CHAPTER 1

# An Introduction to Chemistry

The colors, fragrances, and textures of a tulip garden are all the results of chemistry.

## Chapter Outline

Do you know how the battery in your car works to start your engine? Have you ever wondered how a tiny seedling can grow into a corn stalk 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.

## 1.1 Why Study 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 doctors, health care professionals, attorneys, homemakers, businesspeople, 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.

## 1.2 The Nature of Chemistry

**chemistry**

**Key words are highlighted in bold and color in the margin to alert you to new terms defined in the text.**

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.

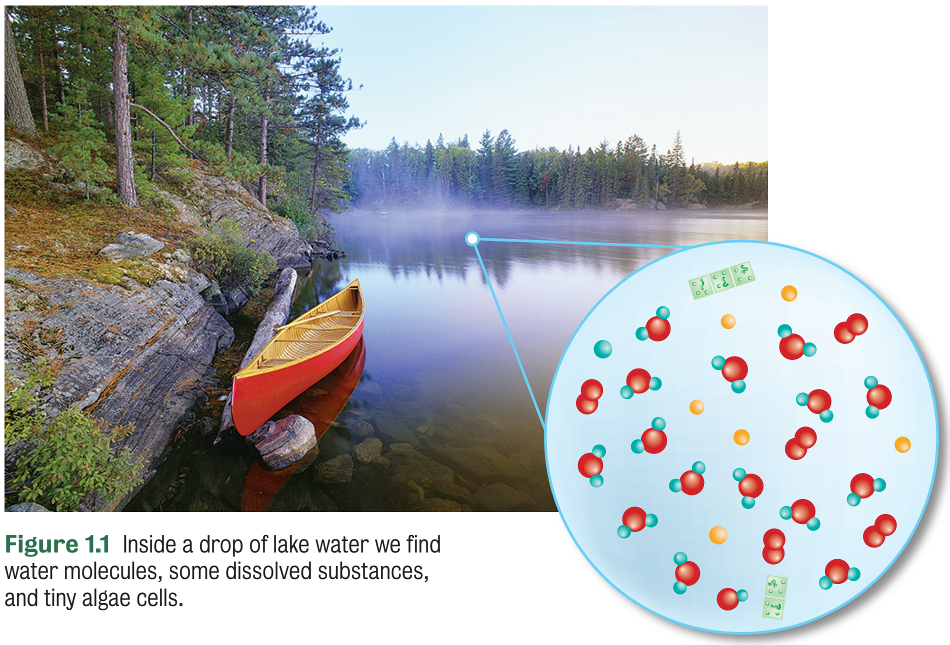


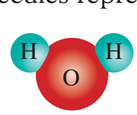
**Figure 1.1** Inside a drop of lake water we find water molecules, some dissolved substances, and tiny algae cells.

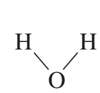
## 1.3 Thinking Like a Chemist

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



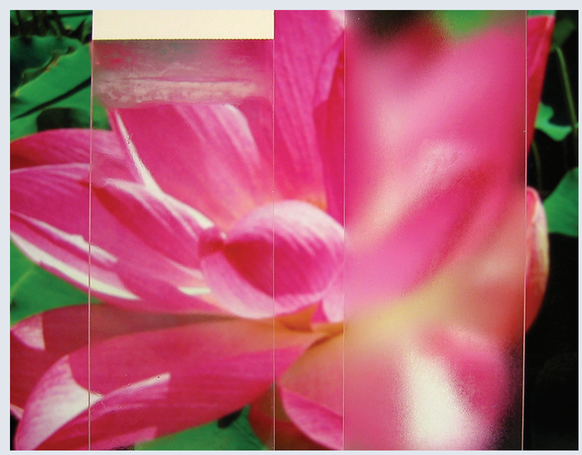

In this case H represents a hydrogen atom and O an oxygen atom. The water molecule is represented by $H_2O$ since it is made up of two hydrogen atoms and one oxygen atom.

## CHEMISTRY IN ACTION • Clearing the Fog

If only someone could find a way to keep that annoying fog off mirrors in the bathroom on a more permanent basis. Michael Rabner, a materials scientist at MIT, just might have figured out how to clear the fog from glass surfaces. He found his inspiration in the beautiful lotus plant. It turns out that lotus leaves repel water so well that when raindrops hit the leaf, the drops remain spherical. He began exploring the possibility of trying to make a coating that did the same thing. Fogging occurs when water drops from the air condense on a cool surface. The drops scatter light, creating the fogging. The majority of antifogging sprays are polymers that flatten the drops so they do not scatter light. Unfortunately, they wear off the surface quickly.

Rubner and his colleagues found a nanocoating (a very thin coating) that had the opposite effect of the lotus leaf. Their coating is extremely water loving, or superhydrophilic. It is composed of tiny, hydrophilic glass particles that are packed together very irregularly. This leaves tiny pockets between the particles that can fill with water, spreading the droplets into a film that doesn't scatter light.

An additional bonus of the glass and air coating is that it prevents glare. Nearly 100% of light travels through this nanocoat, compared to 92% on untreated glass. The coating is made from 7-nanometer layers of polymer alternating with layers of glass particles. The layers are constructed so that the glass particles don't pack together well, producing a Swiss cheese structure. To increase the durability of the coating, it is heated to 500°C to fuse the glass particles and disintegrate the polymer. This makes the coating scratch-resistant and also makes the antifog property last for more than a year.



A lotus flower seen through nanocoated glass.

## 1.4 A Scientific Approach to Problem Solving

One of the most common and important things we do every day is to solve problems. For example,

- You have two exams and a laboratory report due on Monday. How should you divide your time?
- You leave for school and learn from the radio that there is a big accident on the freeway. What is your fastest alternate route to avoid the traffic problem?
- You need to buy groceries, mail some packages, attend your child's soccer game, and pick up the dry cleaning. What is the most efficient sequence of events?

We all face these kind of problems and decisions. A logical approach can be useful for solving daily problems:

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, businessperson, or writer.

Scientists employ the scientific method every day in their laboratory work.

## 1.5 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:

**scientific method**

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.

**hypothesis**

**theory**

**scientific laws**

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.

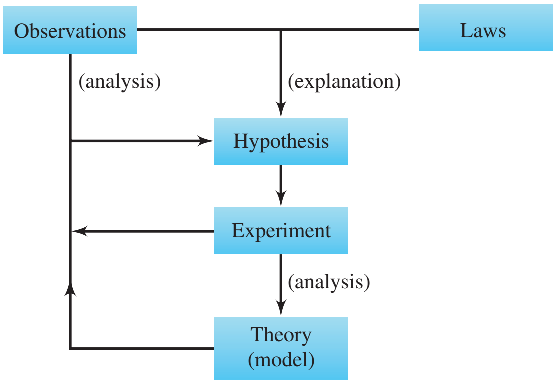



**Figure 1.2**
The scientific method.

Chemists continue to explore the effects of nicotine on the smoker in order to help those who want to quit smoking.

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.

## 1.6 The Particulate Nature 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**

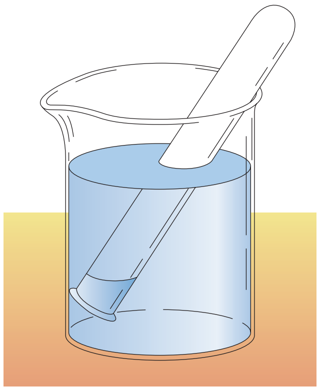


**Figure 1.3** An apparently empty test tube is submerged, mouth downward, in water. Only a small volume of water rises into the tube, which is actually filled with invisible matter—air.

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*. 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*.

## 1.7 Physical States of Matter

Matter exists in three physical states: solid, liquid, and gas (see Figure 1.4). 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 1.4a 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.

**solid**

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 1.5). 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").

**amorphous**

**liquid**

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 1.4b.

**gas**

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.

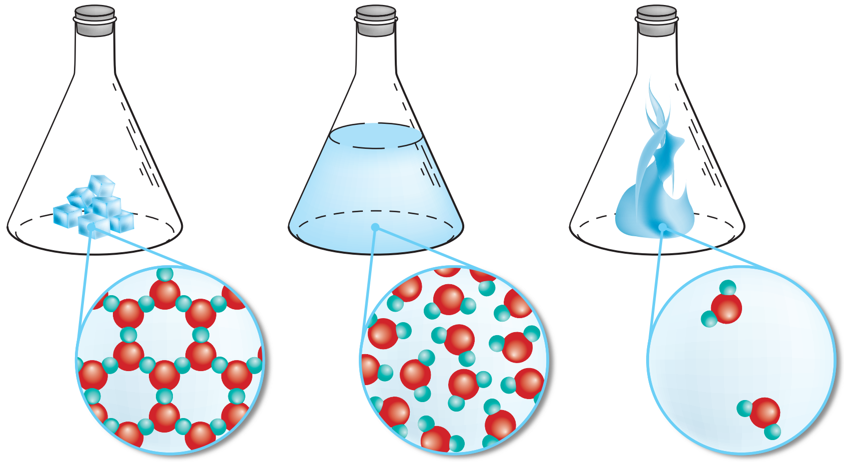



**Figure 1.4** The three states of matter. (a) Solid—water molecules are held together rigidly and are very close to each other. (b) Liquid—water molecules are close together but are free to move around and slide over each other. (c) Gas—water molecules are far apart and move freely and randomly.

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 1.4c 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.


**Figure 1.5** A large crystal of table salt. A salt crystal is composed of a three-dimensional array of particles.

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**

| Solids | Liquids | Gases |
|---|---|---|
| Aluminum | Alcohol | Acetylene |
| Copper | Blood | Air |
| Gold | Gasoline | Butane |
| Polyethylene | Honey | Carbon dioxide |
| Salt | Mercury | Chlorine |
| Sand | Oil | Helium |
| Steel | Vinegar | Methane |
| Sulfur | Water | Oxygen |

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

| State | Shape | Volume | Particles | Compressibility |
|---|---|---|---|---|
| Solid | Definite | Definite | Rigidly clinging; tightly packed | Very slight |
| Liquid | Indefinite | Definite | Mobile; adhering | Slight |
| Gas | Indefinite | Indefinite | Independent of each other and relatively far apart | High |

## 1.8 Classifying Matter

**substance**

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.

(a) (b)

(a) Water is the liquid in the beaker, and the white solid in the spoon is sugar.
(b) Sugar can be dissolved in the water to produce a solution.

**homogeneous**
**heterogeneous**
**phase**
**system**

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.

**mixture**

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.

**Flowcharts can help you to visualize the connections between concepts.**

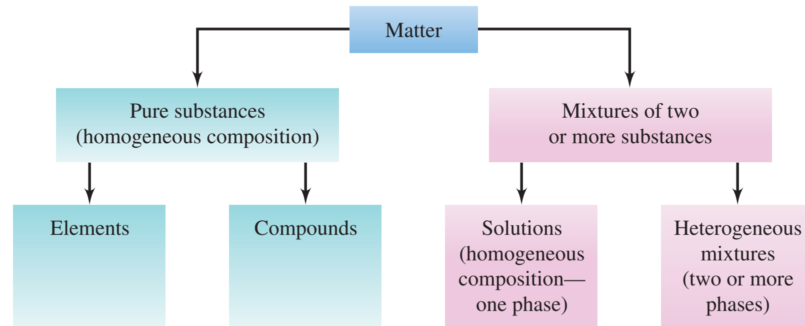



**Figure 1.6** Classification of matter. A pure substance is always homogeneous in composition, whereas a mixture always contains two or more substances and may be either homogeneous or heterogeneous.

Granite is a heterogeneous mixture.

If we examine soil, granite, iron ore, or other naturally occurring mineral deposits, we find them to be heterogeneous mixtures. Figure 1.6 illustrates the relationships of substances and mixtures.

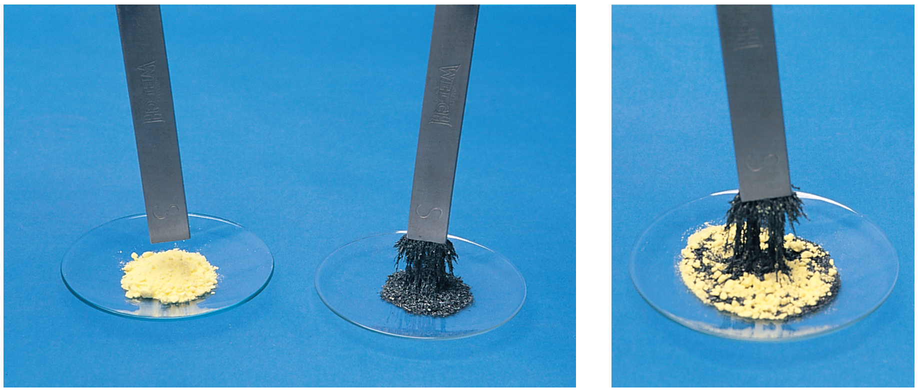
## Distinguishing Mixtures from Pure Substances

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.

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.



(a) (b)

(a) When iron and sulfur exist as pure substances, only the iron is attracted to a magnet.
(b) A mixture of iron and sulfur can be separated by using the difference in magnetic attraction.

## Chapter 1 Review

### 1.1 Why Study Chemistry?

- Chemistry is important to everyone because chemistry occurs all around us in our daily lives.

### 1.2 The Nature of Chemistry

**KEY TERM**

Chemistry

- Chemistry is the science dealing with matter and the changes in composition that matter undergoes.
- Chemists seek to understand the general principles governing the behavior of all matter.

### 1.3 Thinking Like a Chemist

- Chemistry "looks inside" ordinary objects to study how their components behave.
- Chemistry connects the macroscopic and microscopic worlds.

### 1.4 A Scientific Approach to Problem Solving

- Scientific thinking helps us solve problems in our daily lives.
- General steps for solving problems include:
  - Defining the problem
  - Proposing possible solutions
  - Solving the problem

### 1.5 The Scientific Method

**KEY TERMS**

Scientific method
Hypothesis
Theory
Scientific laws

- The scientific method is a procedure for processing information in which we:
  - Collect the facts
  - Formulate a hypothesis
  - Plan and do experiments
  - Modify the hypothesis if necessary

### 1.6 The Particulate Nature of Matter

**KEY TERM**

Matter

- Matter is anything with the following two characteristics:
  - Has mass
  - Occupies space
- On the macroscopic level matter is continuous.
- On the microscopic level matter is discontinuous and composed of atoms.

### 1.7 Physical States of Matter

**KEY TERMS**

Solid
Amorphous
Liquid
Gas

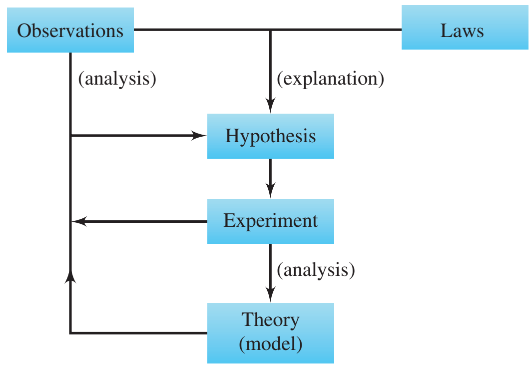
- Solid—rigid substance with a definite shape
- Liquid—fluid substance with a definite volume that takes the shape of its container
- Gas—takes the shape and volume of its container

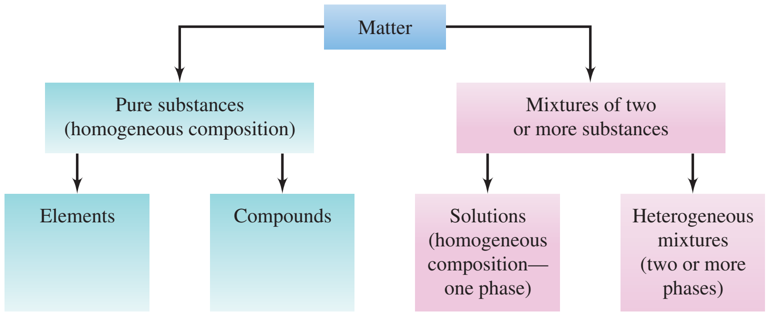
### 1.8 Classifying Matter

**KEY TERMS**

Substance
Homogeneous
Heterogeneous
Phase
System
Mixture

- Matter can be classified as a pure substance or a mixture.
- A mixture has variable composition:
  - Homogeneous mixtures have the same properties throughout.
  - Heterogeneous mixtures have different properties in different parts of the system.
- A pure substance always has the same composition.
  - There are two types of pure substances
    - Elements
    - Compounds



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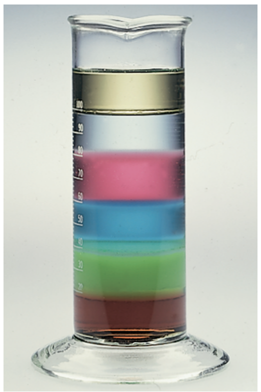
## Review Questions

*All questions with blue numbers have answers in the appendix of the text.*

1. Explain the difference between
   (a) a hypothesis and a theory
   (b) a theory and a scientific law
2. Define a phase.
3. How many phases are present in the graduated cylinder?

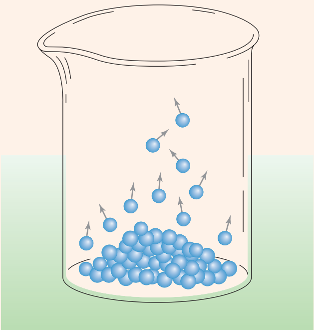


4. Consider each of the following statements and determine whether it represents an observation, a hypothesis, a theory, or a scientific law:
   (a) The battery in my watch must be dead since it is no longer keeping time.
   (b) My computer must have a virus since it is not working properly.
   (c) The 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.
5. List four different substances in each of the three states of matter.
6. In terms of the properties of the ultimate particles of a substance, explain
   (a) why a solid has a definite shape but a liquid does not
   (b) why a liquid has a definite volume but a gas does not
   (c) why a gas can be compressed rather easily but a solid cannot be compressed appreciably
7. What evidence can you find in Figure 1.3 that gases occupy space?
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 vinegarlike 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
   (d) maple syrup
   (e) eggs

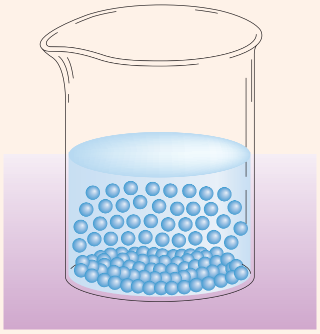
## Paired Exercises

*All exercises with blue numbers have answers in the appendix of the text.*

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

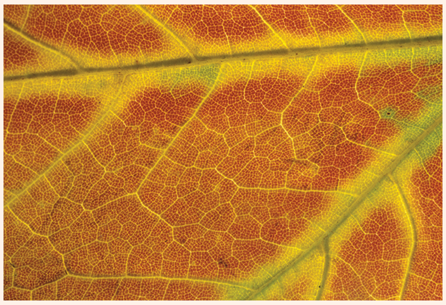


2. Refer to the illustration and determine which states(s) of matter are present.



**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

*All exercises with blue numbers have answers in the appendix of the text.*

**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.