8.3 The Phases of Matter

You will notice that on a hot day, a glass of iced tea (or any cold beverage) has liquid water on the outside (Figure 8.12). The water does not come from inside the glass. The ice (the *solid* form of water) and cold liquid inside the glass cause the outside of the glass to also become cold. This "outside" cold temperature causes water vapor in the air—a *gas*—to condense into *liquid* water on the exterior of the glass. What is happening at the level of atoms and molecules? Why can water take the form of solid, liquid, or gas?

VOCABULARY

solid - a phase of matter that holds its shape and does not flow.

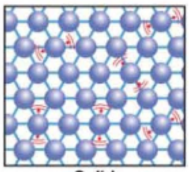
liquid - a phase of matter that holds its volume, does not hold its shape, and flows.

gas - a phase of matter that flows, does not hold its volume, and can expand or contract to fill a container.

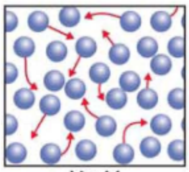
Solid, liquid, and gas

Phases of matter On Earth, pure substances are usually found as solids, liquids, or gases. These are called *phases of matter*. Another phase of matter called *plasma* is discussed later in the section.

Solids A **solid** holds its shape and does not flow. The molecules in a solid vibrate in place, but, on average, don't move far from their places.


Solid

Liquids A **liquid** holds its *volume* but does not hold its shape—it flows. The molecules in a liquid are about as close together as they are in a solid. But they have enough energy to change positions with their neighbors. Liquids flow because the molecules can move around.


Liquid

Gases A **gas** flows like a liquid, but can also expand or contract to fill a container. A gas does not hold its volume. The molecules in a gas have enough energy to completely break away from each other and are much farther apart than molecules in a liquid or a solid.

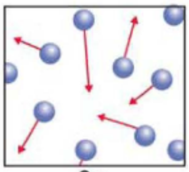
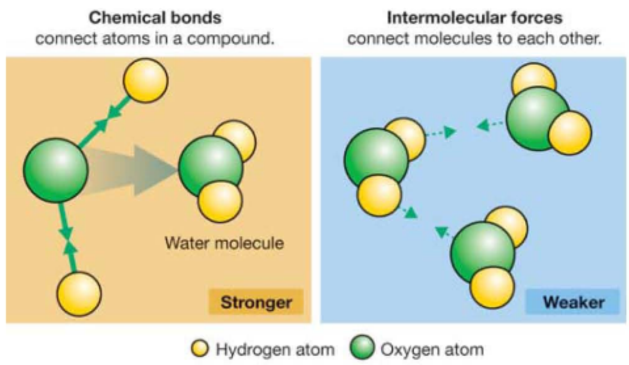

Gas

Figure 8.12: *Why can water take the form of solid, liquid, and gas?*

Intermolecular forces

What are intermolecular forces?

When they are close together, molecules are attracted through **intermolecular forces**. These forces are not as strong as the chemical bonds between atoms, but are strong enough to attach neighboring molecules to each other. Intermolecular forces have different strengths in different elements and compounds. Iron is a solid at room temperature. Water is a liquid at room temperature. This tells us that the intermolecular forces between iron atoms are stronger than those between water molecules.



Temperature vs. intermolecular forces

Within all matter there is a constant competition between temperature and intermolecular forces. The kinetic energy from temperature tends to push atoms and molecules apart. When temperature wins the competition, molecules break away from each other and you have a gas. Intermolecular forces tend to bring molecules together. When intermolecular forces win the competition, molecules clump tightly together and you have a solid. Liquid is somewhere in the middle. Molecules in a liquid are not stuck firmly together, but, at the same time, they cannot escape and break away from each other (Figure 8.13).

VOCABULARY

intermolecular forces - forces between atoms or molecules in a substance that determine the phase of matter.

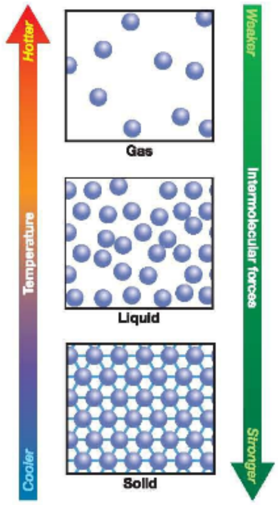


Figure 8.13: *The relationship between temperature, intermolecular forces, and phase of matter.*

Changing phase

Melting and freezing

The **melting point** is the temperature at which a substance changes from solid to liquid (melting) or from liquid to solid (freezing). The melting point is sometimes called the *freezing point*. Different substances have different melting points because intermolecular forces vary. When these forces are strong, it takes more energy to separate molecules from each other. Water melts at 0°C. Iron melts at a much higher temperature, about 1,500°C. The difference in melting points tells us the intermolecular forces between iron atoms are stronger than those between water molecules.

Boiling and condensing

When enough energy is added, the intermolecular forces are completely pulled apart and a liquid becomes a gas. The **boiling point** is the temperature at which a substance changes from liquid to gas (boiling) or from gas to liquid (condensing). When water boils, you can easily see the change within the liquid as bubbles of water vapor (gas) form and rise to the surface. The bubbles in boiling water are not air, they are water vapor.

Changes in phase require energy

It takes energy to break the intermolecular forces between particles. This explains a peculiar thing that happens when you heat an ice cube. As you add heat energy, the temperature increases. Once it reaches 0°C, *the temperature stops increasing* as ice starts to melt and form liquid water (Figure 8.14). As you add more heat energy, more ice becomes liquid but the temperature stays the same. This is because the energy you are adding is being used to break the intermolecular forces and change solid into liquid. Once all the ice has become liquid, the temperature starts to rise again as more energy is added. Figure 8.14 shows the temperature change in an experiment. When heat energy is added or subtracted from matter, either the temperature changes, or the phase changes, but usually not both at the same time.

VOCABULARY

melting point - the temperature at which a substance changes from solid to liquid (melting) or liquid to solid (freezing).

boiling point - the temperature at which a substance changes from liquid to gas (boiling) or from gas to liquid (condensing).

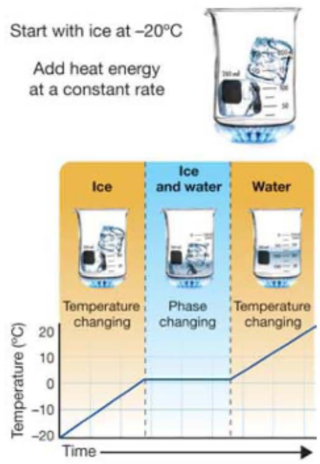


Figure 8.14: *Note how the temperature stays constant as the ice is melting into water.*

Melting and boiling points, sublimation, and plasmas

All substances can exist as a solid, liquid, or gas

On Earth, elements and compounds are usually found as solids, liquids, or gases. Each substance can exist in each of the three phases, and each substance has a characteristic temperature and pressure at which it will undergo a phase change. Figure 8.15 lists some examples.

Sublimation and deposition

Sometimes a solid can change directly to a gas with no liquid phase when heat energy is added. This process is called *sublimation*. Solid iodine is a substance that readily undergoes sublimation at room temperature. This is evident by the formation of a purple cloud above the crystals (Figure 8.16). A more common example is the shrinking of ice cubes (solid water) over time in the freezer. The ice doesn't melt in the freezer, but some of the molecules turn directly from solid to gas and the ice cubes shrink. The opposite of sublimation is *deposition*. One example of deposition is when water vapor changes directly into a solid—such as frost on a window on a cold winter night.

Image courtesy of NASA, ESA, M. Robberto (STScI/ESA) and the Hubble Space Telescope Orion Treasury Project Team

Plasma is a fourth phase of matter

At temperatures greater than 10,000°C, the atoms in a gas start to break apart. In the **plasma** phase, matter becomes ionized as electrons are broken loose from atoms. Because the electrons are free to move independently, plasma can conduct electricity. The Sun is made of plasma, as is most of the universe, including the Orion nebula (shown right).

Where else do we find plasma?

A type of plasma is used to make neon and fluorescent lights. Instead of heating the gases to an extremely high temperature, an electrical current is passed through them. The current strips the electrons off the atoms, producing plasma. You also see plasma every time you see lightning!

VOCABULARY

plasma - a phase of matter in which the matter is heated to such a high temperature that some of the atoms begin to break apart.

Substance	Melting Point	Boiling Point
helium	–272°C	–269°C
oxygen	–218°C	–183°C
mercury	–39°C	357°C
water	0°C	100°C
lead	327°C	1749°C
aluminum	660°C	2519°C

Figure 8.15: *The melting and boiling points of some common substances.*

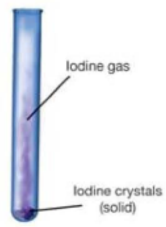
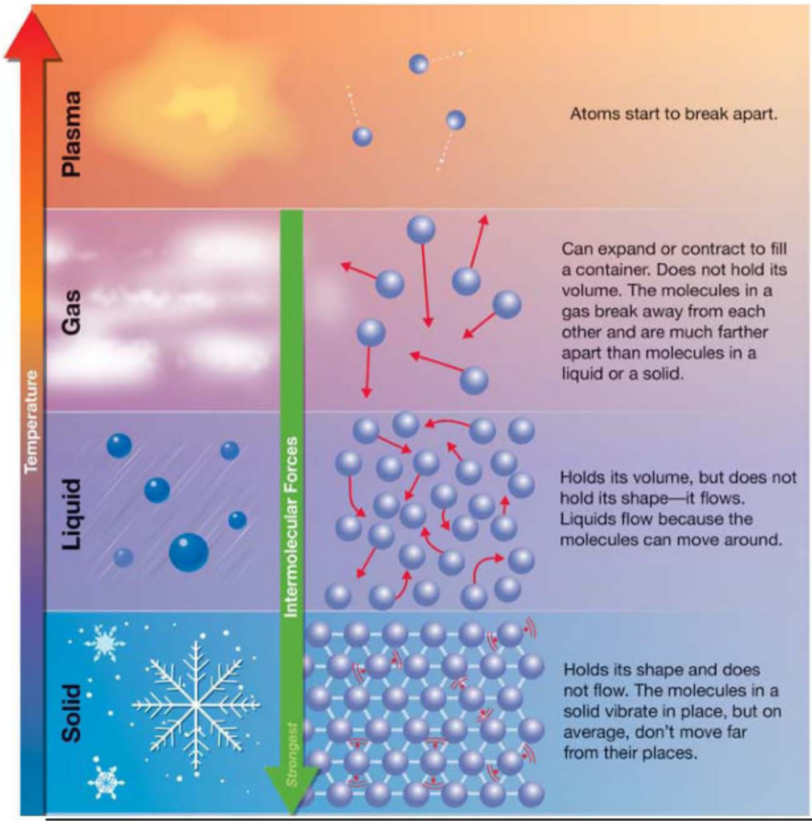


Figure 8.16: *Solid iodine readily undergoes sublimation at room temperature.*

Summarizing the phases of matter



SCIENCE FACT

Evaporation

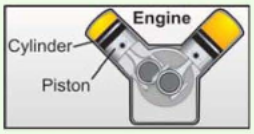
If you leave a pan of water in a room, eventually it will dry out. Why does this happen? *Evaporation* occurs when molecules go from liquid to gas at temperatures below the boiling point. Remember, temperature measures the *average* random kinetic energy of molecules. Some molecules have energy above the average and some below the average. Some of the highest-energy molecules have enough energy to overcome the intermolecular forces between them and their neighbors and become a gas if they are near the surface of the liquid. Molecules with higher than average energy are the source of evaporation.

Evaporation takes energy away from a liquid. The molecules that escape are the ones with the most energy. The average energy of the molecules left behind is lowered. Evaporation cools the surface of a liquid because the fastest molecules escape and carry energy away. This is how your body cools off on a hot day. The evaporation of sweat from your skin cools your body.

Section 8.3 Review

1. Identify the phase or phases of matter (solid, liquid, gas) that apply to each description. More than one phase of matter may apply to each description.
   a. Molecules vibrate in place but are not free to move around
   b. Has volume but no particular shape
   c. Flows
   d. Molecules break free of intermolecular forces
   e. Does not maintain a volume or shape
   f. Molecules can move around and switch places, but remain close together
2. Explain why particles in a gas are free to move far away from each other.
3. Explain why liquids flow but solids do not.
4. Would you expect a substance to be a solid, liquid, or gas at absolute zero? Explain your answer.
5. Describe what happens at the molecular level during melting.
6. Describe what happens at the molecular level when a substance boils.
7. What is the most common phase of matter in the universe?
8. What is plasma? Where can you find plasma?
9. List the four phases in order of increasing temperature (lowest to highest).
10. Put the following terms in order from strongest intermolecular forces to weakest intermolecular forces: *liquid*, *gas*, *solid*.
11. Which would you expect to have stronger intermolecular forces:
    a. Hydrogen, which exists as a gas at room temperature
    b. Iron, which exists as a solid at room temperature
12. Identify the segment(s) of the graph (A-B, B-C, C-D, D-E) in Figure 8.17 where a phase change is occurring. There could be more than one place. Explain your reasoning.

TECHNOLOGY



One of the ways to make car engines more efficient is to let them reach higher temperatures. Unfortunately, steel melts at about 1,500°C,. Steel gets soft before it melts, so engines typically can't operate at temperatures even close to the melting point. Some new engine technologies use cylinders and pistons made of ceramic. Ceramic stays hard and strong at a much higher temperature than steel.

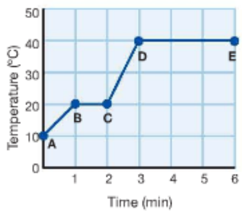


Figure 8.17: *Question 12.*