SECTION 2

Changes of State

Thermal Energy and Heat

Shards of ice fly from the sculptor's chisel. As the crowd looks on, a swan slowly emerges from a massive block of ice. As the day wears on, however, drops of water begin to fall from the sculpture. Drip by drip, the sculpture is transformed into a puddle of liquid water. What makes matter change from one state to another? To answer this question, you need to take another look at the particles that make up matter.

Energy Simply stated, energy is the ability to do work or cause change. The energy of motion is called kinetic energy. Particles within matter are in constant motion. The amount of motion of these particles depends on the kinetic energy they possess. Particles with more kinetic energy move faster and farther apart. Particles with less energy move more slowly and stay closer together.

The total energy of all the particles in a sample of matter is called thermal energy. Thermal energy depends on the number of particles in a substance as well as the amount of energy each particle has. If either the number of particles or the amount of energy each particle in a sample has increases, the thermal energy of the sample increases. The hot water and snow in **Figure 7** have different amounts of energy.

As You Read

What You'll Learn

- **Define and Compare** thermal energy and temperature.
- **Relate** changes in thermal energy to changes of state.
- **Explore** energy and temperature changes on a graph.

Vocabulary

temperature
heat
melting
freezing
vaporization
condensation

Why It's Important

Matter changes state as it heats up or cools down.

Figure 7
You know how it feels to be hot and cold. This hot spring, for example, feels much hotter than the snow around it. *How is hot matter different from cold matter?*

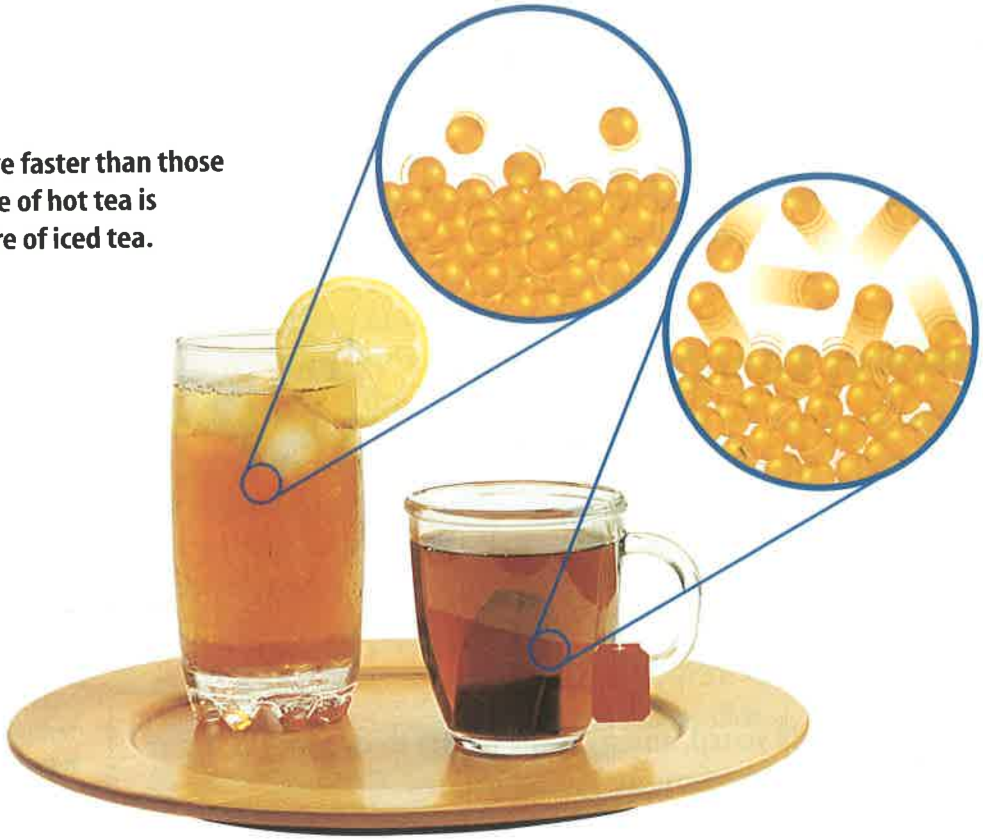


Figure 8
The particles in hot tea move faster than those in iced tea. The temperature of hot tea is higher than the temperature of iced tea.

Temperature Not all of the particles in a sample of matter have the same amount of energy. Some have more energy than others. The average kinetic energy of the individual particles is the **temperature** of the substance. You can find an average by adding up a group of numbers and dividing the total by the number of items in the group. For example, the average of the numbers 2, 4, 8, and 10 is $(2 + 4 + 8 + 10) \div 4 = 6$. Temperature is different from thermal energy because thermal energy is a total and temperature is an average.

You know that the iced tea is colder than the hot tea, as shown in **Figure 8.** Stated differently, the temperature of iced tea is lower than the temperature of hot tea. You also could say that the average kinetic energy of the particles in the iced tea is less than the average kinetic energy of the particles in the hot tea.

Physics INTEGRATION

Thermal energy is one of several different forms of energy. Other forms include the chemical energy in chemical compounds, the electrical energy used in appliances, the electromagnetic energy of light, and the nuclear energy stored in the nucleus of an atom. Make a list of examples of energy that you are familiar with.

Heat When a warm object is brought near a cooler object, thermal energy will be transferred from the warmer object to the cooler one. The movement of thermal energy from a substance at a higher temperature to one at a lower temperature is called **heat.** When a substance is heated, it gains thermal energy. Therefore, its particles move faster and its temperature rises. When a substance is cooled, it loses thermal energy, which causes its particles to move more slowly and its temperature to drop.

Reading Check *How is heat related to temperature?*

Specific Heat

If you walk from the grass to the pavement on a hot summer day, you know that the pavement is much hotter than the grass. Both surfaces were heated by the Sun and therefore received the same amount of thermal energy. Why does the temperature of one increase faster than the temperature of the other? The reason is that each surface has a different specific heat. The specific heat of a substance is the amount of heat needed to raise the temperature of 1 g of a substance 1°C.

Figure 9
One reason the water in this lake is much colder than the surrounding sand is because the specific heat of water is higher than that of sand.

Substances that have a low specific heat, such as most metals, heat up quickly because they require only small amounts of heat to cause their temperatures to rise. A substance with a high specific heat, such as the water in **Figure 9,** heats up slowly because a much larger quantity of heat is required to cause its temperature to rise by the same amount.

Changes Between the Solid and Liquid States

Matter can change from one state to another when thermal energy is absorbed or released. A change from one physical state of matter to another is known as change of state. The graph in **Figure 11** shows the changes in temperature and thermal energy that occur as you gradually heat a container of ice.

Melting As the ice in **Figure 11** is heated, it absorbs thermal energy and its temperature rises. At some point, the temperature stops rising and the ice begins to change into liquid water. The change from the solid state to the liquid state is called **melting.** The temperature at which a substance changes from a solid to a liquid is called the melting point. The melting point of water is 0°C.

Amorphous solids, such as rubber and glass, don't melt in the same way as crystalline solids. Because they don't have crystal structures to break down, these solids get softer and softer as they are heated, as you can see in **Figure 10.**

Figure 10
Rather than melting into a liquid, glass gradually softens. Glass blowers use this characteristic to shape glass into beautiful vases while it is hot.

Freezing The process of melting a crystalline solid can be reversed if the liquid is cooled. As the liquid cools, it loses thermal energy. As a result, its particles slow down and come closer together. Attractive forces begin to trap particles, and the crystals of a solid begin to form. The change from the liquid state to the solid state is called **freezing**. As you can see in **Figure 11,** freezing and melting are opposite processes.

The temperature at which a substance changes from the liquid state to the solid state is called the freezing point. The freezing point of the liquid state of a substance is the same temperature as the melting point of the solid state. For example, solid ice melts at 0°C and liquid water freezes at 0°C.

During freezing, the temperature of a substance remains constant while the particles in the liquid form a crystalline solid. Because particles in a liquid have more energy than particles in a solid, energy is released during freezing. This energy is released into the surroundings. After all of the liquid has become a solid, the temperature begins to decrease again.

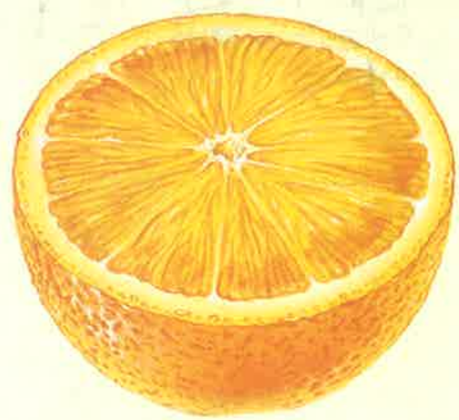
SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about freezing. Make a list of several substances and the temperatures at which they freeze. Find out how the freezing point affects how the substance is used. Share your findings with the class.

Problem-Solving Activity

How can ice save oranges?

During the spring, Florida citrus farmers carefully watch the fruit when temperatures drop close to freezing. When the temperatures fall below 0°C, the liquid in the cells of oranges can freeze and expand. This causes the cells to break, making the oranges mushy and the crop useless for sale. To prevent this, farmers spray the oranges with water just before the temperature reaches 0°C. How does spraying oranges with water protect them?



Identifying the Problem

Using the diagram in **Figure 11,** consider what is happening to the water at 0°C. Two things occur. What are they?

Solving the Problem

1. What change of state and what energy changes occur when water freezes?
2. How does the formation of ice on the orange help the orange?

Mini LAB

Explaining What You Feel

Procedure

1. Use a **dropper** to place one drop of **rubbing alcohol** on the back of your hand.
2. Describe how your hand feels during the next 2 min.
3. Wash your hands.

Analysis

1. What changes in the appearance of the rubbing alcohol did you notice?
2. What sensation did you feel during the 2 min? How can you explain this sensation?

Changes Between the Liquid and Gas States

After an early morning rain, you and your friends enjoy stomping through the puddles left behind. But later that afternoon when you head out to run through the puddles once more, the puddles are gone. The liquid water in the puddles changed into a gas. Matter changes between the liquid and gas states through vaporization and condensation.

Vaporization As liquid water is heated, its temperature rises until it reaches 100°C. At this point, liquid water changes into water vapor. The change from a liquid to a gas is known as **vaporization** (vay puhr uh ZAh shun). You can see in **Figure 11** that the temperature of the substance does not change during vaporization. However, the substance absorbs thermal energy. The additional energy causes the particles to move faster until they have enough energy to escape the liquid as gas particles.

Two forms of vaporization exist. Vaporization that takes place below the surface of a liquid is called boiling. When a liquid boils, bubbles form within the liquid and rise to the surface, as shown in **Figure 12**. The temperature at which a liquid boils is called the boiling point. The boiling point of water is 100°C.

Vaporization that takes place at the surface of a liquid is called evaporation. Evaporation, which occurs at temperatures below the boiling point, explains how puddles dry up. Imagine that you could watch individual water molecules in a puddle. You would notice that the molecules move at different speeds. Although the temperature of the water is constant, remember that temperature is a measure of the average kinetic energy of the molecules. Some of the fastest-moving molecules overcome the attractive forces of other molecules and escape from the surface of the water.

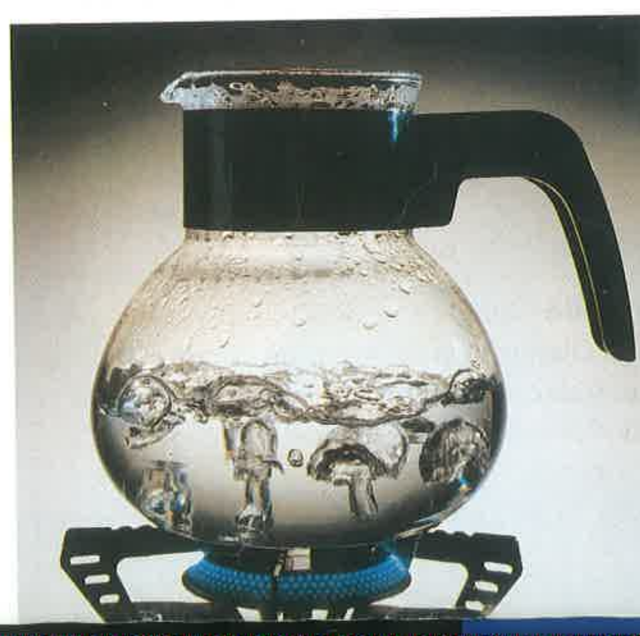


Figure 12
During boiling, liquid changes to gas, forming bubbles in the liquid that rise to the surface.

Figure 13
The drops of water on these glasses and pitcher of lemonade were formed when water vapor in the air lost enough energy to return to the liquid state. This process is called condensation.

Location of Molecules It takes more than speed for water molecules to escape the liquid state. During evaporation, these faster molecules also must be near the surface, heading in the right direction, and they must avoid hitting other water molecules as they leave. With the faster particles evaporating from the surface of a liquid, the particles that remain are the slower, cooler ones. Evaporation cools the liquid and anything near the liquid. You experience this cooling effect when perspiration evaporates from your skin.

Condensation Pour a nice, cold glass of lemonade and place it on the table for a half hour on a warm day. When you come back to take a drink, the outside of the glass will be covered by drops of water, as shown in **Figure 13.** What happened? As a gas cools, its particles slow down. When particles move slowly enough for their attractions to bring them together, droplets of liquid form. This process, which is the opposite of vaporization, is called **condensation.** As a gas condenses to a liquid, it releases the thermal energy it absorbed to become a gas. During this process, the temperature of the substance does not change. The decrease in energy changes the arrangement of particles. After the change of state is complete, the temperature continues to drop, as you saw in **Figure 11.**

Reading Check *What energy change occurs during condensation?*

Condensation formed the droplets of water on the outside of your glass of lemonade. In the same way, water vapor in the atmosphere condenses to form the liquid water droplets in clouds. When the droplets become large enough, they can fall to the ground as rain.

SCIENCE Online

Research Visit the Glencoe Science Web site at **science.glencoe.com** for more information about how condensation is involved in weather. Find out how condensation is affected by the temperature as well as the amount of water in the air.

Figure 14
The solid dry ice at the bottom of this beaker of water is changing directly into gaseous carbon dioxide. This process is called sublimation.

Changes Between the Solid and Gas States

Some substances can change from the solid state to the gas state without ever becoming a liquid. During this process, known as sublimation, the surface particles of the solid gain enough energy to become a gas. One example of a substance that undergoes sublimation is dry ice. Dry ice is the solid form of carbon dioxide. It often is used to keep materials cold and dry. At room temperature and pressure, carbon dioxide does not exist as a liquid. Therefore, as dry ice absorbs thermal energy from the objects around it, it changes directly into a gas. When dry ice becomes a gas, it absorbs thermal energy from water vapor in the air. As a result, the water vapor cools and condenses into liquid water droplets, forming the fog you see in **Figure 14.**

Section 2 Assessment

1. How are thermal energy and temperature similar? How are they different?
2. How does a change in thermal energy cause matter to change from one state to another? Give an example.
3. During which three changes of state is energy absorbed?
4. What are two types of vaporization?
5. **Think Critically** How can the temperature of a substance remain the same even if the substance is absorbing thermal energy?

Skill Builder Activities

6. **Making and Using Graphs** Using the data you collected in the Explore Activity, plot a temperature-time graph. Describe your graph. At what temperature does the graph level off? What was the liquid doing during this time period? **For more help, refer to the Science Skill Handbook.**
7. **Communicating** In your Science Journal, explain why you can step out of the shower into a warm bathroom and begin to shiver. **For more help, refer to the Science Skill Handbook.**