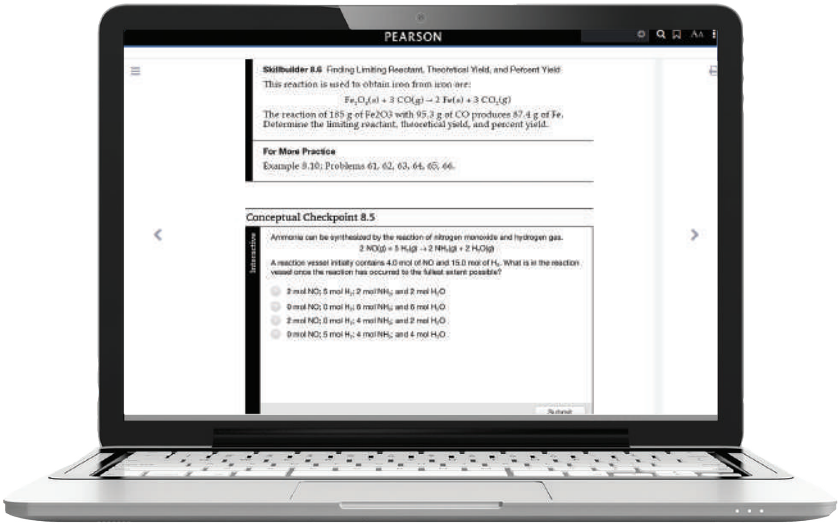
To provide additional scaffolding for students moving from Tutorial Problems to End-of-Chapter Problems we created **NEW! Enhanced End-of-Chapter** Problems that now contain specific wrong-answer feedback.



Students can study anywhere with fully interactive and mobile eText 2.0 features.

NEWLY INTERACTIVE! Self-Assessment Quizzes and Conceptual Checkpoints allow students to interact with all Conceptual Checkpoints and Self-Assessment Quizzes within eText 2.0! With one click these activities are brought to life, allowing students to study on their own and test their understanding in real-time. These interactives help students extinguish misconceptions and deepen their understanding of important concepts and topics.





An icon in the text alerts students to interactive eText 2.0 features. The eText is fully optimized for use on mobile devices, allowing students to study anywhere.

In addition to **Conceptual Checkpoints** and **Self-Assessment Quizzes**, all **Key Concept Videos** and **Interactive Worked Examples** are available in the eText.

Fundamental Physical Constants

Atomic mass unit	$1\ \text{amu} = 1.660539 \times 10^{-27}\ \text{kg}$ $1\ \text{g} = 6.022142 \times 10^{23}\ \text{amu}$
Avogadro's number	$N_A = 6.022142 \times 10^{23}/\text{mol}$
Electron charge	$e = 1.602176 \times 10^{-19}\ \text{C}$
Gas constant	$R = 8.314472\ \text{J/(mol} \cdot \text{K)}$ $= 0.0820582\ (\text{L} \cdot \text{atm})/(\text{mol} \cdot \text{K})$
Mass of electron	$m_e = 5.485799 \times 10^{-4}\ \text{amu}$ $= 9.109382 \times 10^{-31}\ \text{kg}$
Mass of neutron	$m_n = 1.008665\ \text{amu}$ $= 1.674927 \times 10^{-27}\ \text{kg}$
Mass of proton	$m_p = 1.007276\ \text{amu}$ $= 1.672622 \times 10^{-27}\ \text{kg}$
Pi	$\pi = 3.1415926536$
Planck's constant	$h = 6.626069 \times 10^{-34}\ \text{J} \cdot \text{s}$
Speed of light in vacuum	$c = 2.99792458 \times 10^{8}\ \text{m/s}$

Useful Geometric Formulas

Perimeter of a rectangle $= 2l + 2w$

Circumference of a circle $= 2\pi r$

Area of a triangle $= (1/2)(\text{base} \times \text{height})$

Area of a circle $= \pi r^2$

Surface area of a sphere $= 4\pi r^2$

Volume of a sphere $= (4/3)\pi r^3$

Volume of a cylinder or prism $=$ area of base $\times$ height

Important Conversion Factors

Length: SI unit = meter (m)

- 1 m = 39.37 in.
- 1 in. = 2.54 cm (exactly)
- 1 mile = 5280 ft = 1.609 km
- 1 angstrom (Å) = 10^{-10} m

Volume: SI unit = cubic meter (m^3)

- 1 L = 1000 cm^3 = 1.057 qt (U.S.)
- 1 gal (U.S.) = 4 qt = 8 pt
  = 128 fluid ounces
  = 3.785 L

Mass: SI unit = kilogram (kg)

- 1 kg = 2.205 lb
- 1 lb = 16 oz = 453.6 g
- 1 ton = 2000 lb
- 1 metric ton = 1000 kg = 1.103 tons
- 1 g = 6.022×10^{23} atomic mass units (amu)

Pressure: SI unit = pascal (Pa)

- 1 Pa = 1 N/m^2
- 1 bar = 10^5 Pa
- 1 atm = 1.01325×10^5 Pa (exactly)
  = 1.01325 bar
  = 760 mmHg
  = 760 torr (exactly)

Energy: SI unit = joule (J)

- 1 J = 1 N · m
- 1 cal = 4.184 J (exactly)
- 1 L · atm = 101.33 J

Temperature: SI unit = kelvin (K)

- K = °C + 273.15
- °C = (5/9) (°F − 32°)
- °F = (9/5) (°C) + 32°

Atomic Masses of the Elements

Based on carbon-12. A number in parentheses is the atomic mass of the most stable isotope of a radioactive element.

Name	Symbol	Atomic Number	Atomic Weight
Actinium	Ac	89	(227)
Aluminum	Al	13	26.98
Americium	Am	95	(243)
Antimony	Sb	51	121.75
Argon	Ar	18	39.95
Arsenic	As	33	74.92
Astatine	At	85	(210)
Barium	Ba	56	137.33
Berkelium	Bk	97	(247)
Beryllium	Be	4	9.01
Bismuth	Bi	83	208.98
Bohrium	Bh	107	(262)
Boron	B	5	10.81
Bromine	Br	35	79.90
Cadmium	Cd	48	112.41
Calcium	Ca	20	40.08
Californium	Cf	98	(251)
Carbon	C	6	12.01
Cerium	Ce	58	140.12
Cesium	Cs	55	132.91
Chlorine	Cl	17	35.45
Chromium	Cr	24	52.00
Cobalt	Co	27	58.93
Copernicium	Cn	112	(285)
Copper	Cu	29	63.55
Curium	Cm	96	(247)
Darmstadtium	Ds	110	(271)
Dubnium	Db	105	(262)
Dysprosium	Dy	66	162.50
Einsteinium	Es	99	(252)
Erbium	Er	68	167.26
Europium	Eu	63	151.97
Fermium	Fm	100	(257)
Flerovium	Fl	114	(289)
Fluorine	F	9	19.00
Francium	Fr	87	(223)
Gadolinium	Gd	64	157.25
Gallium	Ga	31	69.72
Germanium	Ge	32	72.63
Gold	Au	79	196.97
Hafnium	Hf	72	178.49
Hassium	Hs	108	(265)
Helium	He	2	4.00
Holmium	Ho	67	164.93
Hydrogen	H	1	1.01
Indium	In	49	114.82
Iodine	I	53	126.90
Iridium	Ir	77	192.22
Iron	Fe	26	55.85
Krypton	Kr	36	83.80
Lanthanum	La	57	138.91
Lawrencium	Lr	103	(260)
Lead	Pb	82	207.2
Lithium	Li	3	6.94
Livermorium	Lv	116	(293)
Lutetium	Lu	71	174.97
Magnesium	Mg	12	24.31
Manganese	Mn	25	54.94
Meitnerium	Mt	109	(266)

Name	Symbol	Atomic Number	Atomic Weight
Mendelevium	Md	101	(258)
Mercury	Hg	80	200.59
Molybdenum	Mo	42	95.95
Moscovium	Mc	115	(289)
Neodymium	Nd	60	144.24
Neon	Ne	10	20.18
Neptunium	Np	93	(237)
Nickel	Ni	28	58.69
Nihonium	Nh	113	(284)
Niobium	Nb	41	92.91
Nitrogen	N	7	14.01
Nobelium	No	102	(259)
Oganesson	Og	118	(294)
Osmium	Os	76	190.23
Oxygen	O	8	16.00
Palladium	Pd	46	106.42
Phosphorus	P	15	30.97
Platinum	Pt	78	195.08
Plutonium	Pu	94	(244)
Polonium	Po	84	(209)
Potassium	K	19	39.10
Praseodymium	Pr	59	140.91
Promethium	Pm	61	(147)
Protactinium	Pa	91	(231)
Radium	Ra	88	(226)
Radon	Rn	86	(222)
Rhenium	Re	75	186.21
Rhodium	Rh	45	102.91
Roentgenium	Rg	111	(280)
Rubidium	Rb	37	85.47
Ruthenium	Ru	44	101.07
Rutherfordium	Rf	104	(261)
Samarium	Sm	62	150.36
Scandium	Sc	21	44.96
Seaborgium	Sg	106	(263)
Selenium	Se	34	78.97
Silicon	Si	14	28.09
Silver	Ag	47	107.87
Sodium	Na	11	22.99
Strontium	Sr	38	87.62
Sulfur	S	16	32.06
Tantalum	Ta	73	180.95
Technetium	Tc	43	(99)
Tellurium	Te	52	127.60
Tennessine	Ts	117	(294)
Terbium	Tb	65	158.93
Thallium	Tl	81	204.38
Thorium	Th	90	(232)
Thulium	Tm	69	168.93
Tin	Sn	50	118.71
Titanium	Ti	22	47.88
Tungsten	W	74	183.85
Uranium	U	92	(238)
Vanadium	V	23	50.94
Xenon	Xe	54	131.29
Ytterbium	Yb	70	173.04
Yttrium	Y	39	88.91
Zinc	Zn	30	65.39
Zirconium	Zr	40	91.22

Periodic Table of the Elements

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

GROUP

PERIOD	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.

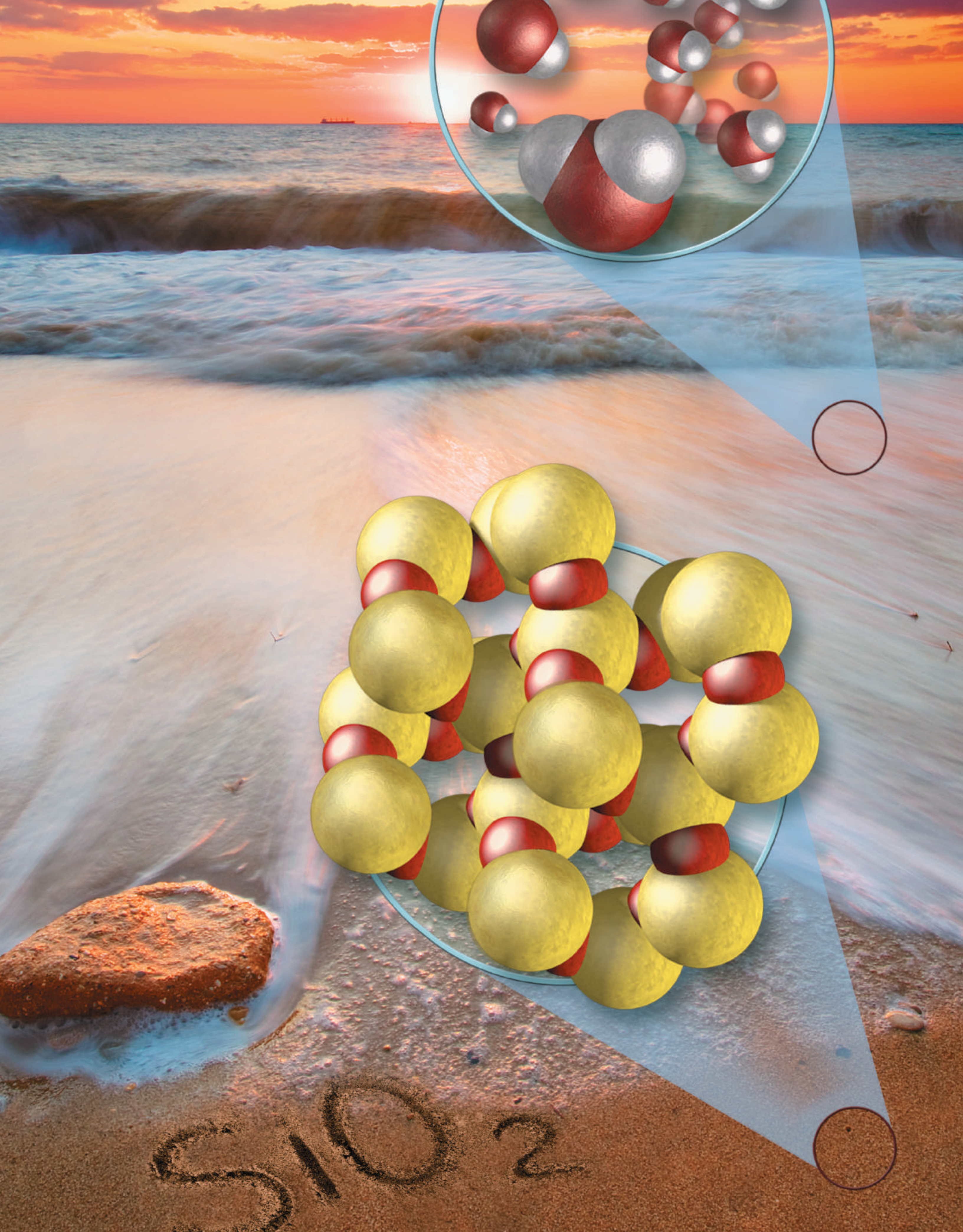
Metals

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) copernicium	113 **Nh** (284) nihonium	114 **Fl** (289) flerovium	115 **Mc** (289) moscovium	116 **Lv** (293) livermorium	117 **Ts** (294) tennessine	118 **Og** (294) oganesson

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


SiO2

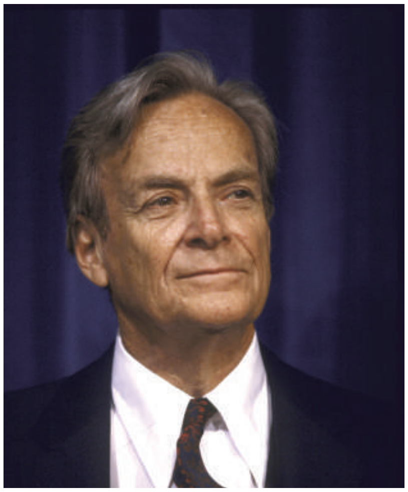
1 The Chemical World

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

CHAPTER OUTLINE

1.1 Sand and Water

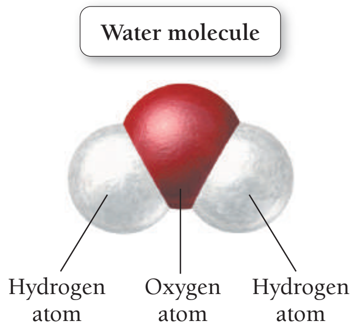
I love the beach but hate sand. Sand gets everywhere and even comes home with you. Sand is annoying because sand particles are so small. They stick to your hands, to your feet, and to any food you might be trying to eat for lunch. But the smallness of sand particles pales in comparison to the smallness 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.



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

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.

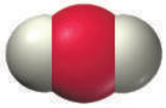
Atoms, and the molecules they compose, determine how matter behaves—if they were different, matter would be different. The nature of water molecules, for example, determines how water behaves. If water molecules were different—even in a small way—then water would be a different sort of substance. For 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:



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

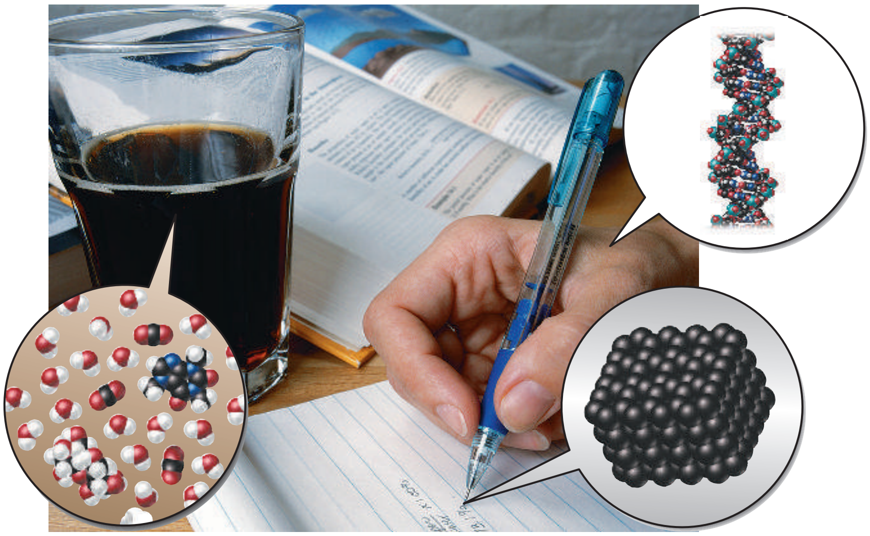
How would water be different if the shape of the water molecule was different? What if the hydrogen atoms bonded to oxygen to form a linear molecule instead of a bent one?

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.

▲ 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.

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

As you experience the world around you, molecules are interacting to create your reality. Imagine watching a sunset. Molecules are involved in every step. Molecules in the 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.

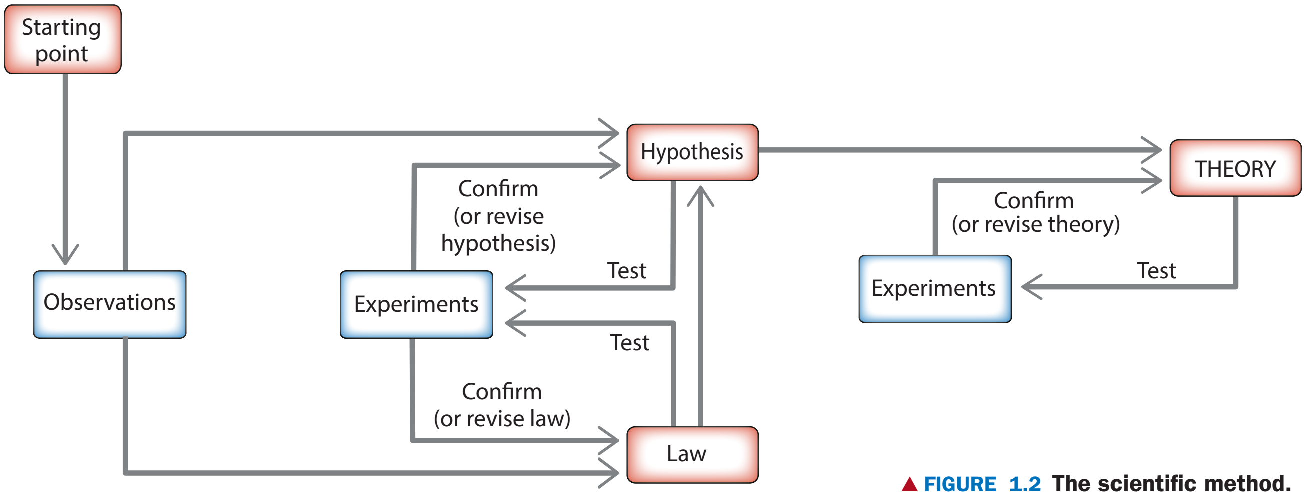
Chemists are interested in why ordinary substances are the way they are. Why is water a liquid? Why is salt a solid? Why does soda fizz? Why is a sunset red? Throughout this book, you will learn the answers to these questions and many others. *You will learn the connections between the behavior of matter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

1.3 The Scientific Method: How Chemists Think

▶ 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



▲ **FIGURE 1.2 The scientific method.**

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.

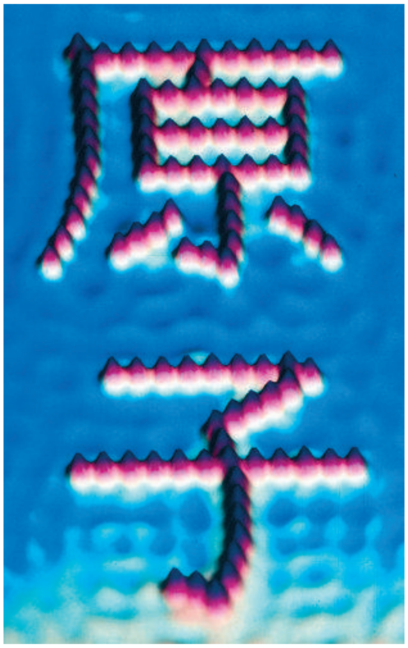
Observations often lead scientists to formulate a **hypothesis**, a tentative interpretation or explanation of the observations. Lavoisier explained his observations on combustion by hypothesizing that combustion involved the combination of a substance with a component of air. A good hypothesis is *falsifiable*, 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 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.

▶ (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.



▲ **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.

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.

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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.

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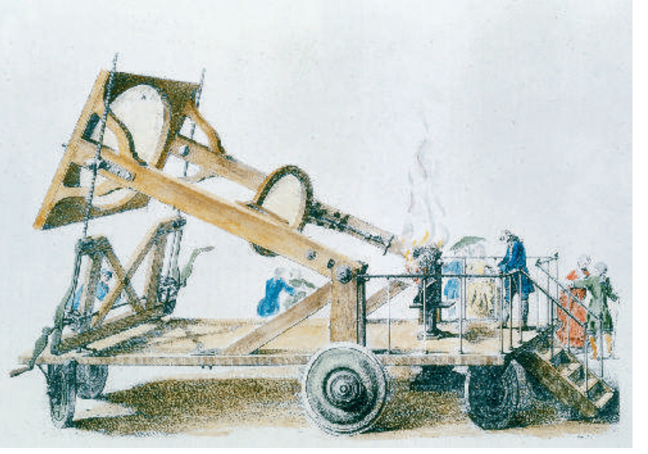
The first modification was that phlogiston was a very light substance, so that it actually "buoyed up" the materials that contained it. Thus when phlogiston was released, the material became heavier. Such a modification seemed to fit the observations but also seemed far-fetched. Antoine Lavoisier developed 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.

1.4 Analyzing and Interpreting Data

▶ Identify patterns in data and interpret graphs.

We just learned how early scientists such as Lavoisier and Dalton saw patterns in a series of related measurements. Sets of measurements constitute scientific *data*, and learning to analyze and interpret data is an important scientific skill.

Identifying Patterns in Data

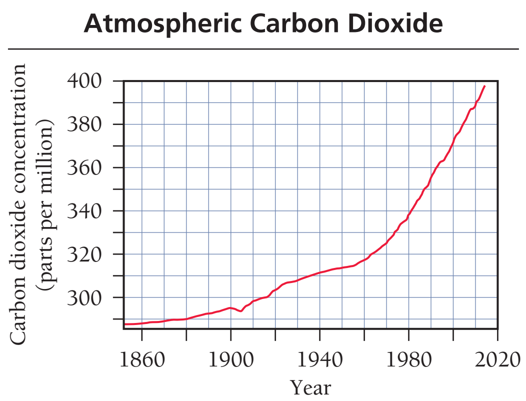
Suppose you are an early chemist trying to understand the composition of water. You know that water is composed of the elements hydrogen and oxygen. You do several experiments in which you decompose different samples of water into hydrogen and oxygen, and you get the following results:

Sample	Mass of Water Sample	Mass of Hydrogen Formed	Mass of Oxygen Formed
A	20.0 g	2.2 g	17.8 g
B	50.0 g	5.6 g	44.4 g
C	100.0 g	11.1 g	88.9 g

Do you notice any patterns in this data? The first and easiest pattern to see is that the sum of the masses of oxygen and hydrogen always sums to the mass of the water sample. For example, for the first water sample, 2.2 g hydrogen + 17.8 g oxygen = 20.0 g water. The same is true for the other samples. Another pattern, which is a bit more difficult to see, is that the ratio of the masses of oxygen and hydrogen is the same for each sample.

Sample	Mass of Hydrogen Formed	Mass of Oxygen Formed	$\frac{\text{Mass Oxygen}}{\text{Mass Hydrogen}}$
A	2.2 g	17.8 g	8.1
B	5.6 g	44.4 g	7.9
C	11.1 g	88.9 g	8.01

The ratio is 8—the small variations are due to experimental error, which is common in all measurements and observations.



▲ **FIGURE 1.5 Atmospheric carbon dioxide levels from 1860 to present.**

Seeing patterns in data is a creative process that requires you to not just merely tabulate laboratory measurements, but to see relationships that may not always be obvious. The best scientists see patterns that others have missed. As you learn to interpret data in this course, be creative and try looking at data in new ways.

Interpreting Graphs

Data is often visualized using graphs or images, and scientists must constantly analyze and interpret graphs. For example, the graph in ◀ **FIGURE 1.5** shows the concentration of carbon dioxide in Earth's atmosphere as a function of time. Carbon dioxide is a greenhouse gas that has been rising as result of the burning of fossil fuels (such as gasoline and coal). When you look at a graph such as this one, you should first examine the x and y axes and make sure you understand what each axis represents. You should also examine the numerical range of the axes. In Figure 1.5, the y axis does not begin at zero in order to better display the change that is occurring. How would this graph look different if the y axis began at zero instead of at 290? Notice also that, in this graph, the increase in carbon dioxide has not been constant over time. The rate of increase—represented by the slope of the line—has intensified since about 1960.

EXAMPLE 1.1 Interpreting Graphs

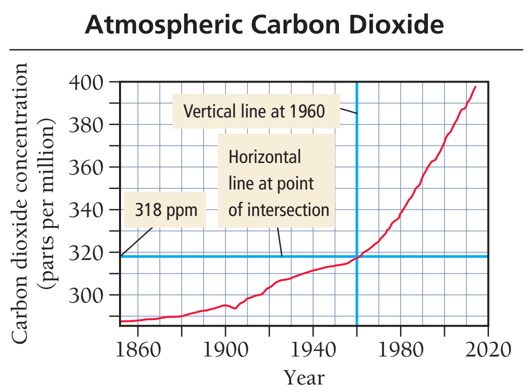
Examine the graph in Figure 1.5 and answer each question.

(a) What was the concentration of carbon dioxide in 1960?
(b) What was the concentration in 2000?
(c) How much did the concentration increase between 1960 and 2000?
(d) What is the average rate of increase over this time?
(e) If the average rate of increase remains constant, estimate the carbon dioxide concentration in 2030.

SOLUTION

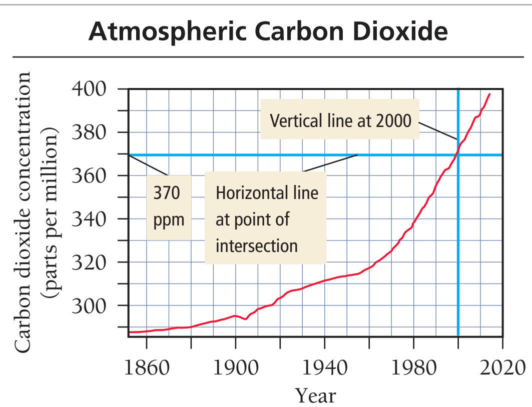
a) What was the concentration of carbon dioxide in 1960?

To determine the concentration of carbon dioxide in 1960, draw a vertical line at the year 1960. At the point where the vertical line intersects the carbon dioxide concentration curve, draw a horizontal line. The point where the horizontal line intercepts the y axis represents the concentration in 1960. So, the concentration in 1960 was 318 ppm.



b) What was the concentration in 2000?

Apply the same procedure as in part a, but now shift the vertical line to the year 2000. The concentration in the year 2000 was 370 ppm.



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c) How much did the concentration increase between 1960 and 2000? The increase in the carbon dioxide concentration is the difference between the two concentrations. When calculating changes in quantities such as this, take the final quantity minus the initial quantity.	increase in concentration = concentration in 2000 − concentration in 1960 = 390 ppm − 318 ppm = 72 ppm
d) What is the average rate of increase over this time? The average rate of increase over this time is the change in the concentration divided by the number of years that passed. Determine the number of years that have passed by subtracting the initial year from the final year. Determine the average rate of increase by dividing the change in concentration (from part c) by the number of years that you just calculated.	number of years = final year − initial year = 2000 − 1960 = 40 years $\text{average rate} = \dfrac{\text{change in concentration}}{\text{number of years}}$ $= \dfrac{72 \text{ ppm}}{40 \text{ years}}$ $= \dfrac{1.8 \text{ ppm}}{\text{year}}$
e) If the average rate of increase remains constant, estimate the carbon dioxide concentration in 2030. Determine the increase in concentration between 2000 and 2030 by multiplying the number of years that pass in that time interval by the average rate of change (from part d). Lastly, determine the concentration in 2030 by adding the increase between 2000 and 2030 to the concentration in 2000.	$\text{increase} = 30 \text{ years} \times \dfrac{1.8 \text{ ppm}}{\text{year}}$ = 54 ppm concentration in 2030 = 370 ppm + 54 ppm = 424 ppm

▶ **SKILLBUILDER 1.1** | What was the average rate of increase in carbon dioxide concentration between 1880 and 1920? Why might that rate be different than the rate between 1960 and 2000?

▶ **FOR MORE PRACTICE** Problem 25.

1.5 A Beginning Chemist: How to Succeed

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

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 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 Hoffmann (1937–), 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 Hoffmann 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 1 in Review

MasteringChemistry™ provides end-of-chapter exercises, feedback-enriched tutorial problems, animations, and interactive activities to encourage problem solving practice and deeper understanding of key concepts and topics.

Self-Assessment Quiz

PEARSON eText 2.0

The eText 2.0 icon indicates that this feature is embedded and interactive in the eText.

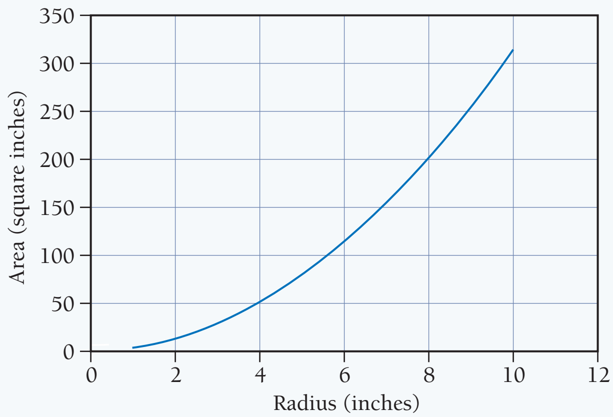
Q1. Where can you find chemicals?
- **(a)** In a hardware store
- **(b)** In a chemical stockroom
- **(c)** All around you and even inside of you
- **(d)** All of the above

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. The graph below shows the area of a circle as a function of its radius. What is the radius of a circle that has an area of 155 square inches?



- **(a)** 7.0 inches
- **(b)** 6.5 inches
- **(c)** 6.8 inches
- **(d)** 6.2 inches

Q6. 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: a, 6: 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

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.

The Scientific Method

Chemists employ the scientific method, which makes use of observations, hypotheses, laws, theories, and experiments. Observations involve measuring or observing some aspect of nature. Hypotheses are tentative interpretations of observations. Laws summarize the results of a large number of observations, and theories are models that explain and give the underlying causes for observations and laws. Hypotheses, laws, and theories must be tested and validated by experiment. If they are not confirmed, they are revised and tested through further experimentation.

The scientific method is a way to understand the world. Since the inception of the scientific method, knowledge about the natural world has grown rapidly. The application of the scientific method has produced technologies that have raised living standards throughout the world with advances such as increased food production, rapid transportation, unparalleled access to information, and longer life spans.

Analyzing and Interpreting Data

A series of measurements are often referred to as data. Scientific data can be graphed to better see relationships between variables.

Virtually all scientists have to analyze and interpret the data they collect. This skill is an important part of understanding chemistry.

Success as a Beginning Chemist

To succeed as a beginning chemist, you must be curious and imaginative, be willing to do calculations, and be committed to learning the material.

To succeed as a beginning chemist, you must be curious and imaginative, be willing to do calculations, and be committed to learning the material.

Key Terms

atomic theory [1.3]
chemistry [1.1]
experiment [1.3]
hypothesis [1.3]
law of conservation of mass [1.3]
observation [1.3]
scientific law [1.3]
scientific method [1.3]
theory [1.3]

Exercises

Questions

Answers to all questions numbered in blue appear in the Answers section at the back of the book.

1. Why does soda fizz?
2. What are chemicals? Give some examples.
3. What do chemists try to do? How do they understand the natural world?
4. What is meant by the statement, "Matter does what molecules do"? Give an example.
5. Define *chemistry*.
6. How is chemistry connected to everyday life? How is chemistry relevant outside the chemistry laboratory?
7. Explain the scientific method.
8. Cite an example from this chapter of the scientific method at work.
9. What is the difference between a law and a theory?
10. What is the difference between a hypothesis and a theory?
11. What is wrong with the statement, "It is just a theory"?
12. What is the law of conservation of mass, and who discovered it?
13. What is the atomic theory, and who formulated it?
14. What are three things you need to do to succeed in this course?

Problems

Note: The exercises in the Problems section are paired, and the answers to the odd-numbered exercises (numbered in blue) appear in the Answers section at the back of the book.

15. Classify each statement as an observation, a law, or a theory.
    (a) When a metal is burned in a closed container, the sum of the masses of the container and its contents does not change.
    (b) Matter is made of atoms.
    (c) Matter is conserved in chemical reactions.
    (d) When wood is burned in a closed container, its mass does not change.
16. Classify each statement as an observation, a law, or a theory.
    (a) The star closest to Earth is moving away from Earth at high speed.
    (b) A body in motion stays in motion unless acted upon by a force.
    (c) The universe began as a cosmic explosion called the Big Bang.
    (d) A stone dropped from an altitude of 450 m falls to the ground in 9.6 s.

17. A student prepares several samples of the same gas and measures their mass and volume. The results are tabulated as follows. Formulate a tentative law from the measurements.

Mass of Gas (in g)	Volume of Gas (in L)
22.5	1.60
35.8	2.55
70.2	5.00
98.5	7.01

18. A student measures the volume of a gas sample at several different temperatures. The results are tabulated as follows. Formulate a tentative law from the measurements.

Temperature of Gas (in K)	Volume of Gas (in L)
298	4.55
315	4.81
325	4.96
335	5.11

19. A chemist in an imaginary universe does an experiment that attempts to correlate the size of an atom with its chemical reactivity. The results are tabulated as follows.

Size of Atom	Chemical Reactivity
small	low
medium	intermediate
large	high

(a) Formulate a law from this data.
(b) Formulate a theory to explain the law.

20. A chemist decomposes several samples of water into hydrogen and oxygen and measures the mass of the hydrogen and the oxygen obtained. The results are tabulated as follows.

Sample Number	Grams of Hydrogen	Grams of Oxygen
1	1.5	12
2	2	16
3	2.5	20

(a) Summarize these observations in a short statement.
Next, the chemist decomposes several samples of carbon dioxide into carbon and oxygen. The results are tabulated as follows:

Sample Number	Grams of Carbon	Grams of Oxygen
1	0.5	1.3
2	1.0	2.7
3	1.5	4.0

(b) Summarize these observations in a short statement.
(c) Formulate a law from the observations in **(a)** and **(b)**.
(d) Formulate a theory that might explain your law in **(c)**.

Questions for Group Work

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

21. The manufacturer of a particular brand of toothpaste claims that the brand contains "no chemicals." Using a few grammatically correct English sentences, describe what you think the company means by that statement. Would a scientist consider the manufacturer's statement to be correct? Why or why not?

22. Make a list (including up to ten items) of all the atoms or molecules group members can name off the top of their heads. Get at least one contribution from each group member.

23. In your own words, provide a brief definition for each of the following: observation, law, hypothesis, and theory.

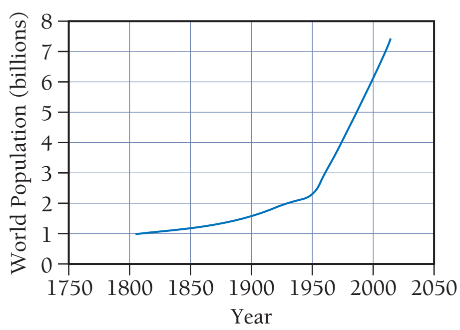
24. How curious are you? How good are your quantitative skills? How hard are you willing to work to succeed in chemistry? Answer these questions individually on a scale of 1 (= not at all) to 5 (= very), then share your answers with your group. Report the group average for each question.

Data Interpretation and Analysis

25. The graph displays world population over time. Study the graph and answer the following questions.

(a) What was the world population in 1950?
(b) What was the world population in 2010?
(c) How much did the population increase between 1950 and 2010?
(d) What is the average rate of increase over this time?
(e) If the average rate of increase remains constant, estimate the world population in 2035.

World Population Versus Time



Source: http://www.worldometers.info/world-population/

Answers to Skillbuilder Exercises

Skillbuilder 1.1........................0.33 ppm/yr; The rate is smaller because less fossil fuels were being used.

Answers to Conceptual Checkpoints

1.1 (c) Answers a and d are observations. Answer b is a scientific law. Answer c is the only answer that proposes a *model* for what a gas is like.


USA TIMES
CITY EDITION
September 24, 1999
Unit Mix-up Causes Crash
Baffled NASA officials said they were struggling to figure out how this happened
Mars Climate Orbiter Disaster
Chief takes full responsibilty
insertion maneuver that would bring the spacecraft
110.012
Calculator
QP2000

2 Measurement and Problem Solving

"The important thing in science is not so much to obtain new facts as to discover new ways of thinking about them."

—Sir William Lawrence Bragg (1890–1971)

CHAPTER OUTLINE

2.1 The Metric Mix-up: A $125 Million Unit Error

On December 11, 1998, NASA launched the Mars Climate Orbiter, which was to become the first weather satellite for a planet other than Earth. The Orbiter's mission was to monitor the atmosphere on Mars and to serve as a communications relay for the Mars Polar Lander, a probe that was to follow the Orbiter and land on the planet's surface three weeks later. Unfortunately, the mission ended in disaster. A unit mix-up caused the Orbiter to enter the Martian atmosphere at an altitude that was too low. Instead of settling into a stable orbit, the Orbiter likely disintegrated. The cost of the failed mission was estimated at $125 million.

Later investigations showed that the Orbiter had come within 57 km of the planet surface, which was too close. When a spacecraft enters a planet's atmosphere too close to the planet's surface, friction with the atmosphere can cause the spacecraft to burn up. The on-board computers that controlled the trajectory corrections were programmed in metric units (newton · second), but the ground engineers entered the trajectory corrections in English units (pound · second). The English and the metric units are not equivalent (1 pound · second = 4.45 newton · second). The corrections that the ground engineers entered were 4.45 times too small and did not alter the trajectory enough to keep the Orbiter at a sufficiently high altitude. In chemistry as in space exploration, *units* (see Section 2.5) are critical. If we get them wrong, the consequences can be disastrous.

A unit is a standard, agreed on quantity by which other quantities are measured.

2.2 Scientific Notation: Writing Large and Small Numbers

▶ Express very large and very small numbers using scientific notation.

Science constantly pushes the boundaries of the very large and the very small. We can, for example, now measure time periods as short as 0.000000000000001 second and distances as great as 14,000,000,000 light-years. Because the many zeros