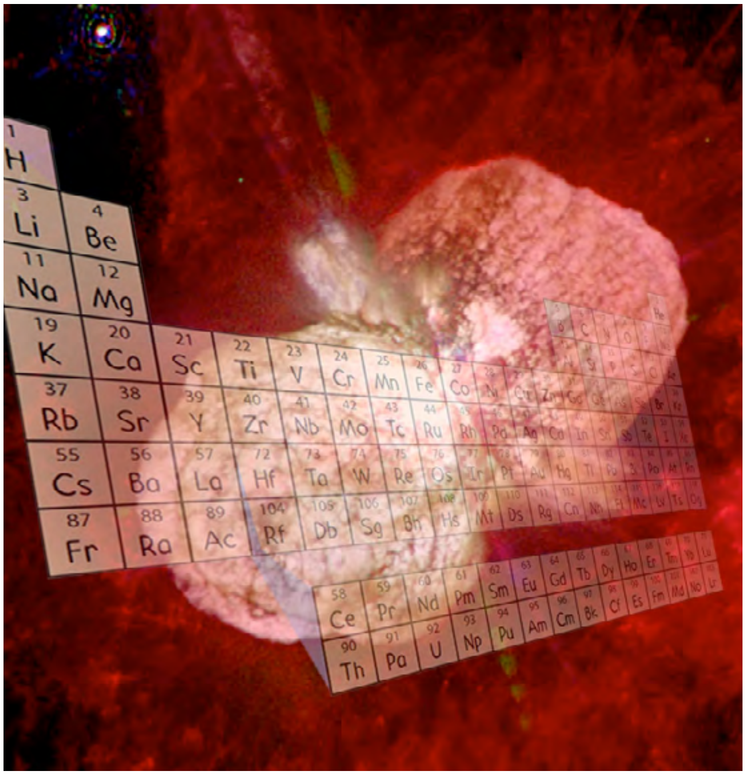


Chapter 2

Particles of Matter

THE MAIN IDEA

Matter is made of particles called atoms

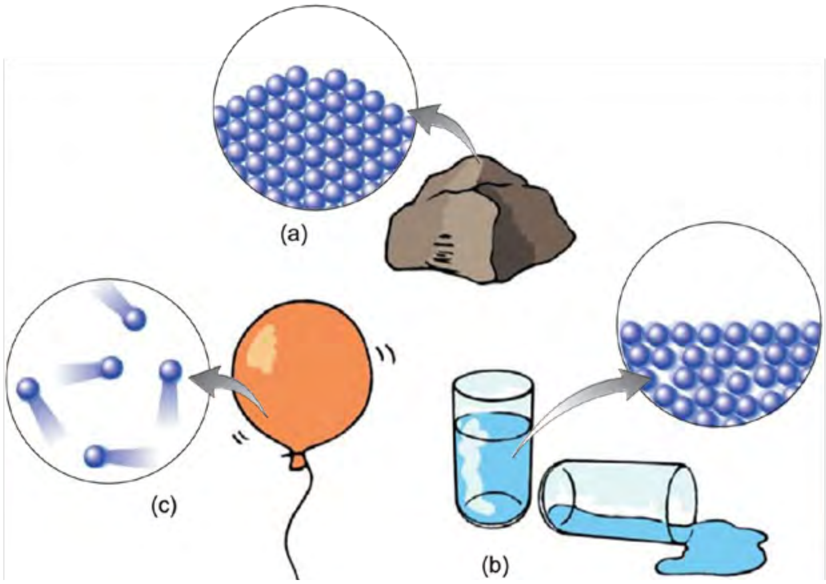
2.7 Phases of Matter

One of the most evident ways we can describe matter is by its physical form, which may be one of three *phases* (also sometimes described as physical states): solid, liquid, or gas. A solid material, such as a rock, occupies a constant amount of space and does not readily deform upon applying pressure. In other words, a solid has both a definite volume and a definite shape. A liquid also occupies a constant amount of space (it has a definite volume), but its form changes readily (it has an indefinite shape). A liter of milk, for example, may take the shape of its carton or the shape of a puddle, but its volume is the same in both cases. A gas is diffuse, having neither a definite volume nor a definite shape. Any sample of gas assumes both the shape and the volume of the container it occupies. A given amount of air, for example, may assume the volume and shape of a toy balloon or be compressed into the volume and shape of a bicycle tire. Released from its container, a gas diffuses into the atmosphere, which is a collection of various gases held to our planet by the force of gravity.

On the submicroscopic level, the solid, liquid, and gaseous phases are distinguished by the extent of interaction between the submicroscopic particles (the atoms or molecules). This is illustrated in **Figure 2.23**. In solid matter, the attractions between particles are strong enough to hold all the particles together in some fixed 3-dimensional arrangement. The particles are able to vibrate about fixed positions, but they cannot move past one another. Adding heat causes these vibrations to increase until, at a certain temperature, the vibrations are rapid enough to disrupt the fixed arrangement. The particles can then slip past one another and tumble around much like a bunch of marbles in a bag. This kind of motion is representative of the liquid phase of matter, and it is the mobility of the particles that gives rise to the liquid's fluid character—its ability to flow and take on the shape of its container.

READING CHECK

On a submicroscopic level, how are solids, liquids, and gases distinguished?

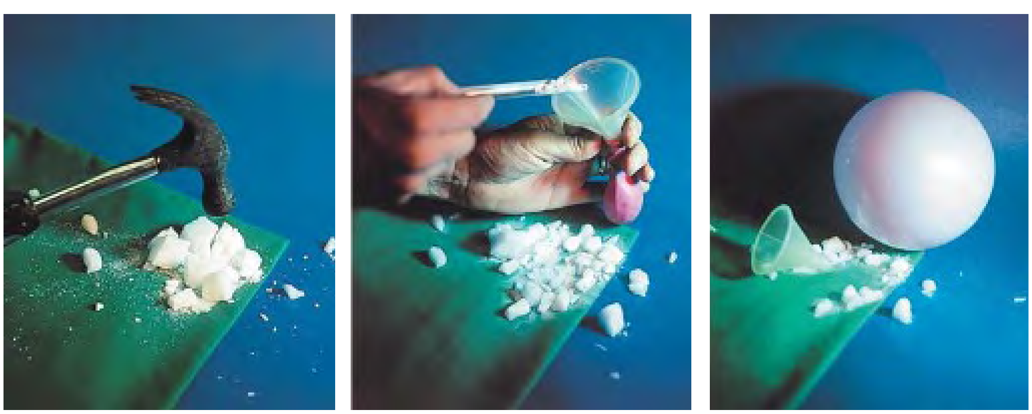


< Figure 2.23

The familiar bulk properties of a solid, liquid, and gas. (a) The particles of the solid phase vibrate about fixed positions. (b) The particles of the liquid phase slip past one another. (c) The fast-moving particles of the gaseous phase are separated by large average distances.

Further heating causes the particles in the liquid to move so fast that any attractions they have for one another are unable to hold them together. They then separate from one another, forming a gas. Moving at an average speed of 500 meters per second (1100 miles per hour), the particles of a gas are widely separated from one another. Matter in the gaseous phase therefore occupies much more volume than it does in the solid or liquid phase, as **Figure 2.24** shows. Applying pressure to a gas squeezes the gas particles closer together, which reduces their volume. Enough air for an underwater diver to breathe for many minutes, for example, can be squeezed (compressed) into a tank small enough to be carried on the diver's back.

Although gas particles move at high speeds, the speed at which they can travel from one side of a room to the other is relatively slow. This is because the gas particles are continually hitting one another, and the path they end up taking is circuitous. At home, you get a sense of how long it takes for gas particles to migrate each time someone opens the oven door after baking, as **Figure 2.25** shows. A shot of aromatic gas particles escapes the oven, but there is a notable delay before the aroma reaches the nose of someone sitting in the next room.



< Figure 2.24

The gaseous phase of any material occupies significantly more volume than either its solid or liquid phase. (a) Solid carbon dioxide (dry ice) is broken up into powder form. (b) The powder is funneled into a balloon. (c) The balloon expands as the contained carbon dioxide becomes a gas as the powder warms up.

CHEMICAL CONNECTIONS

How is your sense of smell connected to temperature?

Figure 2.25 >

In traveling from point A to point B, the typical gas particle travels an indirect path because of numerous collisions with other gas particles—about 8 billion collisions every second! The changes in direction shown here represent only a few of these collisions. Although the particle travels at very high speeds, it takes a relatively long time to cross between two distant points because of these numerous collisions.

CONCEPT **CHECK**

Why are gases so much easier to compress into smaller volumes than solids and liquids?

CHECK YOUR ANSWER Because there is a lot of space between gas particles. The particles of a solid or liquid, on the other hand, are already close to one another, meaning there is little room left for a further decrease in volume.

Terms Used to Describe Phase Changes

Figure 2.26 illustrates that you must either add heat to a substance or remove heat from it if you want to change its phase. The process by which a solid transforms into a liquid is called **melting**. To visualize what happens when heat begins to melt a solid, imagine that you are holding hands with a group of people and each of you starts jumping around randomly. The more violently you jump, the more difficult it is to hold onto one another. If everyone jumps violently enough, keeping hold is impossible. Something like this happens to the particles of a solid when it is heated. As heat is added to the solid, the particles vibrate more and more violently. If enough heat is added, the attractive forces between the particles are no longer able to hold them together. The solid melts.

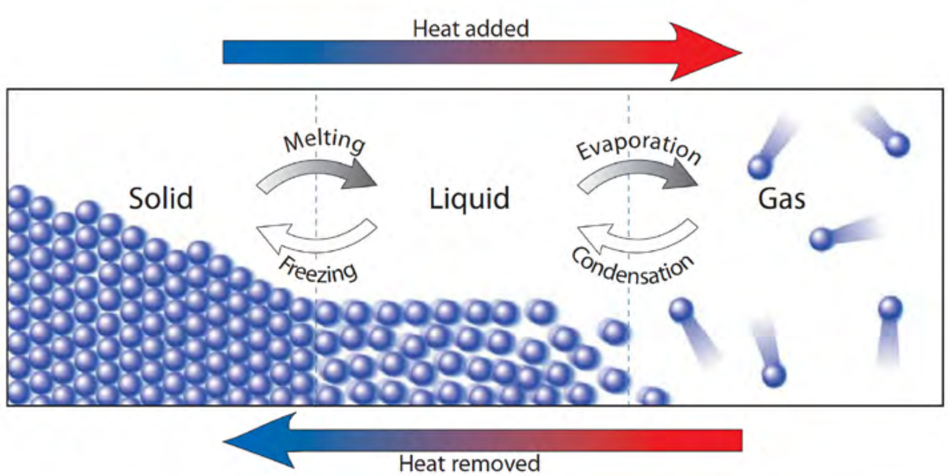


Figure 2.26 >

Melting and evaporation involve the addition of heat; condensation and freezing involve the removal of heat.

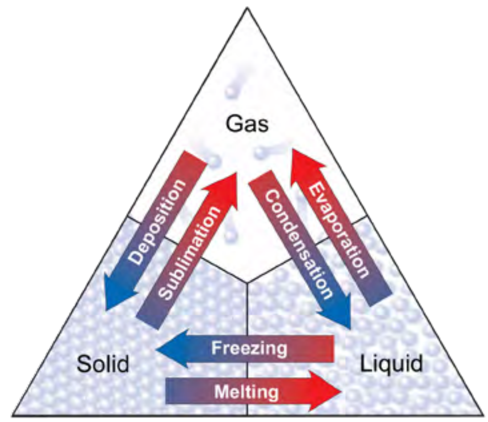
A liquid can be changed to a solid by the removal of heat. This process is called **freezing**. As heat is withdrawn from the liquid, particle motion diminishes until the particles are moving slowly enough on average for the attractive forces between them to take firm hold. The only motion the particles are capable of then is vibration about fixed positions, which means the liquid has solidified, or frozen. As we explore further in Chapter 8, freezing is merely the reverse of melting. The temperature at which a substance freezes or melts is the same. For pure water, this freezing/melting point is 0°C.

A liquid can be heated so that it becomes a gas—a process called **evaporation**. As heat is added, the particles of the liquid acquire more kinetic energy and move faster. Particles at the liquid surface eventually gain enough energy to fly out of the liquid. In other words, they enter the gaseous phase. As more and more particles absorb the heat being added, they too acquire enough energy to escape from the liquid surface and become gas particles. Because a gas results from evaporation, this phase is also sometimes referred to as *vapor*. Water in the gaseous phase, for example, may be referred to as *water vapor*.

The rate at which a liquid evaporates increases with temperature. A puddle of water, for example, evaporates from a hot pavement more quickly than it does from your cool kitchen floor. When the temperature is hot enough, evaporation occurs beneath the surface of the liquid. As a result, bubbles form and are buoyed up to the surface. We say that the liquid is **boiling**. A substance is often characterized by its boiling point, which is the temperature at which it boils. At sea level, the boiling point of fresh water is 100°C.

The transformation from gas to liquid—the reverse of evaporation—is called **condensation**. This process can occur when the temperature of a gas decreases. The water vapor held in the warm daylight air, for example, may condense to form a wet dew in the cool of the night.

Sublimation and deposition are two less commonly mentioned phase changes. **Sublimation** is the transformation of a solid directly to a gas. Snow readily sublimes from mountain tops on sunny days. Dry ice, as shown in Figure 2.24 , also readily sublimes. **Deposition** is the transformation of a gas directly to a solid. An example of deposition is the formation of frost. The various phase transformations are summarized in **Figure 2.27**.



Λ Figure 2.27

A summary of terms used to describe phase changes.