Section 2
Heat and Energy

Key Concept Heat flows in a predictable way from warmer objects to cooler objects until all of the objects are at the same temperature.

What You Will Learn
- Temperature is a measure of the average kinetic energy of particles in an object.
- Heat is energy that is transferred between objects.
- Heat flows by conduction, convection, and radiation.

Why It Matters
The ability of heat to move from one object to another is the basis for the flow of energy in Earth's systems.

Imagine that you are outside on a hot day. You step on a shady porch where a fan is blowing. You feel cool there. Then, your friend comes out onto the porch from an air-conditioned house. She says that she feels hot! Whether you think something is hot or cold depends on your point of reference. If you really want to be clear about how hot or cold something is, you must talk about its temperature.

What Is Temperature?
You might think of temperature as a measure of how hot or cold something is. But using the terms *hot* and *cold* can be unclear. Using the word *temperature* instead of the words *hot* and *cold* is much clearer. Scientifically, **temperature** is a measure of the average kinetic energy of the particles in an object.

Temperature and Kinetic Energy
All matter is made up of constantly moving particles, such as atoms or molecules. The particles are moving even though you cannot see them moving. When particles are in motion, they have *kinetic energy.* The faster that the particles move, the more kinetic energy that they have. The temperature of a substance depends on the kinetic energy of all of the particles that make up the substance. The more kinetic energy that the particles of an object have, the higher that the temperature of the object is. **Figure 1** shows two substances that have different temperatures.

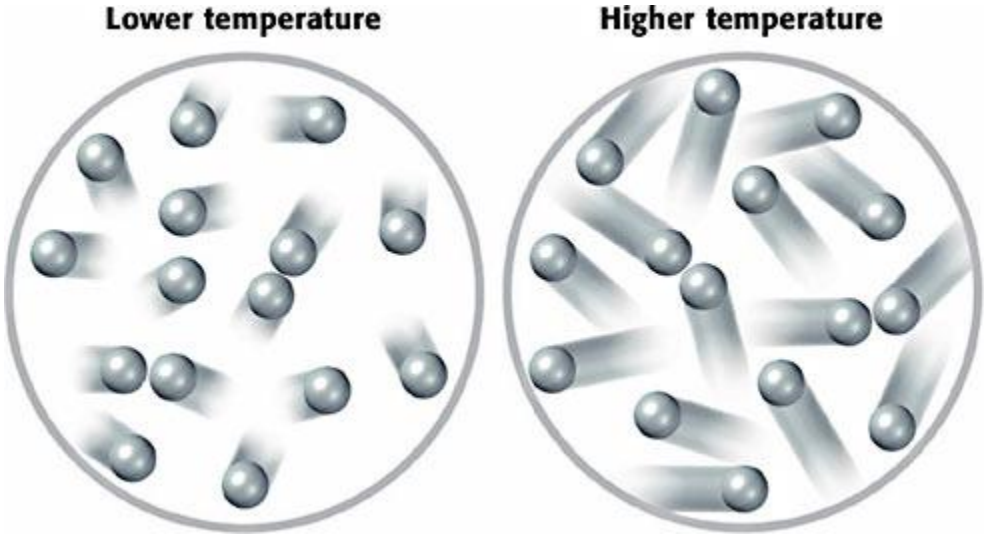


Figure 1 The gas particles on the right are moving faster and have a higher average kinetic energy than the particles on the left do. So, the gas on the right is at a higher temperature than the gas on the left is.

Average Kinetic Energy of Particles

Particles of matter move at random and at different speeds. As a result, the particles have different amounts of kinetic energy. But the *average* kinetic energy of all of the particles in an object can be measured. When you measure an object's temperature, you measure the average kinetic energy of all of the particles in the object.

The temperature of a substance depends on the average kinetic energy of all particles in the substance. The temperature does not depend on the amount of particles. A teapot holds more tea than a teacup does. But if the atoms of tea in both containers have the same average kinetic energy, then the tea in the pot and the tea in the cup are at the same temperature.

Thermal Expansion

When a substance's temperature increases, the substance's particles have more kinetic energy. Thus, the particles move faster and move apart. As the space between the particles increases, the substance expands. The increase in volume resulting from an increase in temperature is called *thermal expansion.*

Thermal expansion is the process that causes hot-air balloons to rise. **Figure 2** shows a hot-air balloon being filled with hot air. Heat is added to the air inside the balloon. The air expands as its particles gain kinetic energy and move faster and farther apart. As the air expands, it becomes less dense than the air outside the balloon. The less-dense air inside the balloon is forced upward by the colder, denser air outside the balloon. As a result, the balloon goes up, up, and away!

Figure 2 Thermal expansion of heated gases gets these hot-air balloons off the ground.

Thermal expansion is also the mecha nism by which thermometers measure temperature. Thermometers hold a fluid, such as mercury or alcohol. This fluid expands by known amounts for a given change in temperature. A scale on the thermometer shows the temperature based on how much the fluid expands.

This same principle affects air movement in the atmosphere. It also affects water movement in the oceans and rock movement in the geosphere.

What Is Heat?

You might think of the word *heat* when you imagine something that feels hot. But heat also has to do with things that feel cold. In fact, heat is what causes objects to feel hot or cold. Heat also causes objects to get hot or cold under the right conditions. You may often use the word *heat* to mean different things. However, in this chapter, the word *heat* has only one meaning. **Heat** is the energy that is transferred between objects that are at different temperatures.

Transferring Heat

Why do some things feel hot or cold? Heat is passed from one object to another according to the difference in temperature. Energy is always passed from the object that has the higher temperature to the object that has the lower temperature. When you touch something "cold," heat flows from your body to that object. When you touch something "hot," heat flows from the object into your body.

Imagine that you are getting a checkup. The doctor places a metal stethoscope on your back. You jump a little and say, "Whoa! That's cold!" You may feel like the girl in **Figure 3** does. Why did the metal feel cold? It felt cold because your back has a higher temperature than the metal does. Your back is about 30°C. But the metal is about 20°C, or room temperature. When the metal touches your back, heat is passed from your back to the metal. This heat passes very quickly, so the metal feels cold to you. But why does the metal quickly stop feeling cold? No more heat is being transferred to the metal because the temperature of the metal is equal to the temperature of your skin.

Figure 3 The metal stethoscope feels cold because heat flows from the girl’s warm skin to the cold metal!

Heat and Thermal Energy

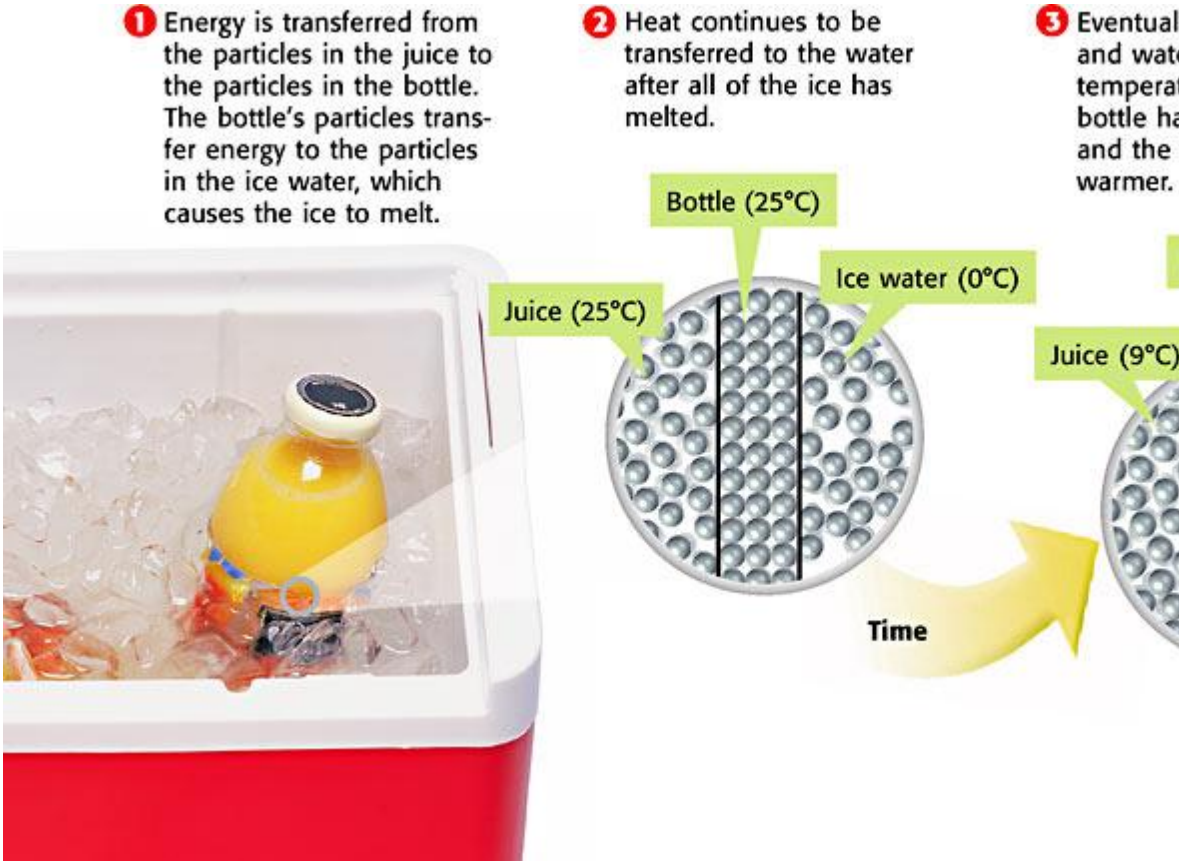
When heat is transferred between objects, the thermal energy of each object changes. **Thermal energy** is the total kinetic energy of the particles that make up a substance. Thermal energy depends partly on temperature. Something at a high temperature has more thermal energy than something at a lower temperature does. As **Figure 4** shows, thermal energy also depends on the amount of particles in a substance. The more particles in a substance at a given temperature, the greater the thermal energy of the substance.

Figure 4 Both soups are at the same temperature, but the pan holds more soup. So, the soup in the pan has more thermal energy than the soup in the bowl does.

Reaching the Same Temperature

When things that have different temperatures come into contact, energy will always be transferred. Energy will pass from the warmer object to the cooler object until both have the same temperature. When objects that are touching each other have the same temperature, there is no net change in the thermal energy of either object. Although one object may have more thermal energy than the other object, both objects will be at the same temperature. The process of transferring heat is shown in **Figure 5.**

Figure 5 Transfer of Heat

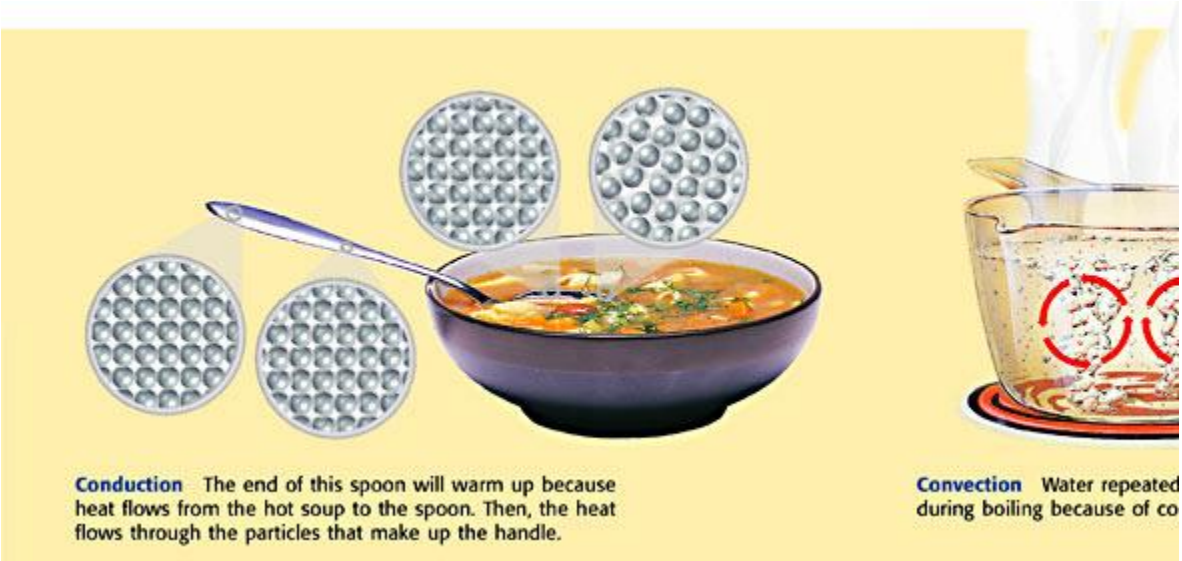


Standards Check What will happen if two objects at different temperatures come into contact?

How Is Heat Transferred?

Heat flows in solids and fluids by conduction and by convection. Heat flows between objects that are not in contact by radiation. These processes are shown in **Figure 6.**

Figure 6 Conduction, Convection, and Radiation



Conduction The end of this spoon will warm up because heat flows from the hot soup to the spoon. Then, the heat flows through the particles that make up the handle.

Convection Water repeated during boiling because of co

Conduction

The transfer of heat from one object to another through direct contact is called **conduction.** Heat flows from the particles of the hot soup to the part of the spoon that is in the soup. The particles from that part of the spoon interact with particles in the handle of the spoon. The interaction transfers heat particle by particle all the way up the spoon's handle.

Convection

The transfer of energy due to the movement of matter, such as liquid or gas, is called **convection.** When you boil water in a pot, the water moves in a circular pattern. Heat is passed from the hot burner to the pot and from the pot to the water by conduction. As it heats, the water becomes less dense because its higher-energy particles spread apart. The denser, cold water at the top of the pot sinks. As it sinks, the cold water forces the warmer water toward the surface. At the surface, the warm water cools as it passes heat to other water particles and to the air above the pot. At the bottom of the pot, more water is heated by conduction. As the water moves, the energy is spread throughout the water.

Radiation

The transfer of heat or other energy as electromagnetic waves, such as visible light or infrared waves, is called **radiation.** Unlike conduction and convection, radiation can occur between objects that are not in direct contact with each other. Energy can be transferred through empty space by radiation. The sun transfers energy through space by radiation. Most of this energy is emitted as visible light, which you can see. The sun also emits waves of other frequencies, such as infrared waves and ultraviolet waves. But you cannot see these waves.

Standards Check How is radiation different from conduction?

States of Matter

The matter that makes up an ice cube has the same chemical composition whether the ice is frozen or has melted. The matter is simply in a different form, or state. The states of matter are the physical forms in which a substance can exist. The three states of matter are solid, liquid, and gas. These three states are shown in **Figure 7.**

Figure 7 Particles of a Solid, a Liquid, and a Gas

Particles of a solid have a strong attraction between them. The particles are closely locked in position and can only vibrate.

Particles of a liquid are more loosely connected than those of a solid and can collide with and move past one another.

Particles of a gas move fast enough so that they overcome the attractions between them. The particles move independently and collide frequently.

State and Chemical Properties

Matter is made up of particles that move around at different speeds. A substance's state depends on the speed of its particles, the attraction between them, and the pressure around them. A substance's chemical composition also influences the state of the substance at a given temperature. Different materials are solid at different temperatures. For example, butter is usually solid at room temperature. But milk is liquid at room temperature. Milk is solid at a different temperature than butter is, because milk has a different chemical composition than butter does.

Changes of State

A change of state occurs when a substance changes from one state of matter to another. Changes of state include *condensing* (gas to liquid), *freezing* (liquid to solid), *melting* (solid to liquid), and *evaporating* (liquid to gas). A change of state involves a transfer of heat from one substance to another. Energy is released or added to the substance that changes its state. When it melts or boils, a substance gains energy. When it condenses or freezes, a substance loses energy.

Section Summary

- Heat moves from warmer objects to cooler objects until all of the objects are at the same temperature.
- Conduction is the transfer of energy as heat through a solid material.
- Convection is the transfer of energy due to the movement of matter.
- Radiation is the transfer of energy as electromagnetic waves. Radiation differs from conduction and convection because radiation can transfer energy through empty space.
- A substance's state of matter depends on the speed of the particles in the substance. Changes of state result from the transfer of energy.