Do you know how the beautiful, intricate fireworks displays are created? Have you ever wondered how a tiny seedling can grow into a cornstalk taller than you in just one season? Perhaps you have been mesmerized by the flames in your fireplace on a romantic evening as they change color and form. And think of your relief when you dropped a container and found that it was plastic, not glass. These phenomena are the result of chemistry that occurs all around us, all the time. Chemical changes bring us beautiful colors, warmth, light, and products to make our lives function more smoothly. Understanding, explaining, and using the diversity of materials we find around us is what chemistry is all about.
CHAPTER 1  •  An Introduction to Chemistry

1.1 THE NATURE OF CHEMISTRY

A knowledge of chemistry is useful to virtually everyone—we see chemistry occurring around us every day. An understanding of chemistry is useful to engineers, teachers, health care professionals, attorneys, homemakers, business people, firefighters, and environmentalists, just to name a few. Even if you’re not planning to work in any of these fields, chemistry is important and is used by us every day. Learning about the benefits and risks associated with chemicals will help you to be an informed citizen, able to make intelligent choices concerning the world around you. Studying chemistry teaches you to solve problems and communicate with others in an organized and logical manner. These skills will be helpful in college and throughout your career.

What is chemistry? One dictionary gives this definition: “Chemistry is the science of the composition, structure, properties, and reactions of matter, especially of atomic and molecular systems.” Another, somewhat simpler definition is “Chemistry is the science dealing with the composition of matter and the changes in composition that matter undergoes.” Neither of these definitions is entirely adequate. Chemistry and physics form a fundamental branch of knowledge. Chemistry is also closely related to biology, not only because living organisms are made of material substances but also because life itself is essentially a complicated system of interrelated chemical processes.

The scope of chemistry is extremely broad. It includes the whole universe and everything, animate and inanimate, in it. Chemistry is concerned with the composition and changes in the composition of matter and also with the energy and energy changes associated with matter. Through chemistry we seek to learn and to understand the general principles that govern the behavior of all matter.

The chemist, like other scientists, observes nature and attempts to understand its secrets: What makes a tulip red? Why is sugar sweet? What is occurring when iron rusts? Why is carbon monoxide poisonous? Problems such as these—some of which have been solved, some of which are still to be solved—are all part of what we call chemistry.

A chemist may interpret natural phenomena, devise experiments that reveal the composition and structure of complex substances, study methods for improving natural processes, or synthesize substances. Ultimately, the efforts of successful chemists advance the frontiers of knowledge and at the same time contribute to the well-being of humanity.

Thinking Like a Chemist

Chemists take a special view of things in order to understand the nature of the chemical changes taking place. Chemists “look inside” everyday objects to see how the basic components are behaving. To understand this approach, let’s consider a lake. When we view the lake from a distance, we get an overall picture of the water and shoreline. This overall view is called the macroscopic picture.

As we approach the lake we begin to see more details—rocks, sandy beach, plants submerged in the water, and aquatic life. We get more and more curious. What makes the rocks and sand? What kind of organisms live in the water? How do plants survive underwater? What lies hidden in the water? We can use a microscope to learn the answers to some of these questions. Within the water and the plants, we can see single cells and inside them organelles working to keep the organisms alive. For answers to other questions, we need to go even further inside the lake. A drop of lake water can itself become a mysterious and fascinating microscopic picture full of molecules and motion. (See Figure 1.1.) A chemist looks into the world of atoms and molecules and their motions. Chemistry makes
the connection between the microscopic world of molecules and the macroscopic world of everyday objects.

Think about the water in the lake. On the surface it has beauty and colors, and it gently laps the shore of the lake. What is the microscopic nature of water? It is composed of tiny molecules represented as

\[ \text{H}_2\text{O} \]

In this case H represents a hydrogen atom and O an oxygen atom. The water molecule is represented by \( \text{H}_2\text{O} \) since it is made up of two hydrogen atoms and one oxygen atom.

**EXAMPLE 1.1**

You are given eight oxygen atoms and fifteen hydrogen atoms. How many water molecules can you make from them?

**SOLUTION**

From the model shown above for a water molecule you can see that one molecule of water contains one atom of oxygen and two atoms of hydrogen. Using this model as reference, you can make eight water molecules from eight oxygen atoms. But you can make only seven water molecules from fifteen hydrogen atoms with one H atom and one O atom left over. The answer is seven water molecules.

**PRACTICE 1.1**

You are given ten hydrogen atoms and eight oxygen atoms. How many water molecules can you make from them?

**LEARNING OBJECTIVE**

In this case H represents a hydrogen atom and O an oxygen atom. The water molecule is represented by \( \text{H}_2\text{O} \) since it is made up of two hydrogen atoms and one oxygen atom.

1. Define the problem. We first need to recognize we have a problem and state it clearly, including all the known information. When we do this in science, we call it making an observation.
2. Propose possible solutions to the problem. In science this is called making a hypothesis.
3. Decide which is the best way to proceed or solve the problem. In daily life we use our memory of past experiences to help us. In the world of science we perform an experiment.

Using a scientific approach to problem solving is worthwhile. It helps in all parts of your life whether you plan to be a scientist, doctor, business person, or writer.
The Scientific Method

Chemists work together and also with other scientists to solve problems. As scientists conduct studies they ask many questions, and their questions often lead in directions that are not part of the original problem. The amazing developments from chemistry and technology usually involve what we call the *scientific method*, which can generally be described as follows:

1. Collect the facts or data that are relevant to the problem or question at hand. This is usually done by planned experimentation. The data are then analyzed to find trends or regularities that are pertinent to the problem.
2. Formulate a hypothesis that will account for the data and that can be tested by further experimentation.
3. Plan and do additional experiments to test the hypothesis.
4. Modify the hypothesis as necessary so that it is compatible with all the pertinent data.

Confusion sometimes arises regarding the exact meanings of the words *hypothesis*, *theory*, and *law*. A *hypothesis* is a tentative explanation of certain facts that provides a basis for further experimentation. A well-established hypothesis is often called a *theory* or model. Thus, a theory is an explanation of the general principles of certain phenomena with considerable evidence or facts to support it. Hypotheses and theories explain natural phenomena, whereas *scientific laws* are simple statements of natural phenomena to which no exceptions are known under the given conditions.

These four steps are a broad outline of the general procedure that is followed in most scientific work, but they are not a “recipe” for doing chemistry or any other science (*Figure 1.2*). Chemistry is an experimental science, however, and much of its progress has been due to application of the scientific method through systematic research.

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**CHEMISTRY IN ACTION**

*Egyptians, the First Medicinal Chemists*

Look at any images of the ancient Egyptians and notice the black eyeliner commonly worn at that time. As chemists analyzed the composition of a sample of this eyeliner in the antiquities collection at the Louvre Museum in Paris, they were appalled to discover the high concentration of lead in the samples. Today lead is routinely removed from most consumer products because it is very toxic even in low concentrations. It is toxic to many organs and can cause symptoms such as abdominal pain, dementia, anemia, seizures, and even death. It turns out the lead compounds found in the Egyptian eyeliner are not found in nature but must be synthesized. The synthesis of these lead salts is complicated and the products are not lustrous. This led chemists to question why the Egyptians would add these compounds to their eyeliner. The answer was revealed after reading some of the ancient manuscripts from that time. Lead salts were synthesized for use in treating eye ailments, scars, and discolorations. So even if the lead salts were not the best ingredients for beauty, they were added for the perceived health benefits.

Since we now know that lead compounds are very toxic, Christian Amatore, an analytical chemist at the Ecole Normale Supérieure in Paris, wondered if the lead compounds in Egyptian eyeliner could have actually conferred any health benefits. He introduced lead salts into samples of human tissue growing in the laboratory and observed that the cells began forming compounds that trigger an immune response. Perhaps the ancient Egyptians did know something about medicinal chemistry after all. So should we follow the Egyptians example and add lead to our cosmetics? This is probably not a good idea because the risks associated with prolonged lead exposure outweigh the benefits.

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Scientists employ the scientific method every day in their laboratory work.
We study many theories and laws in chemistry; this makes our task as students easier because theories and laws summarize important aspects of the sciences. Certain theories and models advanced by great scientists in the past have since been substantially altered and modified. Such changes do not mean that the discoveries of the past are any less significant. Modification of existing theories and models in the light of new experimental evidence is essential to the growth and evolution of scientific knowledge. Science is dynamic.

1.3 THE PARTICULATE NATURE OF MATTER

Describe the characteristics of matter, including the states of matter.

The entire universe consists of matter and energy. Every day we come into contact with countless kinds of matter. Air, food, water, rocks, soil, glass, and this book are all different types of matter. Broadly defined, matter is anything that has mass and occupies space.

Matter may be quite invisible. For example, if an apparently empty test tube is submerged mouth downward in a beaker of water, the water rises only slightly into the tube. The water cannot rise further because the tube is filled with invisible matter: air (see Figure 1.3).

To the macroscopic eye, matter appears to be continuous and unbroken. We are impressed by the great diversity of matter. Given its many forms, it is difficult to believe that on a microscopic level all of matter is composed of discrete, tiny, fundamental particles called atoms (Figure 1.4). It is truly amazing to understand that the fundamental particles in ice cream are very similar to the particles in air that we breathe. Matter is actually discontinuous and is composed of discrete, tiny particles called atoms.
Physical States of Matter

Matter exists in three physical states: solid, liquid, and gas (see Figure 1.5). A **solid** has a definite shape and volume, with particles that cling rigidly to one another. The shape of a solid can be independent of its container. In Figure 1.5a we see water in its solid form. Another example, a crystal of sulfur, has the same shape and volume whether it is placed in a beaker or simply laid on a glass plate.

Most commonly occurring solids, such as salt, sugar, quartz, and metals, are **crystalline**. The particles that form crystalline materials exist in regular, repeating, three-dimensional, geometric patterns (see Figure 1.6). Some solids such as plastics, glass, and gels do not have any regular, internal geometric pattern. Such solids are called **amorphous** solids. (*Amorphous* means “without shape or form.”)

A **liquid** has a definite volume but not a definite shape, with particles that stick firmly but not rigidly. Although the particles are held together by strong attractive forces and are in close contact with one another, they are able to move freely. Particle mobility gives a liquid fluidity and causes it to take the shape of the container in which it is stored. Note how water looks as a liquid in Figure 1.5b.

A **gas** has indefinite volume and no fixed shape, with particles that move independently of one another. Particles in the gaseous state have gained enough energy to overcome the attractive forces that held them together as liquids or solids. A gas presses continuously in all directions on the walls of any container. Because of this quality, a gas completely fills a container. The particles of a gas are relatively far apart compared with those of solids and liquids. The actual volume of the gas particles is very small compared with the volume of the space occupied by the gas. Observe the large space between the water molecules in Figure 1.5c compared to ice and liquid water. A gas therefore may be compressed into a very small volume or expanded almost indefinitely. Liquids cannot be compressed to any great extent, and solids are even less compressible than liquids.

If a bottle of ammonia solution is opened in one corner of the laboratory, we can soon smell its familiar odor in all parts of the room. The ammonia gas escaping from the solution demonstrates that gaseous particles move freely and rapidly and tend to permeate the entire area into which they are released.
Although matter is discontinuous, attractive forces exist that hold the particles together and give matter its appearance of continuity. These attractive forces are strongest in solids, giving them rigidity; they are weaker in liquids but still strong enough to hold liquids to definite volumes. In gases, the attractive forces are so weak that the particles of a gas are practically independent of one another. Table 1.1 lists common materials that exist as solids, liquids, and gases. Table 1.2 compares the properties of solids, liquids, and gases.

**TABLE 1.1** Common Materials in the Solid, Liquid, and Gaseous States of Matter

<table>
<thead>
<tr>
<th>Solids</th>
<th>Liquids</th>
<th>Gases</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aluminum</td>
<td>Alcohol</td>
<td>Acetylene</td>
</tr>
<tr>
<td>Copper</td>
<td>Blood</td>
<td>Air</td>
</tr>
<tr>
<td>Gold</td>
<td>Gasoline</td>
<td>Butane</td>
</tr>
<tr>
<td>Polyethylene</td>
<td>Honey</td>
<td>Carbon dioxide</td>
</tr>
<tr>
<td>Salt</td>
<td>Mercury</td>
<td>Chlorine</td>
</tr>
<tr>
<td>Sand</td>
<td>Oil</td>
<td>Helium</td>
</tr>
<tr>
<td>Steel</td>
<td>Vinegar</td>
<td>Methane</td>
</tr>
<tr>
<td>Sulfur</td>
<td>Water</td>
<td>Oxygen</td>
</tr>
</tbody>
</table>

**TABLE 1.2** Physical Properties of Solids, Liquids, and Gases

<table>
<thead>
<tr>
<th>State</th>
<th>Shape</th>
<th>Volume</th>
<th>Particles</th>
<th>Compressibility</th>
</tr>
</thead>
<tbody>
<tr>
<td>Solid</td>
<td>Definite</td>
<td>Definite</td>
<td>Rigidly clinging; tightly packed</td>
<td>Very slight</td>
</tr>
<tr>
<td>Liquid</td>
<td>Indefinite</td>
<td>Definite</td>
<td>Mobile; adhering Independent of each other and relatively far apart</td>
<td>Slight</td>
</tr>
<tr>
<td>Gas</td>
<td>Indefinite</td>
<td>Indefinite</td>
<td></td>
<td>High</td>
</tr>
</tbody>
</table>

1.4 CLASSIFYING MATTER

Distinguish among a pure substance, a homogeneous mixture, and a heterogeneous mixture.

The term matter refers to all materials that make up the universe. Many thousands of distinct kinds of matter exist. A substance is a particular kind of matter with a definite, fixed composition. Sometimes known as pure substances, substances are either elements or compounds. Familiar examples of elements are copper, gold, and oxygen. Familiar compounds are salt, sugar, and water. We’ll discuss elements and compounds in more detail in Chapter 3.

We classify a sample of matter as either homogeneous or heterogeneous by examining it. Homogeneous matter is uniform in appearance and has the same properties throughout. Matter consisting of two or more physically distinct phases is heterogeneous. A phase is a homogeneous part of a system separated from other parts by physical boundaries. A system is simply the body of matter under consideration. Whenever we have a system in which visible boundaries exist between the parts or components, that system has more than one phase and is heterogeneous. It does not matter whether these components are in the solid, liquid, or gaseous states.

A pure substance may exist as different phases in a heterogeneous system. Ice floating in water, for example, is a two-phase system made up of solid water and liquid water. The water in each phase is homogeneous in composition, but because two phases are present, the system is heterogeneous.

A mixture is a material containing two or more substances and can be either heterogeneous or homogeneous. Mixtures are variable in composition. If we add a spoonful of sugar to a glass of water, a heterogeneous mixture is formed immediately. The two phases are a solid (sugar) and a liquid (water). But upon stirring, the sugar dissolves to form a homogeneous mixture or solution.
Both substances are still present: All parts of the solution are sweet and wet. The proportions of sugar and water can be varied simply by adding more sugar and stirring to dissolve. Solutions do not have to be liquid. For example, air is a homogeneous mixture of gases. Solid solutions also exist. Brass is a homogeneous solution of copper and zinc.

Many substances do not form homogeneous mixtures. If we mix sugar and fine white sand, a heterogeneous mixture is formed. Careful examination may be needed to decide that the mixture is heterogeneous because the two phases (sugar and sand) are both white solids. Ordinary matter exists mostly as mixtures. If we examine soil, granite, iron ore, or other naturally occurring mineral deposits, we find them to be heterogeneous mixtures. Figure 1.7 illustrates the relationships of substances and mixtures.

Distinguishing Mixtures from Pure Substances

Single substances—elements or compounds—seldom occur naturally in a pure state. Air is a mixture of gases; seawater is a mixture of a variety of dissolved minerals; ordinary soil is a complex mixture of minerals and various organic materials.

<table>
<thead>
<tr>
<th>Mixture</th>
<th>Pure Substance</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. A mixture always contains two or more substances that can be present in varying amounts.</td>
<td>1. A pure substance (element or compound) always has a definite composition by mass.</td>
</tr>
<tr>
<td>2. The components of a mixture do not lose their identities and may be separated by physical means.</td>
<td>2. The elements in a compound lose their identities and may be separated only by chemical means.</td>
</tr>
</tbody>
</table>

PRACTICE 1.2

Which of the following is a mixture and which is a pure substance? Explain your answer.

(a) vinegar (4% acetic acid and 96% water)
(b) sodium chloride (salt) solution
(c) gold
(d) milk
How is a mixture distinguished from a pure substance? A mixture always contains two or more substances that can be present in varying concentrations. Let’s consider two examples.

**Homogeneous Mixture** Homogeneous mixtures (solutions) containing either 5% or 10% salt in water can be prepared simply by mixing the correct amounts of salt and water. These mixtures can be separated by boiling away the water, leaving the salt as a residue.

**Heterogeneous Mixture** The composition of a heterogeneous mixture of sulfur crystals and iron filings can be varied by merely blending in either more sulfur or more iron filings. This mixture can be separated physically by using a magnet to attract the iron.
1. Explain the difference between
(a) a hypothesis and a theory
(b) a theory and a scientific law
2. Consider each of the following statements and determine whether it represents an observation, a hypothesis, a theory, or a scientific law:
(a) The battery in my watch must be dead since it is no longer keeping time.
(b) My computer must have a virus since it is not working properly.
(c) The air feels cool.
(d) The candle burns more brightly in pure oxygen than in air because oxygen supports combustion.
(e) My sister wears red quite often.
(f) A pure substance has a definite, fixed composition.
3. Determine whether each of the following statements refers to a solid, a liquid, or a gas:
(a) It has a definite volume but not a definite shape.
(b) It has an indefinite volume and high compressibility.
(c) It has a definite shape.
(d) It has an indefinite shape and slight compressibility.
4. Some solids have a crystalline structure, while others have an amorphous structure. For each of the following 5 descriptions, determine whether it refers to a crystalline solid or an amorphous solid:
(a) has a regular repeating pattern
(b) plastic
(c) has no regular repeating pattern
(d) glass
(e) gold
5. Define a phase.
6. How many phases are present in the graduated cylinder?
7. What is another name for a homogeneous mixture?
8. Which liquids listed in Table 1.1 are not mixtures?
9. Which of the gases listed in Table 1.1 are not pure substances?
10. When the stopper is removed from a partly filled bottle containing solid and liquid acetic acid at 16.7°C, a strong vinegar-like odor is noticeable immediately. How many acetic acid phases must be present in the bottle? Explain.
11. Is the system enclosed in the bottle in Question 10 homogeneous or heterogeneous? Explain.
12. Is a system that contains only one substance necessarily homogeneous? Explain.
13. Is a system that contains two or more substances necessarily heterogeneous? Explain.
14. Distinguish between homogeneous and heterogeneous mixtures.
15. Which of the following are pure substances?
(a) sugar
(b) sand
(c) gold
16. Use the steps of the scientific method to help determine the reason that your cell phone has suddenly stopped working:
(a) observation
(b) hypothesis
Most of the exercises in this chapter are available for assignment via the online homework management program, WileyPLUS (www.wileyplus.com).
All exercises with blue numbers have answers in Appendix VI.

**PAIRED EXERCISES**

1. Refer to the illustration and determine which state(s) of matter are present.

2. Refer to the illustration and determine which state(s) of matter are present.

3. Look at the photo and determine whether it represents a homogeneous or heterogeneous mixture.

4. Look at the maple leaf below and determine whether it represents a homogeneous or heterogeneous mixture.

5. For each of the following mixtures, state whether it is homogeneous or heterogeneous:
   (a) tap water
   (b) carbonated beverage
   (c) oil and vinegar salad dressing
   (d) people in a football stadium

6. For each of the following mixtures, state whether it is homogeneous or heterogeneous:
   (a) stainless steel
   (b) motor oil
   (c) soil
   (d) a tree

**ADDITIONAL EXERCISES**

7. At home, check your kitchen and bathroom cabinets for five different substances; then read the labels and list the first ingredient of each.

8. During the first week of a new semester, consider that you have enrolled in five different classes, each of which meets for 3 hours per week. For every 1 hour that is spent in class, a minimum of 1 hour is required outside of class to complete assignments and study for exams. You also work 20 hours per week, and it takes you 1 hour to drive to the job site and back home. On Friday nights, you socialize with your friends. You are fairly certain that you will be able to successfully complete the semester with good grades. Show how the steps in the scientific method can help you predict the outcome of the semester.
1.1 five water molecules: \( \text{H}_2\text{O}, \text{H}_2\text{O}, \text{H}_2\text{O}, \text{H}_2\text{O}, \text{H}_2\text{O} \)

1.2 (a) mixture; concentration can be changed by adding more acetic acid or more water. (b) mixture; concentration can be changed by adding more or less salt. (c) pure substance; gold is 100% gold. (d) mixture; milk contains several substances.

ANSWERS TO PRACTICE EXERCISES

9. Identify the following ingredients as either a pure substance or a mixture.
   (a) water
   (b) chicken stock (the liquid that remains in the pot after cooking the chicken)
   (c) salt
   (d) mustard flour

10. Using the food label, make a hypothesis regarding the nutritional quality of this food. Propose a way to determine whether your hypothesis is valid.

11. Read the following passage (from Science News) and identify the observation and hypothesis.

   Could an invisibility cloak, like the one used by Harry Potter, really exist? For scientists in Cambridge, Massachusetts, it may be a reality. Researchers at MIT have developed an invisibility cloak for small objects such as an ant or a grain of sand. Calcite crystals have the ability to reflect light around an object, rendering it invisible, or at least “unseeable.” If a larger crystal were to be used, it should be able to hide larger objects. The invisibility cloak works only with laser light aimed directly at the crystal. Future work will improve the effectiveness of these invisibility cloaks.

Nutrition Facts

<table>
<thead>
<tr>
<th>Serv. Size 1 cup (249g)</th>
<th>Amount/serving %DV</th>
<th>Amount/serving %DV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calories 220</td>
<td>Total Fat 12g</td>
<td>18% Sodium 940mg 39%</td>
</tr>
<tr>
<td>Total Carbo 26g</td>
<td>6g</td>
<td>30% Cholesterol 60mg</td>
</tr>
<tr>
<td>Cholesterol 60mg</td>
<td>6g</td>
<td>30% Sodium 940mg 39%</td>
</tr>
<tr>
<td>Polyunsat. Fat 1.5g</td>
<td>Dietary Fiber 1g</td>
<td>4% Vitamin A 0%</td>
</tr>
<tr>
<td>Monounsat. Fat 2.5g</td>
<td>Sugar 1g</td>
<td>Vitamin C 0%</td>
</tr>
<tr>
<td>Monounsat. Fat 2.5g</td>
<td>Sugar 1g</td>
<td>Calcium 6%</td>
</tr>
<tr>
<td>Polyunsat. Fat 1.5g</td>
<td>Dietary Fiber 1g</td>
<td>Iron 8%</td>
</tr>
<tr>
<td>Total Fat 12g</td>
<td>18%</td>
<td>Cholesterol 60mg</td>
</tr>
</tbody>
</table>

INGREDIENTS: WATER, CHICKEN STOCK, ENRICHED PASTA (SEMOLINA WHEAT FLOUR, EGG WHITE SOLIDS, NIACIN, IRON, THIAMINE MONONITRATE [VITAMIN B1], RIBOFLAVIN [VITAMIN B2] AND FOLIC ACID), CREAM (DERIVED FROM MILK), CHICKEN, CONTAINS LESS THAN 2% OF: CHEESES (GRANULAR, PARMESAN AND ROMANO PASTE [PASTEURIZED COW'S MILK, CULTURES, SALT, ENZYMES], WATER, SALT, LACTIC ACID, CITRIC ACID AND DISODIUM PHOSPHATE), BUTTER (PASTEURIZED SWEET CREAM [DERIVED FROM MILK] AND SALT), MODIFIED CORN STARCH, SALT, WHOLE EGG SOLIDS, SUGAR, RICE STARCH, GARLIC, SPICE, XANTHAN GUM, MUSTARD FLOUR, ISOLATED SOY PROTEIN AND SODIUM PHOSPHATE.

9. Identify the following ingredients as either a pure substance or a mixture.
   (a) water
   (b) chicken stock (the liquid that remains in the pot after cooking the chicken)
   (c) salt
   (d) mustard flour

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