# General Chemistry: ATOMS FIRST

Young ▪ Vining ▪ Day ▪ Botch

# General Chemistry Atoms First

**Susan M. Young**
Hartwick College

**William J. Vining**
State University of New York, Oneonta

**Roberta Day**
University of Massachusetts, Amherst

**Beatrice Botch**
University of Massachusetts, Amherst

CENGAGE

Australia • Brazil • Mexico • Singapore • United Kingdom • United States

CENGAGE

***General Chemistry: Atoms First***
**Susan M. Young, William J. Vining, Roberta Day, Beatrice Botch**

Product Director: Dawn Giovanniello

Product Manager: Lisa Lockwood

Content Developer: Brendan Killion

Product Assistant: Nellie Mitchell

Marketing Manager: Janet Del Mundo

Content Project Manager: Teresa L. Trego

Digital Content Specialist: Alexandra Purcell

Art Director: Sarah B. Cole

Manufacturing Planner: Rebecca Cross

Intellectual Property Analyst: Christine Myaskovsky

Intellectual Property Project Manager: Erika Mugavin

Production Service/Compositor: Lumina Datamatics Ltd.

Text Designer: Pettengill Designs

Cover Designer: Sarah B. Cole

Cover Image Credit: isak55©Shutterstock



Library of Congress Control Number: 2017944192

ISBN: 978-1-337-61229-6

**Cengage Learning**
20 Channel Center Street
Boston, MA 02210
USA

Cengage Learning is a leading provider of customized learning solutions with employees residing in nearly 40 different countries and sales in more than 125 countries around the world. Find your local representative at **www.cengage.com.**

Cengage Learning products are represented in Canada by Nelson Education, Ltd.

To learn more about Cengage Learning Solutions, visit **www.cengage.com**.

Purchase any of our products at your local college store or at our preferred online store **www.cengagebrain.com**.

Printed in the United States of America
Print Number: 01 Print Year: 2017

# Contents

# Acknowledgments

A product as complex as ***MindTap for General Chemistry: Atoms First*** could not have been created by the content authors alone; it also needed a team of talented, hardworking people to design the system, do the programming, create the art, guide the narrative, and help form and adhere to the vision. Although the authors' names are on the cover, what is inside is the result of the entire team's work and we want to acknowledge their important contributions.

Special thanks go to the core team at Cengage Learning that guided us through the entire process: Lisa Lockwood, Senior Product Manager; Brendan Killion, Associate Content Developer; and Rebecca Heider, Content Developer. Thanks also to Beth McCracken, Senior Media Producer; Alexandra Purcell, Digital Content Specialist; Teresa Trego, Senior Content Project Manager; and Ryan Cartmill, Senior Programmer.

This primarily digital learning environment would not have been possible without the talents of Bill Rohan, Jesse Charette, and Aaron Russell of Cow Town Productions, who programmed the embedded media activities, and the entire MindTap Engineering Teams. Nor would it have been possible without the continued effort of David Hart, Stephen Battisti, Cindy Stein, Mayumi Fraser, Gale Parsloe, and Gordon Anderson from the Center for Educational Software Development (CESD) team at the University of Massachusetts, Amherst, the creators of OWL and the first OWLBook, who were there when we needed them most. Many thanks also go to Charles D. Winters for filming the chemistry videos and taking beautiful photographs.

We are grateful to Professor Don Neu of St. Cloud State University for his contributions to the nuclear chemistry chapter, and to the many instructors who gave us feedback in the form of advisory boards, focus groups, and written reviews. We also want to thank those instructors and students who tested early versions of the *OWLBook* in their courses, most especially Professors Maurice Odago and John Schaumloffel of SUNY Oneonta and Barbara Stewart of the University of Maine who bravely tested the earliest versions of this product.

Bill and Susan would like to thank Jack Kotz, who has been a mentor to both of us for many years. This work would also not have been possible without the support and patience of our families, particularly Kathy, John, John, and Peter.

We are grateful to the many instructors who gave us feedback in the form of advisory boards, focus groups, and written reviews, and most of all to those instructors and students who tested early versions of MindTap Chemistry in their courses.

### Advisory Board

Chris Bahn, *Montana State University*
Christopher Collison, *Rochester Institute of Technology*
Cory DiCarlo, *Grand Valley State University*
Stephen Foster, *Mississippi State University*
Thomas Greenbowe, *Iowa State University*
Resa Kelly, *San Jose State University*
James Rudd, *California State University, Los Angeles*
Jessica Vanden Plas, *Grand Valley State University*

### Class Test Participants

Zsuzsanna Balogh-Brunstad, *Hartwick College*
Jacqueline Bennett, *SUNY Oneonta*
Terry Brack, *Hofstra University*
Preston Brown, *Coastal Carolina Community College*
Donnie Byers, *Johnson County Community College*
John Dudek, *Hartwick College*
Deanna (Dede) Dunlavy, *New Mexico State University*
Dan Dupuis, *Coastal Carolina Community College*
Heike Geisler, *SUNY Oneonta*
Victoria Harris, *SUNY Oneonta*
Gary Hiel, *Hartwick College*
Dennis Johnson, *New Mexico State University*
Thomas Jose, *Blinn College*
Kirk Kawagoe, *Fresno City College*

Kristen Kilpatrick, *Coastal Carolina Community College*
Orna Kutai, *Montgomery College—Rockville Campus*
Antonio Lara, *New Mexico State University*
Scott Lefurgy, *Hofstra University*
Barbara Lyons, *New Mexico State University*
Larry Margerum, *University of San Francisco*
Diana Mason, *University of North Texas*
Don Neu, *St. Cloud State University*
Krista Noren-Santmyer, *Hillsborough Community College*
Erik Ruggles, *University of Vermont*
Flora Setayesh, *Nashville State Community College*
Sherril Soman, *Grand Valley State University*
Marjorie Squires, *Felician College*
Paul Tate, *Hillsborough Community College—Dale Mabry Campus*
Trudy Thomas-Smith, *SUNY Oneonta*
John B. Vincent, *University of Alabama*
Mary Whitfield, *Edmonds Community College*
Matthew J. Young, *University of New Hampshire*

### Focus Group Participants

Linda Allen, *Louisiana State University*
Mufeed M. Basti, *North Carolina A&T*
Fereshteh Billiot, *Texas A&M University—Corpus Christi*
Kristen A. Casey, *Anne Arundel Community College*
Brandon Cruickshank, *Northern Arizona University*
William Deese, *Louisiana Technical University*
Cory DiCarlo, *Grand Valley State University*
Deanna (Dede) Dunlavy, *New Mexico State University*
Krishna Foster, *California State University, Los Angeles*
Stephen Foster, *Mississippi State University*
Gregory Gellene, *Texas Technical University*
Anita Gnezda, *Ball State University*
Nathaniel Grove, *University of North Carolina at Wilmington*
Bernadette Harkness, *Delta College*
Hongqiu Zhao, *Indiana University—Purdue University at Indianapolis*
Edith Kippenhan, *University of Toledo*
Joseph d. Kittle, Jr., *Ohio University*
Amy Lindsay, *University of New Hampshire*
Krista Noren-Santmyer, *Hillsborough Community College*
Olujide T. Akinbo, *Butler University*
James Reeves, *University of North Carolina at Wilmington*
James Rudd, *California State University, Los Angeles*
Raymond Sadeghi, *University of Texas at San Antonio*
Mark Schraf, *West Virginia University*
Sherril Soman, *Grand Valley State University*
Matthew W. Stoltzfus, *Ohio State University*
Dan Thomas, *University of Guelph*
Xin Wen, *California State University, Los Angeles*
Kurt Winkelmann, *Florida Institute of Technology*
James Zubricky, *University of Toledo*

### Reviewers

Chris Bahn, *Montana State University*
Yiyan Bai, *Houston Community College*
Mufeed M. Basti, *North Carolina A&T*
James Beil, *Lorain County Community College*
Fereshteh Billiot, *Texas A&M University—Corpus Christi*
Jeffrey Bodwin, *Minnesota State University Moorhead*
Steven Brown, *University of Arizona*
Phil Brucat, *University of Florida*
Donnie Byers, *Johnson County Community College*
David Carter, *Angelo State University*
Allen Clabo, *Francis Marion University*
Beverly Clement, *Blinn College*
Willard Collier, *Mississippi State*
Christopher Collison, *Rochester Institute of Technology*
Cory DiCarlo, *Grand Valley State University*
Jeffrey Evans, *University of Southern Mississippi*
Nick Flynn, *Angelo State University*
Karin Gruet, *Fresno City College*
Bernadette Harkness, *Delta College*
Carl Hoeger, *University of California, San Diego*
Hongqiu Zhao, *Indiana University—Purdue University Indianapolis*
Richard Jarman, *College of DuPage*
Eric R. Johnson, *Ball State University*
Thomas Jose, *Blinn College*
Kirk Kawagoe, *Fresno City College*
Resa Kelly, *San Jose State University*
Jeffrey A. Mack, *Sacramento State University*
Larry Margerum, *University of San Francisco*
Diana Mason, *University of North Texas*
Donald R. Neu, *St. Cloud University*
Al Nichols, *Jacksonville State University*
Olujide T. Akinbo, *Butler University*
John Pollard, *University of Arizona*

James Reeves, *University of North Carolina at Wilmington*
Mark Schraf, *West Virginia University*
Shawn Sendlinger, *North Carolina Central University*
Duane Swank, *Pacific Lutheran University*
Michael Topp, *University of Pennsylvania*
Ray Trautman, *San Francisco State*
John B. Vincent, *University of Alabama*
Keith Walters, *Northern Kentucky University*
David Wright, *Vanderbilt University*
James Zubricky, *University of Toledo*

# About the Authors

Peter W. Samal

## Susan M. Young

**Hartwick College**

Susan Young received her B.S. in Chemistry in 1988 from the University of Dayton and her Ph.D. in Inorganic Chemistry in 1994 from the University of Colorado at Boulder under the direction of Dr. Arlan Norman, where she worked on the reactivity of cavity-containing phosphazanes. She did postdoctoral work with Dr. John Kotz at the State University of New York at Oneonta, teaching and working on projects in support of the development of the first General Chemistry CD-ROM. She taught at Roanoke College in Virginia and then joined the faculty at Hartwick College in 1996, where she is now Professor of Chemistry. Susan maintains an active undergraduate research program at Hartwick and has worked on a number of chemistry textbook projects, including coauthoring an Introduction to General, Organic, and Biochemistry Interactive CD-ROM with Bill Vining.

## William Vining

**State University of New York at Oneonta**

Bill Vining graduated from SUNY Oneonta in 1981 and earned his Ph.D. in inorganic chemistry at the University of North Carolina-Chapel Hill in 1985, working on the modification of electrode surfaces with polymer-bound redox catalysts. After three years working in industry for S.C. Johnson and Son (Johnson Wax) in Racine, Wisconsin, he became an assistant professor of inorganic chemistry at Hartwick College and eventually department chair. It was here that Bill started working on educational software, first creating the set of simulations called Chemland. This led to work with Jack Kotz on the first General Chemistry CD-ROM and a distance-learning course produced with Archipelago Productions. This work led to a move to the University of Massachusetts, where he served as Director of General Chemistry, which serves 1400 students every semester. He was awarded the University of Massachusetts Distinguished Teaching Award in 1999 and the UMass College of Natural Sciences Outstanding Teacher Award in 2003. At UMass, he also ran a research group dedicated to developing interactive educational software, which included 15 professionals, graduate students, undergraduates, postdoctoral students, programmers, and artists. After nine years at UMass, Bill decided to move back to a primarily undergraduate institution and arrived at SUNY Oneonta, where he now works with undergraduates, Cow Town Productions, and the UMass OWL team.

## Roberta Day

**Professor Emeritus, University of Massachusetts**

Roberta Day received a B.S. in Chemistry from the University of Rochester, Rochester, New York; spent 5 years in the research laboratories of the Eastman Kodak Company, Rochester, New York; and then received a Ph.D. in Physical Chemistry from the Massachusetts Institute of Technology, Cambridge, Massachusetts. After postdoctoral work sponsored by both the Damon Runyon Memorial Fund and the National Institutes of Health, she joined the faculty of the University of Massachusetts, Amherst, rising through the ranks to Full Professor in the Chemistry Department. She initiated the use of online electronic homework in general chemistry at UMass, is one of the inventors of the OWL system, has been either PI or Co-I for several major national grants for the development of OWL, and has authored a large percentage of the questions in the OWL database for General Chemistry. Recognition for her work includes the American Chemical Society Connecticut Valley Section

Award for outstanding contributions to chemistry and the UMass College of Natural Science and Mathematics Outstanding Teacher Award. Her research in chemistry as an x-ray crystallographer has resulted in the publication of more than 180 articles in professional journals. She is now a Professor Emeritus at the University of Massachusetts and continues her work on the development of electronic learning environments for chemistry.

## Beatrice Botch

### University of Massachusetts

Beatrice Botch is the Director of General Chemistry at the University of Massachusetts. She received her B.A. in Chemistry from Barat College in Lake Forest, Illinois, and her Ph.D. in Physical Chemistry from Michigan State University. She completed her graduate work at Argonne National Laboratory under the direction of Dr. Thom Dunning Jr. and was a post-doctoral fellow at the California Institute of Technology, working in the group of Professor William A. Goddard III. She taught at Southwest State University in Minnesota and Wittenberg University in Ohio before joining the faculty at the University of Massachusetts in 1988. She received the UMass College of Natural Science and Mathematics Outstanding Teacher Award in 1999. She is one of the inventors of OWL, and she authored questions in OWL for General Chemistry. She has been principal investigator and co-investigator on a number of grants and contracts related to OWL development and dissemination and continues to develop learning materials in OWL to help students succeed in chemistry.

# To the Student

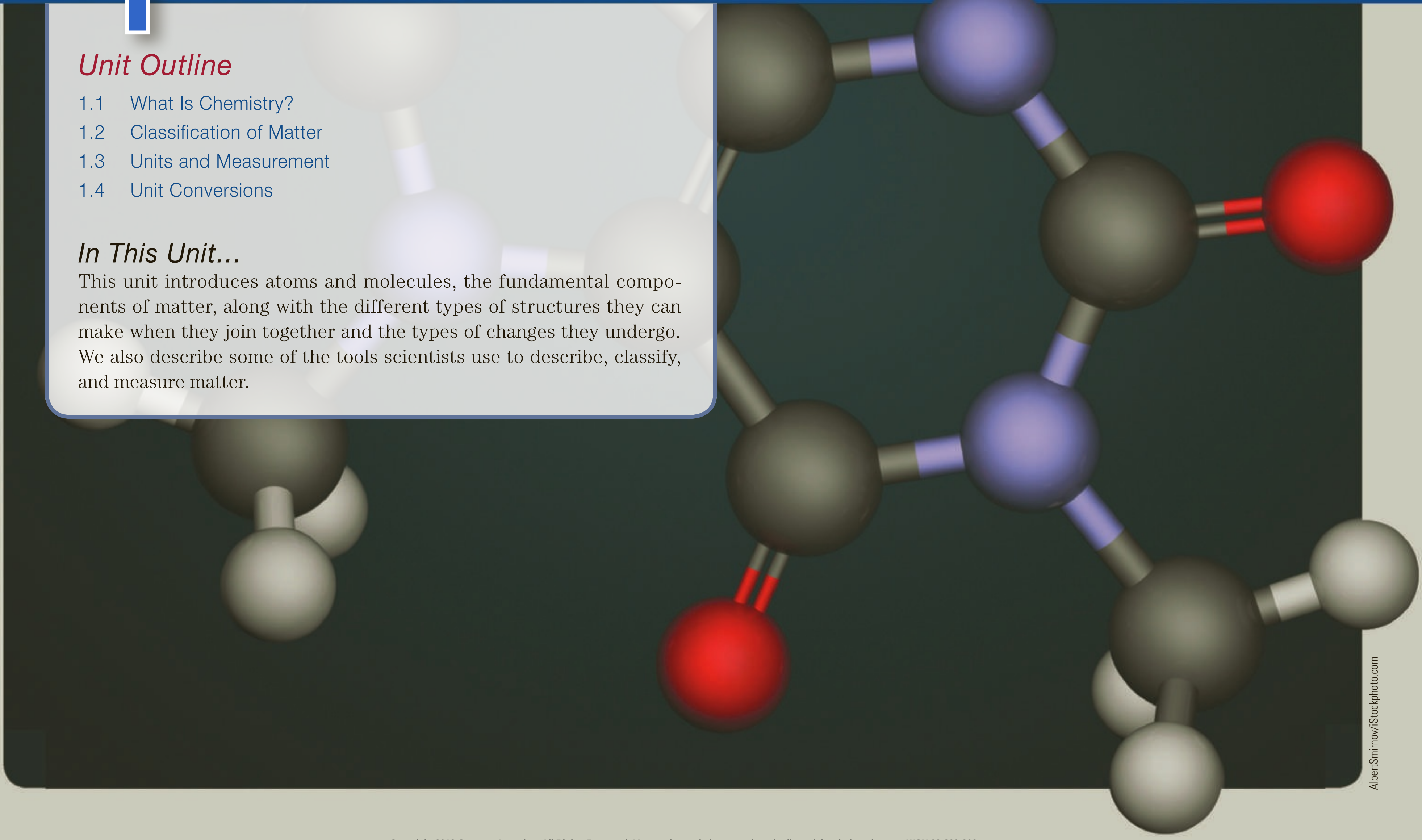
Welcome to a new integrated approach to chemistry. Chemistry is a continually evolving science that examines and manipulates the world on the atomic and molecular level. In chemistry, it's mostly about the molecules. What are they like? What do they do? How can we make them? How do we even know if we have made them? One of the primary goals of chemistry is to understand matter on the molecular scale well enough to allow us to predict which chemical structures will yield particular properties, and the insight to be able to synthesize those structures.

In this first-year course you will learn about atoms and how they form molecules and other larger structures. You will use molecular structure and the ways atoms bond together to explain the chemical and physical properties of matter on the molecular and bulk scales, and in many cases you will learn to predict these behaviors. One of the most challenging and rewarding aspects of chemistry is that we describe and predict bulk, human scale properties through an understanding of particles that are so very tiny they cannot be seen even with the most powerful optical microscope. So, when we see things happen in the world, we translate and imagine what must be occurring to the molecules that we can't ever see.

Our integrated approach is designed to be one vehicle in your learning; it represents a new kind of learning environment built by making the best uses of traditional written explanations, with interactive activities to help you learn the central concepts of chemistry and how to use those concepts to solve a wide variety of useful and chemically important problems. These readings and activities will represent your homework and as such you will find that your book is your homework, and your homework is your book. In this regard, the interactive reading assignments contain integrated active versions of important figures and tables, reading comprehension questions, and suites of problem solving examples that give you step-by-step tutorial help, recorded "video solutions" to important problems, and practice problems with rich feedback that allow you to practice a problem type multiple times using different chemical examples. In addition to the interactive reading assignments, there are additional OWL problems designed to solidify your understanding of each section as well as end-of-chapter assignments.

The authors of the OWLBook have decades of experience teaching chemistry, talking with students, and developing online chemistry learning systems. For us, this work represents our latest effort to help students beyond our own classrooms and colleges. All in all, we hope that your time with us is rewarding and we wish you the best of luck.

# 1 Chemistry: Matter on the Atomic Scale



AlbertSmirnov/iStockphoto.com

## *Unit Outline*



## *In This Unit…*

This unit introduces atoms and molecules, the fundamental components of matter, along with the different types of structures they can make when they join together and the types of changes they undergo. We also describe some of the tools scientists use to describe, classify, and measure matter.

# 1.1 What Is Chemistry?

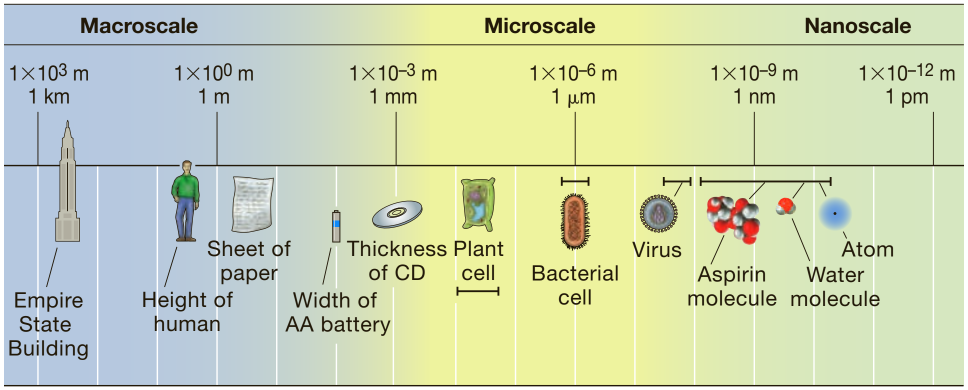
## 1.1a The Scale of Chemistry

**Chemistry** is the study of matter, its transformations, and how it behaves. We define **matter** as any physical substance that occupies space and has mass. Matter consists of atoms and molecules, and it is at the atomic and molecular levels that chemical transformations take place.

Different fields of science examine the world at different levels of detail (Interactive Figure 1.1.1).

**Interactive Figure 1.1.1**

**Understand the scale of science.**




The macroscopic, microscopic, and atomic scales in different fields of science

When describing matter that can be seen with the naked eye, scientists are working on the **macroscopic scale**. Chemists use the **atomic scale** (sometimes called the *nanoscale* or the *molecular scale*) when describing individual atoms or molecules. In general, in chemistry we make observations at the macroscopic level and we describe and explain chemical processes on the atomic level. That is, we use our macroscopic scale observations to explain atomic scale properties.

**Example Problem 1.1.1** Differentiate between the macroscopic and atomic scales.

Classify each of the following as matter that can be measured or observed on either the macroscopic or atomic scale.

a. An RNA molecule
b. A mercury atom
c. A sample of liquid mercury

**Solution:**

**You are asked** to identify whether a substance can be measured or observed on the macroscopic or atomic scale.

**You are given** the identity of the substance.

a. Atomic scale. An RNA molecule is too small to be seen with the naked eye or with an optical microscope.
b. Atomic scale. Individual atoms cannot be seen with the naked eye or with an optical microscope.
c. Macroscopic scale. Liquid mercury can be seen with the naked eye.

Video Solution 1.1.1

## 1.1b Measuring Matter

Chemistry is an experimental science that involves designing thoughtful experiments and making careful observations of macroscopic amounts of matter. Everything that is known about how atoms and molecules interact has been learned through making careful observations on the macroscopic scale and inferring what those observations must mean about atomic scale objects.

For example, careful measurement of the mass of a chemical sample before and after it is heated provides information about the chemical composition of a substance. Observing how a chemical sample behaves in the presence of a strong magnetic field such as that found in a magnetic resonance imaging (MRI) scanner provides information about how molecules and atoms are arranged in human tissues.

An important part of chemistry and science in general is the concept that all ideas are open to challenge. When we perform measurements on chemical substances and interpret the results in terms of atomic scale properties, we must always examine the results to see if there are alternative ways to interpret the data. This method of investigation, called the **scientific method**, ensures that information about the chemical properties and behavior of matter is supported by the results of many different experiments.

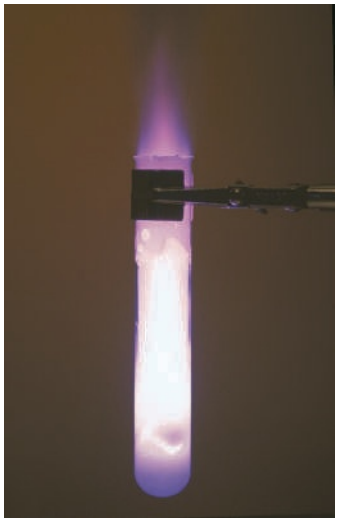
The scientific method consists of the following steps:

1. Choose a system to study. Determine what is already known about it, and then begin by doing experiments and making careful observations.
2. Propose one or more **scientific hypotheses**, tentative statements that could possibly explain an observation and predict future observations. (If a clear pattern is observed over many experiments, scientists might summarize the pattern in a **scientific law**, a concise verbal or mathematical statement that describes a consistent relationship but does not necessarily explain why the pattern of behavior occurs.)
3. Design and perform experiments to test the hypotheses. If the hypotheses are true, these experiments will lead to the predicted results.
4. Use experimental results to confirm or revise existing hypotheses, generate new hypotheses, and/or design further experiments to test the hypotheses.
5. After extensive experimentation and study, use one or more tested hypotheses to propose a **scientific theory**. Theories continue to be tested as new systems are designed, discovered, and studied. If a theory does not stand up to experimentation, it must be revised or discarded, or it could be understood to be useful only within certain limitations.

Interactive Figure 1.1.2 shows a common chemistry demonstration that can be used to demonstrate the scientific method.

Interactive Figure 1.1.2

**Apply the scientific method.**



A vigorous reaction occurs when a red gummi bear is mixed with molten potassium chlorate. How would a scientist investigate this chemical system?

## 1.2 Classification of Matter

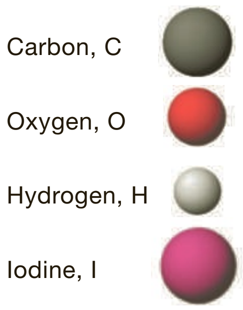
### 1.2a Classifying Matter on the Atomic Scale

Matter can be described by a collection of characteristics called **properties**. One of the fundamental properties of matter is its composition, or the specific types of atoms or molecules that make it up. An **element**, which is the simplest type of matter, is a pure substance that cannot be broken down or separated into simpler substances. You are already familiar with some of the most common elements such as gold, silver, and copper, which are used in making coins and jewelry, and oxygen, nitrogen, and argon, which are the three most abundant gases in our atmosphere. A total of 118 elements have been identified, 90 of which exist in nature (the rest have been synthesized in the laboratory). Elements are represented by a one- or two-letter element symbol, and they are organized in the periodic table, which is shown in Atoms and Elements (Unit 2) and in the Reference Tables. A few common elements and their symbols are shown in Table 1.2.1. Notice that when the symbol for an element consists of two letters, only the first letter is capitalized.

## Atoms

An **atom** is the smallest indivisible unit of an element. For example, the element aluminum (Interactive Figure 1.2.1) is made up entirely of aluminum atoms.

Although individual atoms are too small to be seen directly with the naked eye or with the use of a standard microscope, methods such as scanning tunneling microscopy (STM) allow scientists to view atoms. Both experimental observations and theoretical studies show that isolated atoms are spherical and that atoms of different elements have different sizes. Thus, the model used to represent isolated atoms consists of spheres of different sizes. In addition, chemists often use color to distinguish atoms of different elements. For example, oxygen atoms are usually represented as red spheres, carbon atoms as gray or black spheres, and hydrogen atoms as white spheres.




Elements are made up of only one type of atom. For example, the element oxygen is found in two forms: as $O_2$, in which two oxygen atoms are grouped together, and as $O_3$, in which three oxygen atoms are grouped together.


Dioxygen, $O_2$


Ozone, $O_3$

The most common form of oxygen is $O_2$, dioxygen, a gas that makes up about 21% of the air we breathe. Ozone, $O_3$, is a gas with a distinct odor that can be toxic to humans. Both dioxygen and ozone are elemental forms of oxygen because they consist of only one type of atom.

## Compounds and Molecules

A **chemical compound** is a substance formed when two or more elements are combined in a defined ratio. Compounds differ from elements in that they can be broken down chemically into simpler substances. You have encountered chemical compounds in many common substances, such as table salt, a compound consisting of the elements sodium and chlorine, and phosphoric acid, a compound found in soft drinks that contains hydrogen, oxygen, and phosphorus.

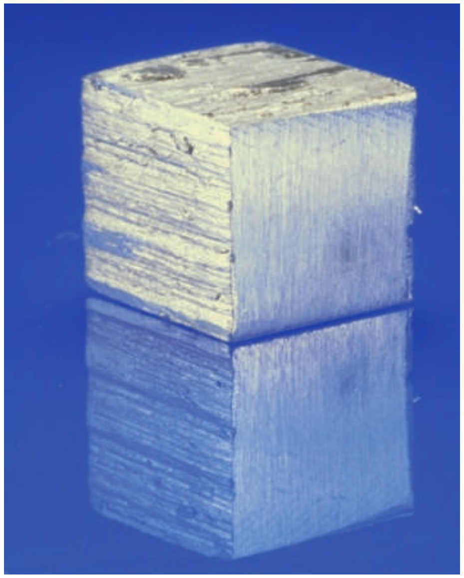
**Molecules** are collections of atoms that are held together by chemical bonds. In models used to represent molecules, chemical bonds are often represented using cylinders or lines that connect atoms, represented as spheres. The composition and arrangement of elements in molecules affects the properties of a substance. For example as shown in Interactive Figure 1.2.2, molecules of both water ($H_2O$) and hydrogen peroxide ($H_2O_2$) contain only the elements hydrogen and oxygen.

**Table 1.2.1** Some Common Elements and Their Symbols

| Name | Symbol |
|---|---|
| Hydrogen | H |
| Carbon | C |
| Oxygen | O |
| Sodium | Na |
| Iron | Fe |
| Aluminum | Al |

**Interactive Figure 1.2.1**

**Explore the composition of elements.**



Charles D. Winters

A piece of aluminum

Water is a relatively inert substance that is safe to drink in its pure form. Hydrogen peroxide, however, is a reactive liquid that is used to disinfect wounds and can cause severe burns if swallowed.

Molecules can also be elements. As you saw above, elemental oxygen consists of both two-atom (dioxygen, $O_2$) and three-atom (ozone, $O_3$) molecules.

**Example Problem 1.2.1** Classify pure substances as elements or compounds.

Classify each of the following substances as either an element or a compound.
a. Si  b. $CO_2$  c. $P_4$

**Solution:**

**You are asked** to classify a substance as an element or a compound.

**You are given** the chemical formula of the substance.
a. Element. Silicon is an example of an element because it consists of only one type of atom.
b. Compound. This compound contains both carbon and oxygen.
c. Element. Although this is an example of a molecular substance, it consists of only a single type of atom.

## 1.2b Classifying Pure Substances on the Macroscopic Scale

A **pure substance** contains only one type of element or compound and has fixed chemical composition. A pure substance also has characteristic properties, measurable qualities that are independent of the sample size. The **physical properties** of a chemical substance are those that do not change the chemical composition of the material when they are measured. Some examples of physical properties include physical state, color, viscosity (resistance to flow), opacity, density, conductivity, and melting and boiling points.

### States of Matter

One of the most important physical properties is the physical state of a material. The three physical **states of matter** are solid, liquid, and gas (Interactive Figure 1.2.3).

The macroscopic properties of these states are directly related to the arrangement and properties of particles at the atomic level. At the macroscopic level, a **solid** is a dense material with a defined shape. At the atomic level, the atoms or molecules of a solid are packed together closely. The atoms or molecules are vibrating, but they do not move past one another. At the macroscopic level, a **liquid** is also dense, but unlike a solid it flows and takes on the shape of its container. At the atomic level, the atoms or molecules of a liquid are close together, but they move more than the particles in a solid and can flow past

**Interactive Figure 1.2.2**

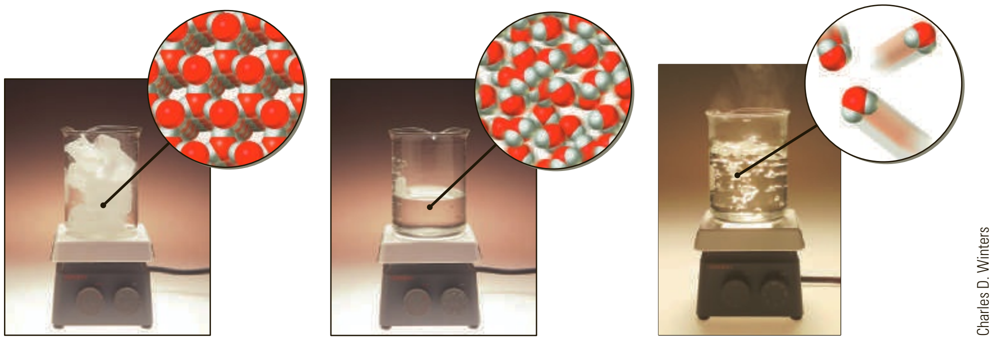
**Explore the composition of compounds and molecules.**


Water and hydrogen peroxide are compounds containing the elements hydrogen and oxygen

**Video Solution 1.2.1**

Interactive Figure 1.2.3

**Distinguish the properties of the three states of matter.**




Representations of a solid, a liquid, and a gas

one another. Finally, at the macroscopic level, a **gas** has no fixed shape or volume. At the atomic level, the atoms or molecules of a gas are spaced widely apart and are moving rapidly past one another. The particles of a gas do not strongly interact with one another, and they move freely until they collide with one another or with the walls of the container.

The physical state of a substance can change when energy, often in the form of heat, is added or removed. When energy is added to a solid, the temperature at which the solid is converted to a liquid is the **melting point** of the substance. The conversion of liquid to solid occurs at the same temperature as energy is removed (the temperature falls) and is called the **freezing point**. A liquid is converted to a gas at the **boiling point** of a substance. As you will see in the following section, melting and boiling points are measured in Celsius (°C) or Kelvin (K) temperature units.

Not all materials can exist in all three physical states. Polyethylene, for example, does not exist as a gas. Heating a solid polyethylene milk bottle at high temperatures causes it to decompose into other substances. Helium, a gas at room temperature, can be liquefied at very low temperatures, but it is not possible to solidify helium.

A change in the physical property of a substance is called a **physical change**. Physical changes may change the appearance or the physical state of a substance, but they do not change its chemical composition. For example, a change in the physical state of water—changing from a liquid to a gas—involves a change in how the particles are packed together at the atomic level, but it does not change the chemical makeup of the material.

## Chemical Properties

The **chemical properties** of a substance are those that involve a chemical change in the material and often involve a substance interacting with other chemicals. For example, a chemical property of methanol, $CH_3OH$, is that it is highly flammable because the compound burns in air (it reacts with oxygen in the air) to form water and carbon dioxide (Interactive Figure 1.2.4).

A **chemical change** involves a change in the chemical composition of the material. The flammability of methanol is a chemical property, and demonstrating this chemical property involves a chemical change.

Interactive Figure 1.2.4

**Investigate the chemical properties of methanol.**

Charles D. Winters

Methanol is a flammable liquid

Example Problem 1.2.2 Identify physical and chemical properties and physical and chemical changes.

a. When aluminum foil is placed into liquid bromine, a white solid forms. Is this a chemical or physical property of aluminum?
b. Iodine is a purple solid. Is this a chemical or physical property of iodine?
c. Classify each of the following changes as chemical or physical.
   i. Boiling water
   ii. Baking bread

**Solution:**

**You are asked** to identify a change or property as chemical or physical.

**You are given** a description of a material or change.

a. Chemical property. Chemical properties are those that involve a chemical change in the material and often involve a substance interacting with other chemicals. In this example, one substance (the aluminum) is converted into a new substance (a white solid).
b. Physical property. A physical property such as color is observed without a change in the chemical identity of the substance.
c. i. Physical change. A physical change alters the physical form of a substance without changing its chemical identity. Boiling does not change the chemical composition of water.
   ii. Chemical change. When a chemical change takes place, the original substances (the bread ingredients) are broken down, and a new substance (bread) is formed.

Video Solution 1.2.2

## 1.2c Classifying Mixtures on the Macroscopic Scale

As you can see when you look around you, the world is made of complex materials. Much of what surrounds us is made up of mixtures of different substances. A **mixture** is a substance made up of two or more elements or compounds that have not reacted chemically.

Unlike compounds, where the ratio of elements is fixed, the relative amounts of different components in a mixture can vary. Mixtures that have a constant composition throughout the material are called **homogeneous mixtures**. For example, dissolving table salt in water creates a mixture of the two chemical compounds water ($H_2O$) and table salt (NaCl). Because the mixture is uniform, meaning that the same ratio of water to table salt is found no matter where it is sampled, it is a homogeneous mixture.

A mixture in which the composition is not uniform is called a **heterogeneous mixture**. For example, a cold glass of freshly squeezed lemonade with ice is a heterogeneous mixture because you can see the individual components (ice cubes, lemonade, and pulp), and the relative amounts of each component will depend on where the lemonade is sampled (from the top of the glass or from the bottom). The two different types of mixtures are explored in Interactive Figure 1.2.5.

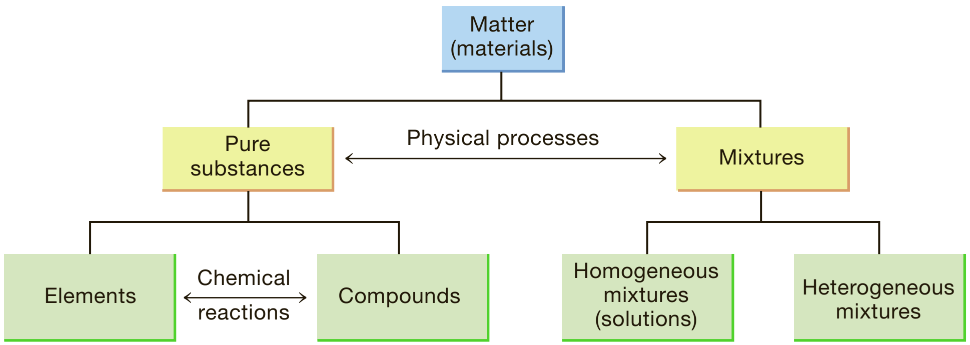
Homogeneous and heterogeneous mixtures can usually be physically separated into individual components. For example, a homogeneous mixture of salt and water is separated by heating the mixture to evaporate the water, leaving behind the salt. A heterogeneous mixture of sand and water is separated by pouring the mixture through filter paper. The sand is trapped in the filter while the water passes through. Heating the wet sand to evaporate the remaining water completes the physical separation.

Like pure substances, mixtures have physical and chemical properties. These properties, however, depend on the composition of the mixture. For example, a mixture of 10 grams of table sugar and 100 grams of water has a boiling point of 100.15 °C, while a mixture of 20 grams of table sugar and 100 grams of water has a boiling point of 100.30 °C.

Interactive Figure 1.2.6 summarizes how we classify different forms of matter in chemistry.

**Interactive Figure 1.2.6**

**Classify matter.**




A flow chart for the classification of matter

**Interactive Figure 1.2.5**

**Identify homogeneous and heterogeneous mixtures.**


Charles D. Winters

Homogeneous and heterogeneous mixtures