CHAPTER 3

Matter and Energy

"Thus, the task is, not so much to see what no one has yet seen; but to think what nobody has yet thought, about that which everybody sees."

Erwin Schrödinger (1887–1961)

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3.1 In Your Room

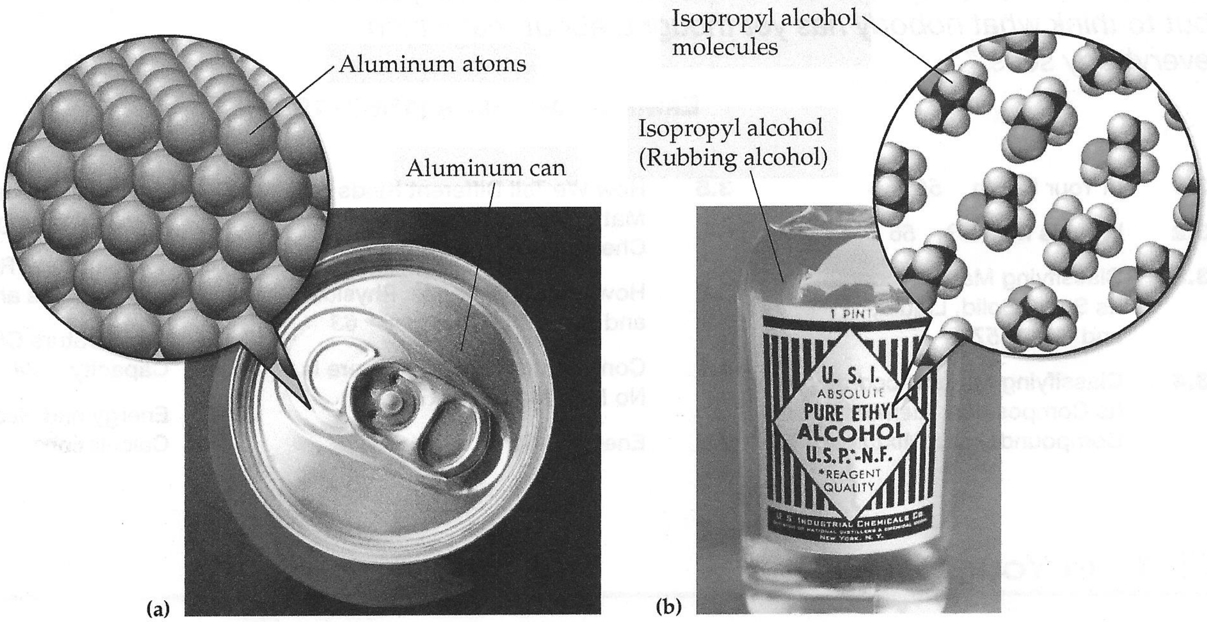
Look around the room you are in—what do you see? You might see your desk, your bed, or a glass of water. Maybe you have a window and can see trees, grass, or mountains. You can certainly see this book and possibly the table it sits on. What are these things made of? They are all made of *matter*, which we will define more carefully shortly. For now, know that all you see is matter—your desk, your bed, the glass of water, the trees, the mountains, and this book. Some of what you don't see is matter as well. For example, you are constantly breathing air, which is also matter, into and out of your lungs. You feel the matter in air when you feel wind on your skin. Virtually everything is made of matter.

◀ Everything that you can see in this room is made of matter. As students of chemistry, we are interested in how the differences between different kinds of matter are related to the differences between the molecules and atoms that compose the matter. The molecular structures shown here are water molecules on the left and carbon atoms in graphite on the right.

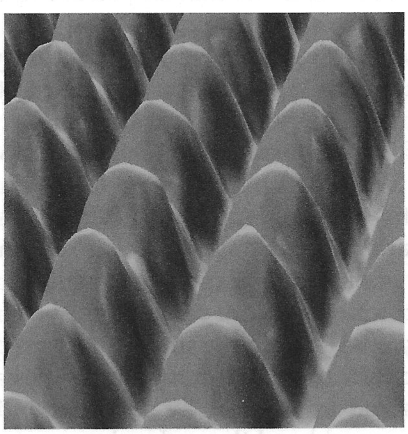
Think about the differences between different kinds of matter. Air is different from water, and water is different from wood. One of our first tasks as we learn about matter is to identify the similarities and differences among different kinds of matter. How are sugar and salt similar? How are air and water different? Why are they different? Why is a mixture of sugar and water similar to a mixture of salt and water but different from a mixture of sand and water? As students of chemistry, we are particularly interested in the similarities and differences between various kinds of matter and how these reflect the similarities and differences between their component atoms and molecules. We strive to understand the connection between the macroscopic world and the molecular one.

3.2 What Is Matter?

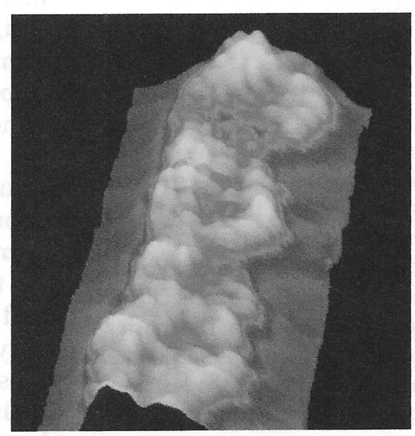
Matter is defined as anything that occupies space and has mass. Some types of matter—such as steel, water, wood, and plastic—are easily visible to our eyes. Other types of matter—such as air or microscopic dust—are impossible to see without magnification. Matter may sometimes appear smooth and continuous, but actually it is not. Matter is ultimately composed of **atoms**, submicroscopic particles that are the fundamental building blocks of matter (▼ Figure 3.1a). In many cases, these atoms are bonded together to form **molecules**, two or more atoms joined to one another in specific geometric arrangements (Figure 3.1b). Recent advances in microscopy have allowed us to image the atoms (▼ Figure 3.2) and molecules (▼ Figure 3.3) that compose matter, sometimes with stunning clarity.



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



▲ **FIGURE 3.2 Scanning tunneling microscope image of nickel atoms** A scanning tunneling microscope (STM) creates an image by scanning a surface with a tip of atomic dimensions. It can distinguish individual atoms, seen as blue bumps, in this image. (*Source:* Reprint Courtesy of International Business Machines Corporation, copyright © International Business Machines Corporation.)

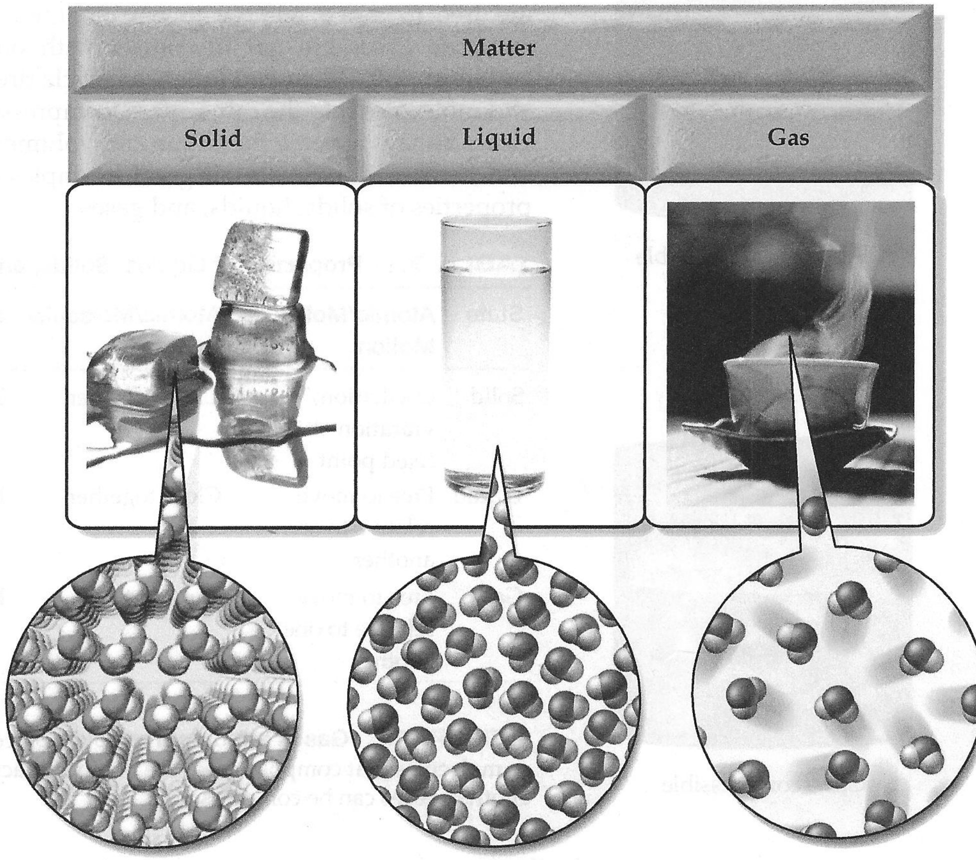


▲ **FIGURE 3.3 Scanning tunneling microscope image of a DNA molecule** DNA is the hereditary material that encodes the operating instructions for most cells in living organisms. In this image, the DNA molecule is yellow, and the double-stranded structure of DNA is discernible.

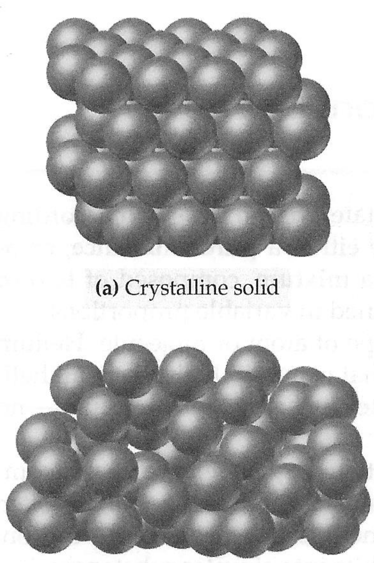
3.3 Classifying Matter According to Its State: Solid, Liquid, and Gas

The common **states of matter** are **solid**, **liquid**, and **gas** (▼ Figure 3.4). In solid matter, atoms or molecules pack close to each other in fixed locations. Although neighboring atoms or molecules in a solid may vibrate or oscillate, they do not move around each other, giving solids their familiar fixed volume and rigid shape.

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



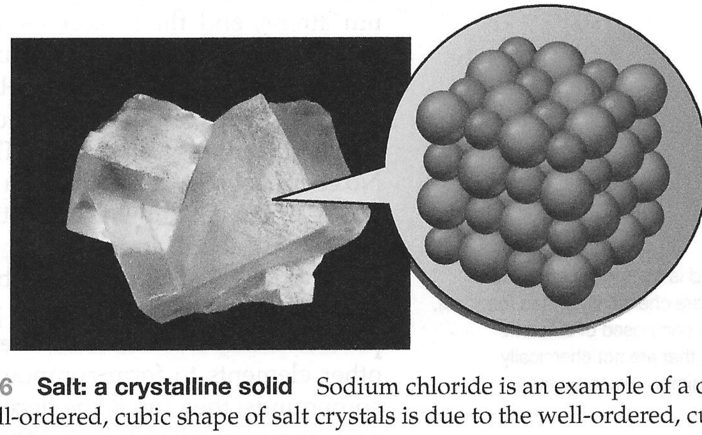
Ice, diamond, quartz, and iron are examples of solid matter. Solid matter may be **crystalline**, in which case its atoms or molecules arrange in geometric patterns with long-range, repeating order (◀ Figure 3.5a), or it may be **amorphous**, in which case its atoms or molecules do not have long-range order (Figure 3.5b). Examples of *crystalline* solids include salt (▼ Figure 3.6) and diamond; the well-ordered, geometric shapes of salt and diamond crystals reflect the well-ordered geometric arrangement of their atoms. Examples of *amorphous* solids include glass, rubber, and plastic.



(a) Crystalline solid

(b) Amorphous solid

▲ **FIGURE 3.5 Types of solid matter** **(a)** In a crystalline solid, atoms or molecules occupy specific positions to create a well-ordered, three-dimensional structure. **(b)** In an amorphous solid, atoms do not have any long-range order.



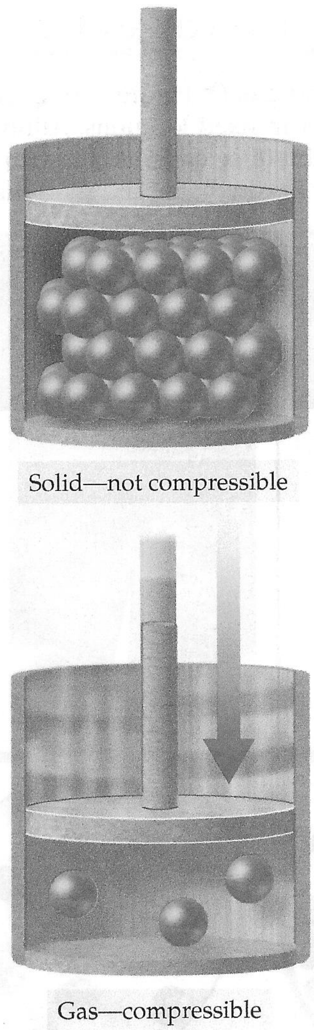
▲ **FIGURE 3.6 Salt: a crystalline solid** Sodium chloride is an example of a crystalline solid. The well-ordered, cubic shape of salt crystals is due to the well-ordered, cubic arrangement of its atoms.

In liquid matter, atoms or molecules are close to each other (about as close as molecules in a solid) but are free to move around and by each other. Like solids, liquids have a fixed volume because their atoms or molecules are in close contact. Unlike solids, however, liquids assume the shape of their container because the atoms or molecules are free to move relative to one another. Water, gasoline, alcohol, and mercury are all examples of liquid matter.

In gaseous matter, atoms or molecules are separated by large distances and are free to move relative to one another. Since the atoms or molecules that compose gases are not in contact with one another, gases are **compressible** (◀ Figure 3.7). When you inflate a bicycle tire, for example, you push more atoms and molecules into the same space, compressing them and making the tire harder. Gases always assume the shape and volume of their containers. Oxygen, helium, and carbon dioxide are all good examples of gases. Table 3.1 summarizes the properties of solids, liquids, and gases.

TABLE 3.1 Properties of Liquids, Solids, and Gases

State	Atomic/Molecular Motion	Atomic/Molecular Spacing	Shape	Volume	Compressibility
Solid	Oscillation/vibration about fixed point	Close together	Definite	Definite	Incompressible
Liquid	Free to move relative to one another	Close together	Indefinite	Definite	Incompressible
Gas	Free to move relative to one another	Far apart	Indefinite	Indefinite	Compressible



◀ **FIGURE 3.7 Gases are compressible** Since the atoms or molecules that compose gases are not in contact with one another, gases can be compressed.

3.4 Classifying Matter According to Its Composition: Elements, Compounds, and Mixtures

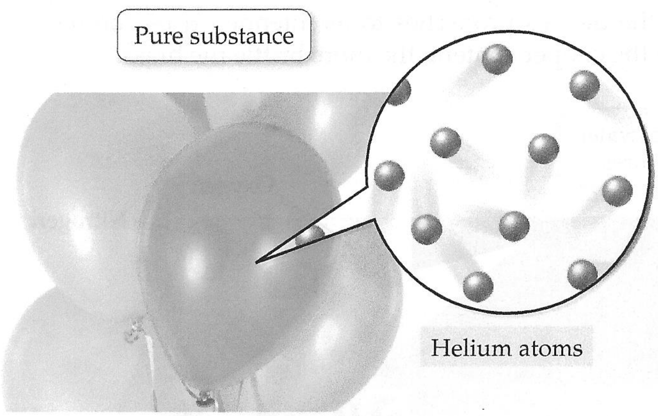
In addition to classifying matter according to its state, we can classify it according to its composition (▶ Figure 3.8). Matter may be either a **pure substance**, composed of only one type of atom or molecule, or a **mixture**, composed of two or more different types of atoms or molecules combined in variable proportions.

Pure substances are composed of only one type of atom or molecule. Helium and water are both pure substances. The atoms that compose helium are all helium atoms, and the molecules that compose water are all water molecules—no other atoms or molecules are mixed in.

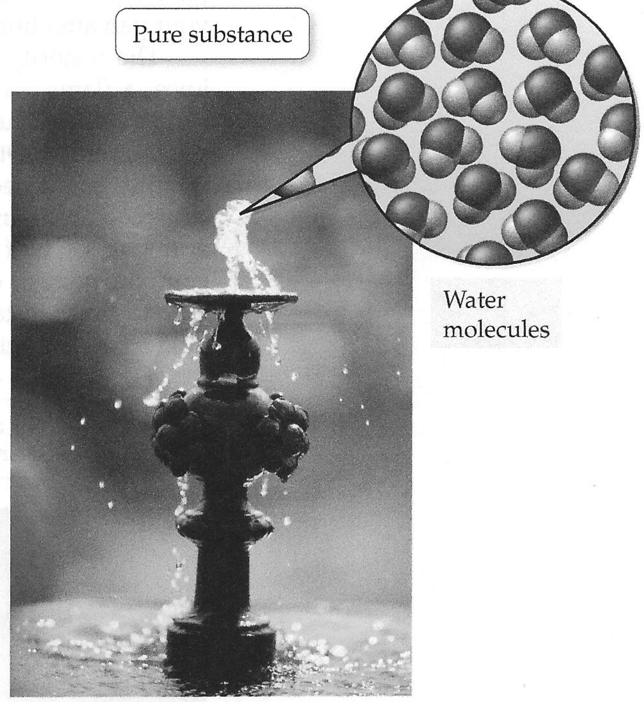
Pure substances can themselves be divided into two types: elements and compounds. Copper is an example of an **element**, a substance that cannot be broken down into simpler substances. The graphite in pencils is also an element—carbon. No chemical transformation can decompose graphite into simpler substances; it is pure carbon. All known elements are listed in the periodic table in the inside front cover of this book and in alphabetical order on the inside back cover of this book.

A compound is composed of different atoms that are chemically united (bonded). A mixture is composed of different substances that are not chemically united, but simply mixed together.

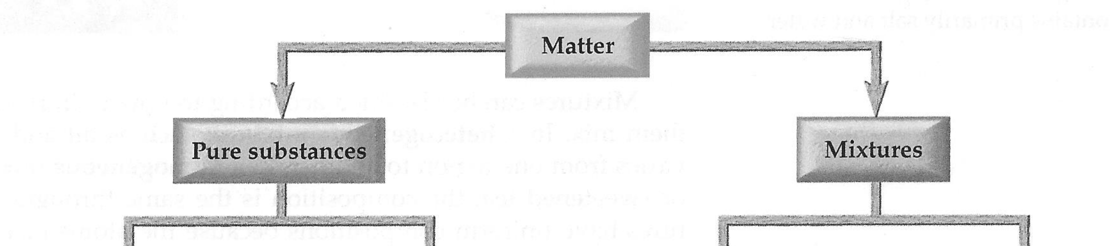
A pure substance can also be a **compound**, a substance composed of two or more elements in fixed definite proportions. Compounds are more common than pure elements because most elements are chemically reactive and combine with other elements to form compounds. Water, table salt, and sugar are examples of compounds; they can all be decomposed into simpler substances. If you heat sugar on a pan over a flame, you decompose it into several substances including carbon



▲ Helium is a pure substance composed only of helium atoms.



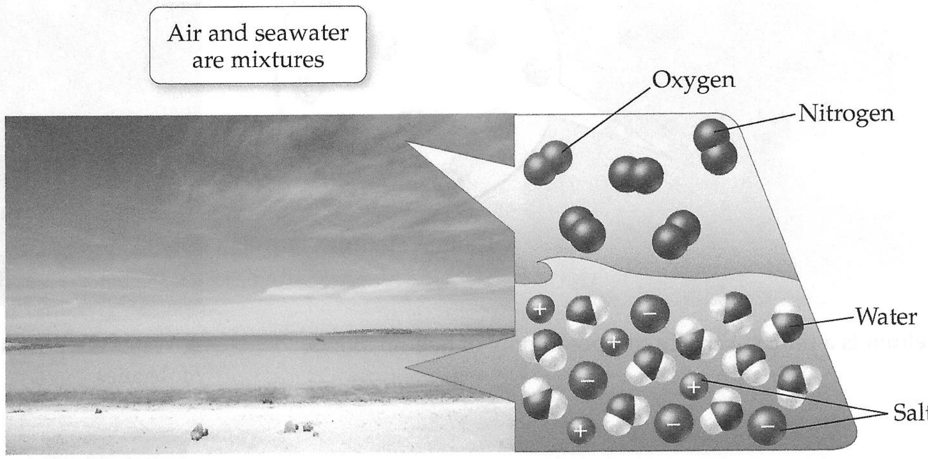
▲ Water is a pure substance composed only of water molecules.



▲ **FIGURE 3.8 Classification of matter** Matter may be a pure substance or a mixture. A pure substance may be either an element (such as copper) or a compound (such as sugar), and a mixture may be either homogeneous (such as sweetened tea) or heterogeneous (such as hydrocarbon and water).

(an element) and gaseous water (a different compound). The black substance left on your pan after burning contains the carbon; the water escapes into the air as steam.

The majority of matter that we encounter is in the form of mixtures. Apple juice, a flame, salad dressing, and soil are all examples of mixtures; they each contain several substances mixed together in proportions that vary from one sample to another. Other common mixtures include air, seawater, and brass. Air is a mixture composed primarily of nitrogen and oxygen gas, seawater is a mixture composed primarily of salt and water, and brass is a mixture composed of copper and zinc. Each of these mixtures can have different proportions of its constituent components. For example, metallurgists vary the relative amounts of copper and zinc in brass to tailor the metal's properties to its intended use—the higher the zinc content relative to the copper content, the more brittle the brass.



▶ Air and seawater are examples of mixtures. Air contains primarily nitrogen and oxygen. Seawater contains primarily salt and water.

Mixtures can be classified according to how uniformly the substances within them mix. In a **heterogeneous mixture**, such as oil and water, the composition varies from one region to another. In a **homogeneous mixture**, such as salt water or sweetened tea, the composition is the same throughout. Homogeneous mixtures have uniform compositions because the atoms or molecules that compose them mix uniformly. Remember that the properties of matter are determined by the atoms or molecules that compose it.

To summarize, as shown in Figure 3.8:

- Matter may be a pure substance, or it may be a mixture.
- A pure substance may be either an element or a compound.
- A mixture may be either homogeneous or heterogeneous.
- Mixtures may be composed of two or more elements, two or more compounds, or a combination of both.

EXAMPLE 3.1 Classifying Matter

Classify each type of matter as a pure substance or a mixture. If it is a pure substance, classify it as an element or a compound; if it is a mixture, classify it as homogeneous or heterogeneous.

(a) a lead weight
(b) seawater
(c) distilled water
(d) Italian salad dressing

SOLUTION

Begin by examining the alphabetical listing of pure elements inside the back cover of this text. If the substance appears in that table, it is a pure substance and an element. If it is not in the table but is a pure substance, then it is a compound.

If the substance is not a pure substance, then it is a mixture. Refer to your everyday experience with each mixture to determine if it is homogeneous or heterogeneous.

(a) Lead is listed in the table of elements. It is a pure substance and an element.
(b) Seawater is composed of several substances, including salt and water; it is a mixture. It has a uniform composition, so it is a homogeneous mixture.
(c) Distilled water is not listed in the table of elements, but it is a pure substance (water); therefore, it is a compound.
(d) Italian salad dressing contains a number of substances and is therefore a mixture. It usually separates into at least two distinct regions with different composition and is therefore a heterogeneous mixture.

▶SKILLBUILDER 3.1 | Classifying Matter

Classify each type of matter as a pure substance or a mixture. If it is a pure substance, classify it as an element or a compound. If it is a mixture, classify it as homogeneous or heterogeneous.

(a) mercury in a thermometer
(b) exhaled air
(c) minestrone soup
(d) sugar

▶FOR MORE PRACTICE Example 3.12; Problems 31, 32, 33, 34, 35, 36.

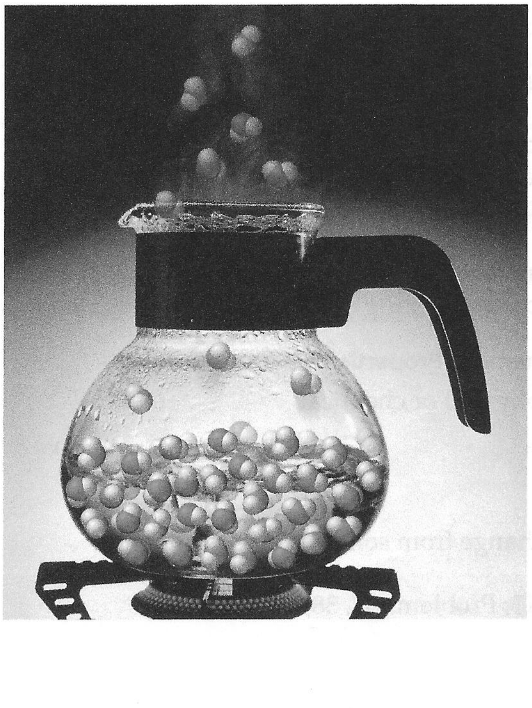
Note: The answers to all Skillbuilders appear at the end of the chapter.

3.5 How We Tell Different Kinds of Matter Apart: Physical and Chemical Properties

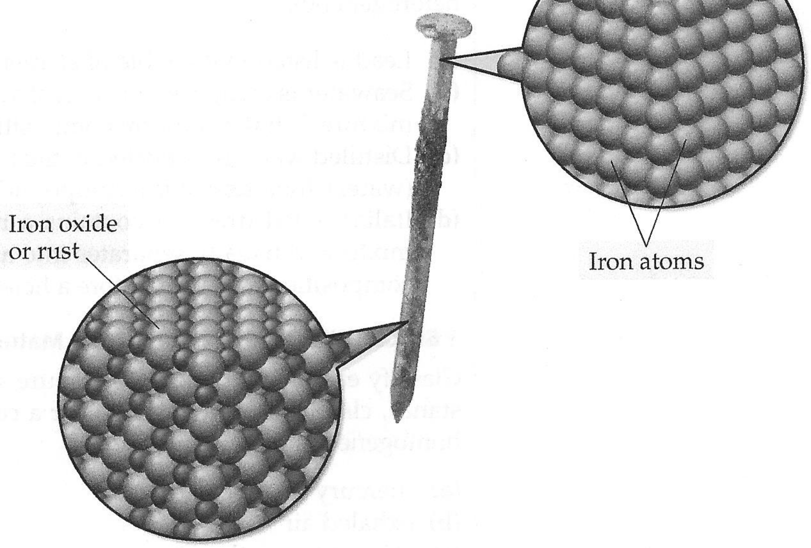
The characteristics that distinguish one substance from another are called **properties**. Different substances have unique properties that characterize them and distinguish them from other substances. For example, we can distinguish water from alcohol based on their different smells, or we can distinguish gold from silver based on their different colors.

In chemistry, we categorize properties into two different types: physical and chemical. A **physical property** is one that a substance displays without changing its composition. A **chemical property** is one that a substance displays only through changing its composition. For example, the characteristic odor of gasoline is a physical property—gasoline does not change its composition when it exhibits its odor. On the other hand, the flammability of gasoline is a chemical property—gasoline does change its composition when it burns.

The atomic or molecular composition of a substance does not change when the substance displays its physical properties. For example, the boiling point of water—a physical property—is 100 °C. When water boils, it changes from a liquid to a gas, but the gas is still water (◀ Figure 3.9).



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



▲ **FIGURE 3.10 A chemical property** The susceptibility of iron to rusting is a chemical property, and rusting is a chemical change. When iron rusts, it turns from iron to iron oxide.

On the other hand, the susceptibility of iron to rust is a chemical property—iron must change into iron oxide to display this property (▲ Figure 3.10). Physical properties include odor, taste, color, appearance, melting point, boiling point, and density. Chemical properties include corrosiveness, flammability, acidity, and toxicity.

EXAMPLE 3.2 Physical and Chemical Properties

Determine whether each property is physical or chemical.

(a) the tendency of copper to turn green when exposed to air
(b) the tendency of automobile paint to dull over time
(c) the tendency of gasoline to evaporate quickly when spilled
(d) the low mass (for a given volume) of aluminum relative to other metals

SOLUTION

(a) Copper turns green because it reacts with gases in air to form compounds; this is a chemical property.
(b) Automobile paint dulls over time because it can fade (decompose) due to sunlight or it can react with oxygen in air. In either case, this is a chemical property.
(c) Gasoline evaporates quickly because it has a low boiling point; this is a physical property.
(d) Aluminum's low mass (for a given volume) relative to other metals is due to its low density; this is a physical property.

▶SKILLBUILDER 3.2 | Physical and Chemical Properties

Determine whether each property is physical or chemical.

(a) the explosiveness of hydrogen gas
(b) the bronze color of copper
(c) the shiny appearance of silver
(d) the ability of dry ice to sublime (change from solid directly to vapor)

▶FOR MORE PRACTICE Example 3.13; Problems 37, 38, 39, 40.

3.6 How Matter Changes: Physical and Chemical Changes

Every day, we witness changes in matter: Ice melts, iron rusts, and fruit ripens, for example. What happens to the atoms and molecules that make up these substances during the change? The answer depends on the kind of change. In a **physical change**, matter changes its appearance but not its composition. For example, when ice melts, it looks different—water looks different from ice—but its composition is the same. Solid ice and liquid water are both composed of water molecules, so melting is a physical change. Similarly, when glass shatters, it looks different, but its composition remains the same—it is still glass. Again, this is a physical change. On the other hand, in a **chemical change**, matter *does* change its composition. For example, copper turns green upon continued exposure to air because it reacts with gases in air to form new compounds. This is a chemical change. Matter undergoes a chemical change when it undergoes a **chemical reaction**. In a chemical reaction, the substances present before the chemical change are called **reactants**, and the substances present after the change are called **products**:

$$\text{Reactants} \xrightarrow[\text{Chemical Change}]{} \text{Products}$$

We cover chemical reactions in much more detail in Chapter 7.

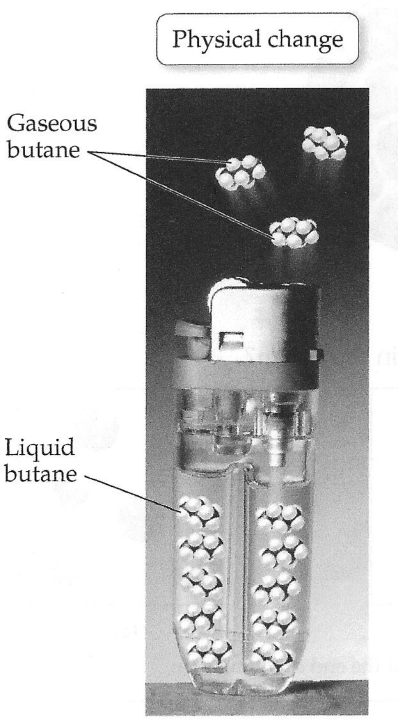
State changes—transformations from one state of matter (such as solid or liquid) to another—are always physical changes.

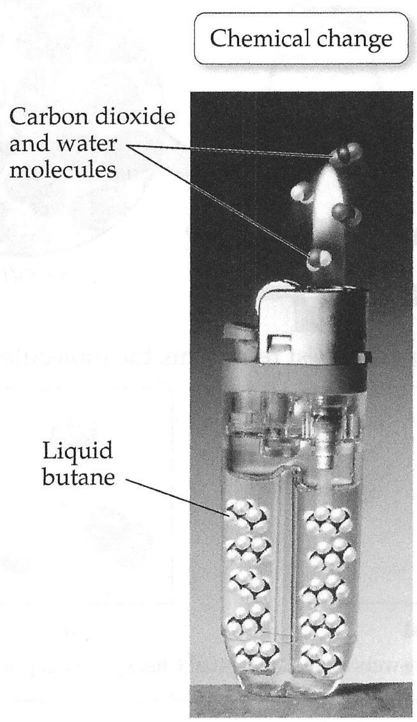
The differences between physical and chemical changes are not always apparent. Only chemical examination of the substances before and after the change can verify whether the change is physical or chemical. For many cases, however, we can identify chemical and physical changes based on what we know about the changes. Changes in state, such as melting or boiling, or changes that involve merely appearance, such as those produced by cutting or crushing, are always physical changes. Changes involving chemical reactions—often evidenced by heat exchange or color changes—are always chemical changes.

The main difference between chemical and physical changes is related to the changes at the molecular and atomic level. In physical changes, the atoms that compose the matter *do not* change their fundamental associations, even though the matter may change its appearance. In chemical changes, atoms do change their fundamental associations, resulting in matter with a new identity. *A physical change results in a different form of the same substance, while a chemical change results in a completely new substance.*

Consider physical and chemical changes in liquid butane, the substance used to fuel butane lighters. In many lighters, you can see the liquid butane through the plastic case of the lighter. If you push the fuel button on the lighter without turning the flint, some of the liquid butane *vaporizes* (changes from liquid to gas). If you listen carefully you can usually hear hissing as the gaseous butane leaks out (◀ Figure 3.11). Since the liquid butane and the gaseous butane are both composed of butane molecules, the change is physical. On the other hand, if you push the button *and* turn the flint to create a spark, a chemical change occurs. The butane molecules react with oxygen molecules in air to form new molecules, carbon dioxide and water (◀ Figure 3.12). The change is chemical because the molecular composition changes upon burning.

▼ **FIGURE 3.11 Vaporization: a physical change** If you push the button on a lighter without turning the flint, some of the liquid butane vaporizes to gaseous butane. Since the liquid butane and the gaseous butane are both composed of butane molecules, this is a physical change.





◀ **FIGURE 3.12 Burning: a chemical change** If you push the button *and* turn the flint to create a spark, you produce a flame. The butane molecules react with oxygen molecules in air to form new molecules, carbon dioxide and water. This is a chemical change.

EXAMPLE 3.3 Physical and Chemical Changes

Determine whether each change is physical or chemical.

(a) the rusting of iron
(b) the evaporation of fingernail-polish remover (acetone) from the skin
(c) the burning of coal
(d) the fading of a carpet upon repeated exposure to sunlight

SOLUTION

(a) Iron rusts because it reacts with oxygen in air to form iron oxide; therefore, this is a chemical change.
(b) When fingernail-polish remover (acetone) evaporates, it changes from liquid to gas, but it remains acetone; therefore, this is a physical change.
(c) Coal burns because it reacts with oxygen in air to form carbon dioxide; this is a chemical change.
(d) A carpet fades on repeated exposure to sunlight because the molecules that give the carpet its color are decomposed by sunlight; this is a chemical change.

▶SKILLBUILDER 3.3 | Physical and Chemical Changes

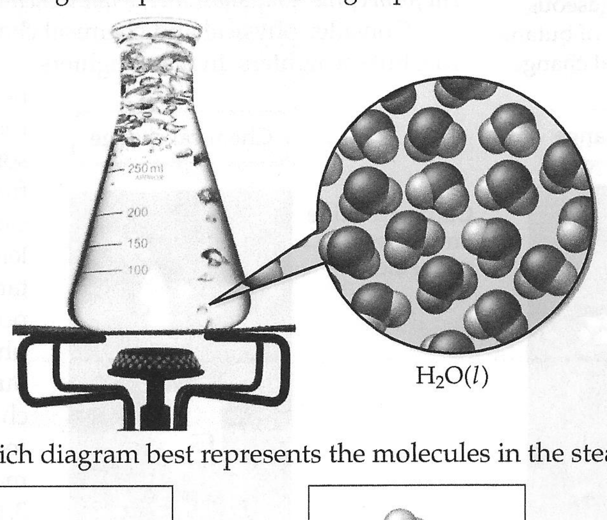
Determine whether each change is physical or chemical.

(a) copper metal forming a blue solution when it is dropped into colorless nitric acid
(b) a train flattening a penny placed on a railroad track
(c) ice melting into liquid water
(d) a match igniting a firework

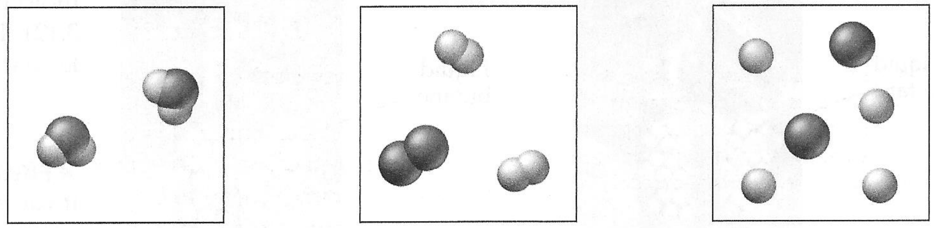
▶FOR MORE PRACTICE Example 3.14; Problems 41, 42, 43, 44.

CONCEPTUAL CHECKPOINT 3.1

In this figure liquid water is being vaporized into steam.

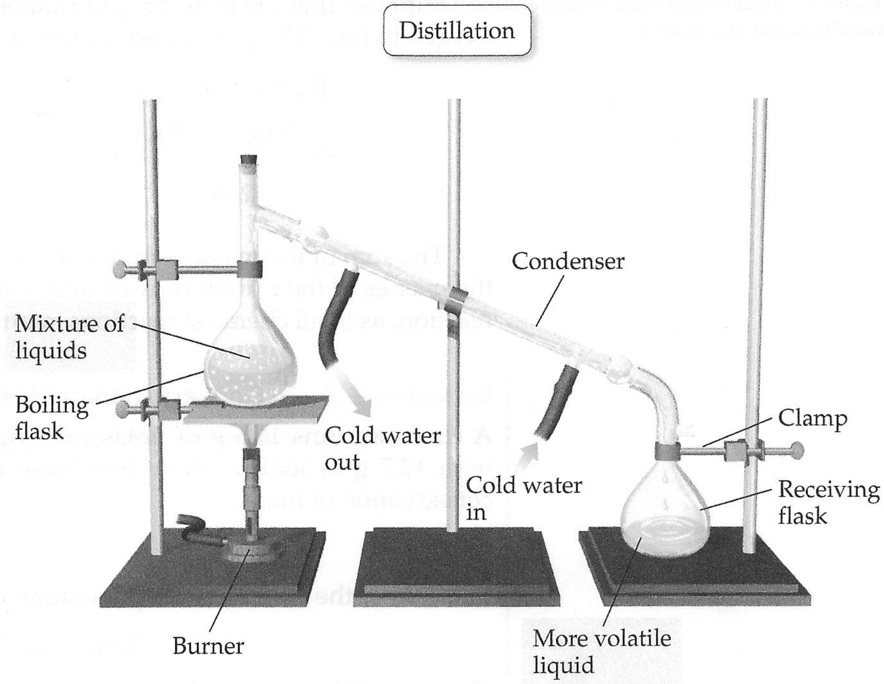


Which diagram best represents the molecules in the steam?

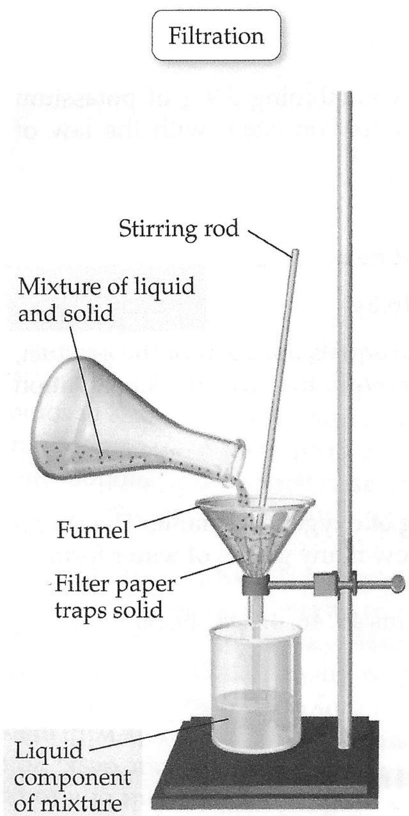


(a) (b) (c)

Note: The answers to all Conceptual Checkpoints appear at the end of the chapter.



▶ **FIGURE 3.13 Separating a mixture of two liquids by distillation** The liquid with the lower boiling point vaporizes first. The vapors are collected and cooled (with cold water) until they condense back into liquid form.



▲ **FIGURE 3.14 Separating a solid from a liquid by filtration**

SEPARATING MIXTURES THROUGH PHYSICAL CHANGES

Chemists often want to separate mixtures into their components. Such separations can be easy or difficult, depending on the components in the mixture. In general, mixtures are separable because the different components have different properties. Various techniques that exploit these differences can be used to achieve separation. For example, oil and water are immiscible (do not mix) and have different densities. For this reason, oil floats on top of water and can be separated from water by **decanting**—carefully pouring off—the oil into another container. Mixtures of miscible liquids can usually be separated by **distillation**, a process in which the mixture is heated to boil off the more **volatile**—the more easily vaporizable—liquid. The volatile liquid is then recondensed in a condenser and collected in a separate flask (▲ Figure 3.13). If a mixture is composed of a solid and a liquid, the two can be separated by **filtration**, in which the mixture is poured through filter paper usually held in a funnel (◀ Figure 3.14).

CHAPTER 4

Atoms and Elements

"Nothing exists except atoms and empty space; everything else is opinion."

DEMOCRITUS (460–370 B.C.)

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4.1 Experiencing Atoms at Tiburon

As we learned in Chapter 3, many atoms exist not as free particles but as groups of atoms bound together to form molecules. Nevertheless, all matter is ultimately made of atoms.

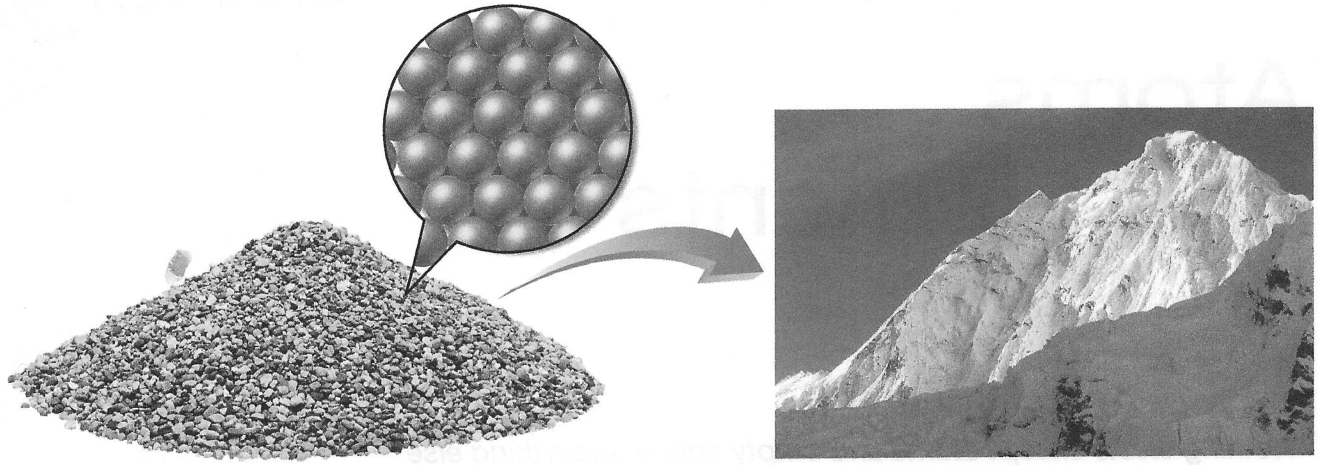
◀ Seaside rocks are typically composed of silicates, compounds of silicon and oxygen atoms. Seaside air, like all air, contains nitrogen and oxygen molecules, and it may also contain substances called amines. The amine shown here is triethylamine, which is emitted by decaying fish. Triethylamine is one of the compounds responsible for the fishy smell of the seaside.

My wife and I recently enjoyed a visit to the northern California seaside town of Tiburon. Tiburon sits next to San Francisco Bay with views of the water, the city of San Francisco, and the surrounding mountains. As we walked along a waterside path, I could feel the wind as it blew over the bay. I could hear the water splashing on the shore, and I could smell the sea air. What was the cause of these sensations? The answer is simple—atoms.

Since all matter is made of atoms, atoms are at the foundation of our sensations. The atom is the fundamental building block of everything you hear, feel, see, and experience. When you feel wind on your skin, you are feeling atoms. When you hear sounds, you are in a sense hearing atoms. When you touch a shoreside rock, you are touching atoms, and when you smell sea air, you are smelling atoms. You eat atoms, you breathe atoms, and you excrete atoms. Atoms are the building blocks of matter; they are the basic units from which nature builds. They are all around us and compose everything, including our own bodies.

Atoms are incredibly small. A single pebble from the shoreline contains more atoms than you could ever count. The number of atoms in a single pebble far exceeds the number of pebbles on the bottom of San Francisco Bay. To get an idea of how small atoms are, imagine this: If every atom within a small pebble were the size of the pebble itself, the pebble would be larger than Mount Everest (▶ Figure 4.1). Atoms are small—yet they compose everything.

The key to connecting the microscopic world with the macroscopic world is the atom. Atoms compose matter; their properties determine matter's properties. An **atom** is the smallest identifiable unit of an element. Recall from Section 3.4 that an *element* is a substance that cannot be broken down into simpler substances.



▲ **FIGURE 4.1 The size of the atom** If every atom within a pebble were the size of the pebble itself, then the pebble would be larger than Mount Everest.

The exact number of naturally occurring elements is controversial because some elements previously considered only synthetic may actually occur in nature in very small quantities.

There are about 91 different elements in nature, and consequently about 91 different kinds of atoms. In addition, scientists have succeeded in making about 20 synthetic elements (not found in nature). In this chapter, we examine atoms: what they are made of, how they differ from one another, and how they are structured. We also examine the elements that atoms compose and some of the properties of those elements.

4.2 Indivisible: The Atomic Theory

▲ Diogenes and Democritus, as imagined by a medieval artist. Democritus is the first person on record to have postulated that matter was composed of atoms.

If we simply look at matter, even under a microscope, it is not obvious that matter is composed of tiny particles. In fact, it appears to be just the opposite. If we divide a sample of matter into smaller and smaller pieces, it seems that we could divide it forever. From our perspective, matter seems continuous. The first people recorded as thinking otherwise were Leucippus (fifth century B.C., exact dates unknown) and Democritus (460–370 B.C.). These Greek philosophers theorized that matter was ultimately composed of small, indivisible particles. Democritus suggested that if you divided matter into smaller and smaller pieces, you would eventually end up with tiny, indestructible particles called *atomos*, or "atoms," meaning "indivisible."

The ideas of Leucippus and Democritus were not widely accepted, and it was not until 1808—over 2000 years later—that John Dalton formalized a theory of atoms that gained broad acceptance. Dalton's atomic theory has three parts:

1. Each element is composed of tiny indestructible particles called atoms.
2. All atoms of a given element have the same mass and other properties that distinguish them from the atoms of other elements.
3. Atoms combine in simple, whole-number ratios to form compounds.

Today, the evidence for the atomic theory is overwhelming. Recent advances in microscopy have allowed scientists not only to image individual atoms but also to pick them up and move them (▶ Figure 4.2). Matter is indeed composed of atoms.

EVERYDAY CHEMISTRY

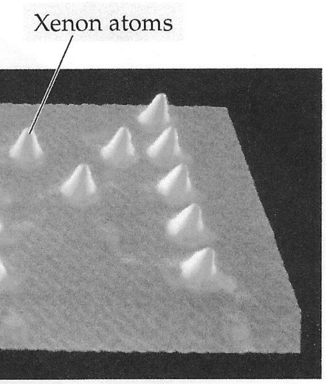
Atoms and Humans

All matter is composed of atoms. What does that mean? What does it imply? It means that everything before you is composed of tiny particles too small to see. It means that even you and I are composed of these same particles. We acquired those particles from the food we have eaten over the years. The average carbon atom in our own bodies has been used by 20 other living organisms before we get to it and will be used by other organisms when we are done with it. In fact, it is likely that at this moment, your body contains over 1 trillion carbon atoms that were at one time part of your chemistry professor.*

The idea that all matter is composed of atoms has far-reaching implications. It implies that our bodies, our hearts, and even our brains are composed of atoms acting according to the laws of chemistry and physics. Some people view this as a devaluation of human life. We have always wanted to distinguish ourselves from everything else, and the idea that we are made of the same basic particles as all other matter takes something away from that distinction . . . or does it?

CAN YOU ANSWER THIS? *Do you find the idea that you are made of atoms disturbing? Why or why not?*

**This calculation assumes that all of the carbon atoms metabolized by your professor over the last 40 years have been uniformly distributed into atmospheric carbon dioxide and subsequently incorporated into plants that you eat.*



▶ **FIGURE 4.2 Writing with atoms** Scientists at IBM used a special microscope, called a scanning tunneling microscope (STM), to move xenon atoms to form the letters I, B, and M. The cone shape of these atoms is due to the peculiarities of the instrumentation. Atoms are, in general, spherical in shape.