10.1 Temperature, Thermal Energy, and Heat

The kinetic molecular theory explains that particles in matter are in constant motion. Matter has thermal energy due to the kinetic and potential energies of its particles. Heat is the amount of thermal energy transferred from a warmer area to a cooler one. Heat transfer occurs by collisions between particles (conduction), the movement of fluids (convection), or the movement of electromagnetic waves (radiation).

Words to Know

conduction
convection
electromagnetic radiation
heat
kinetic energy
kinetic molecular theory
temperature
thermal energy

Did You Know?

In outer space, far away from any planets, stars, or meteors, there are very few particles. However, even these few particles vibrate with kinetic energy. The Big Bang theory is one explanation for this phenomenon. Scientists suggest that the low level of energy in outer space is left over from the Big Bang, the expansion of the universe that began billions of years ago.

You have probably heard expressions like "this classroom is freezing," "this soup is too hot," or "it feels warm outside." All of these expressions may seem to refer to the same idea. However, each relates to a different concept: temperature, thermal energy, or heat. To understand the differences among these concepts, it is important to review the kinetic molecular theory.

As you may have learned in earlier science courses, the **kinetic molecular theory** explains that all matter is composed of particles (atoms and molecules). These particles move constantly in random directions. **Kinetic energy** is the energy of a particle or an object due to its motion. When particles collide, kinetic energy is transferred between them, much as a bowling ball transfers energy to the bowling pins it hits.

The particles of a substance are bonded together differently depending on the state of the substance. When the substance is in a solid state, the particles are very close together and vibrate slowly (Figure 10.1). When the same substance is in a liquid state, the particles are farther apart. When the same substance is in a gas state, the particles spread even farther apart. The particles of a substance move faster when the temperature of the substance increases.

Figure 10.1 Particles in a solid (right) are strongly attracted to one another. Particles in liquids (left) and gases (middle) move freely and are spread farther apart.

10-1A Heat It Up

Find Out ACTIVITY

According to the kinetic molecular theory, the more kinetic energy that particles have, the faster the particles will move and the more they will spread apart. In this activity, you will examine the relationship between particle motion and temperature.

Safety

- Use caution when handling the lamp as the light bulb will become very hot.

Materials

- alcohol thermometer
- 250 mL beaker
- cold water
- lamp with 100 W incandescent bulb

What to Do

1. Read the thermometer.
2. Fill the beaker with 100 mL of cold tap water. Use the thermometer to measure the temperature of the water.
3. Set up the lamp so that the light will shine directly on the beaker of water. Turn on the lamp.
4. Hold the thermometer in the beaker of water for at least 5 min. Observe the thermometer during this time.
5. Clean up and put away the equipment you have used.

What Did You Find Out?

1. State what you saw happening to the liquid in the thermometer:
   (a) when you took the first temperature reading
   (b) while the light was shining on the beaker of water
2. Explain your observations above using the kinetic molecular theory.
3. What made the temperature of the water change?
4. Why did it take time to get a temperature reading of the water?

Temperature

Even within a pure substance, in which the particles are identical, the kinetic energy of the particles will vary. The particles travel at different speeds and in different directions. **Temperature** is a measure of the average kinetic energy of all the particles in a sample of matter. A cup of hot chocolate feels hot because the average kinetic energy of its particles is higher than the average kinetic energy of the particles in your hand. As the particles' average kinetic energy increases, the temperature of a solid, liquid, or gas will also increase. For example, particles in a glass of cold water move slower and have less kinetic energy than particles in a cup of hot water (Figure 10.2).

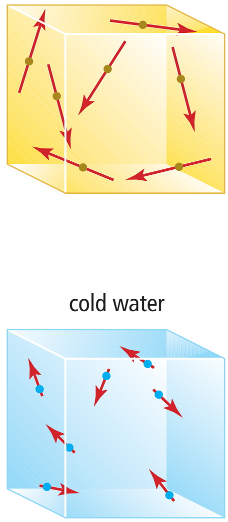

Figure 10.2 The dots represent water molecules. The arrows show how fast the water molecules are moving and in what direction.

Temperature scales

Three different number scales are used to measure temperature: Fahrenheit, Celsius, and Kelvin. The Fahrenheit scale was designed by the German-Dutch physicist Daniel Gabriel Fahrenheit (1686–1736) and has been used since 1724.

The Celsius scale was named after its inventor, the Swedish astronomer Anders Celsius (1701–1744). First used in 1745, the Celsius scale was later included in the metric system and is now used around the world. The Celsius scale is based on two fixed points: the freezing point of pure water (0°C) and the boiling point of pure water (100°C).

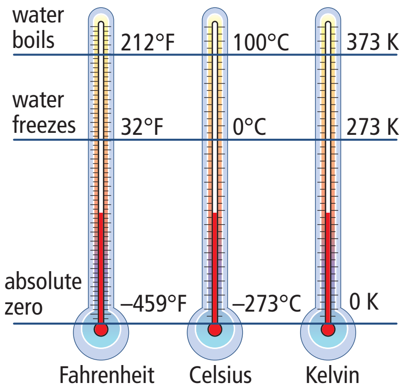

Figure 10.3 The temperature scales

In 1848, William Thompson (1824–1907) of Scotland proposed a temperature scale based on absolute zero, the temperature at which particles would have no kinetic energy. Thompson was later given the title Lord Kelvin, and so his scale is known as the Kelvin scale. Figure 10.3 gives the values of absolute zero and the freezing point and boiling point of water using the three different temperature scales.

Reading Check

1. What is the kinetic molecular theory?
2. Define temperature.
3. Name three temperature scales.

Thermal Energy

Thermal energy is the total energy of all the particles in a solid, liquid, or gas. The more kinetic energy a solid, liquid, or gas has, the more thermal energy it has. A hot bowl of soup, for example, has more thermal energy when it is first served than after it cools. Since thermal energy includes the energy of all of the particles in a sample of matter, a large bowl of soup would have more thermal energy than a small one. In fact, a swimming pool of lukewarm water would have more thermal energy than a small cup of hot tea.

Word Connect

The word "kinetic" comes from the ancient Greek word *kinetikos*, meaning to put in motion.

Kinetic energy is not the only energy associated with moving particles (Figure 10.4). **Potential energy** is the stored energy of an object or particle, due to its position or state. An example is the gravitational attraction between Earth and a textbook you are holding. As you lift the textbook, its gravitational potential energy increases. The lower you hold the book, the less gravitational potential energy it has. Similarly, there are attractive electrical forces between atoms and molecules. The pull of these attractive forces gives particles potential energy.

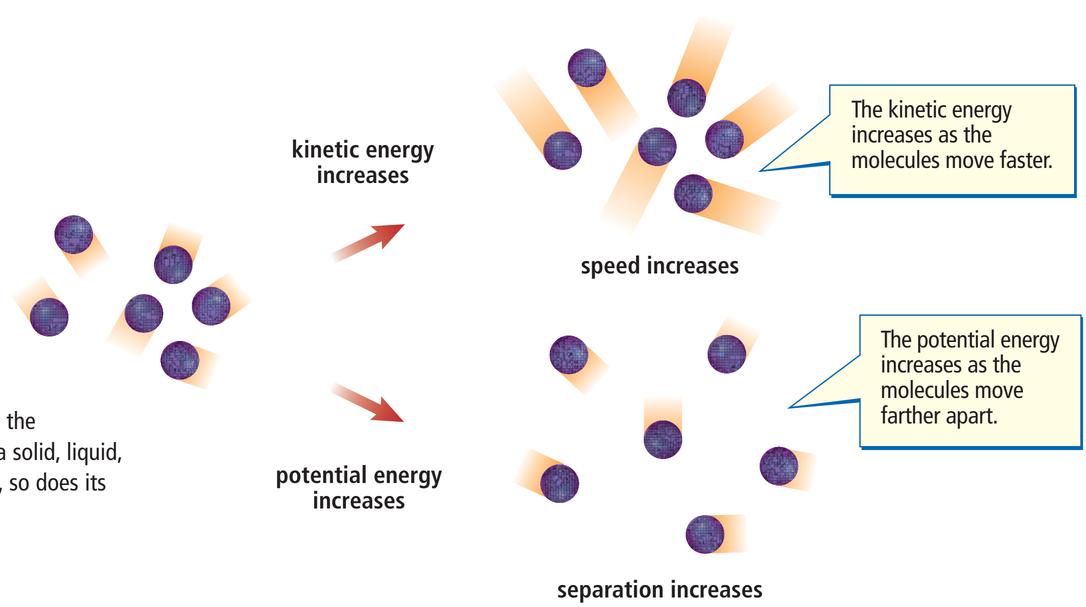

Figure 10.4 As the temperature of a solid, liquid, or gas increases, so does its thermal energy.

Heat

The terms "heat," "temperature," and "thermal energy" are often used as if they have the same meaning, but they do not. **Heat** is the amount of thermal energy that transfers from an area or object of higher temperature to an area or object of lower temperature. Consider how heat is used to cook an egg. Heat flows from the hot stove element to the frying pan and then to the egg. As the egg gains thermal energy, the kinetic energy of the egg's atoms and molecules increases, and so does its temperature. The egg heats up and cooks (Figure 10.5). Heat can similarly flow within and between large systems, such as the oceans and the atmosphere.

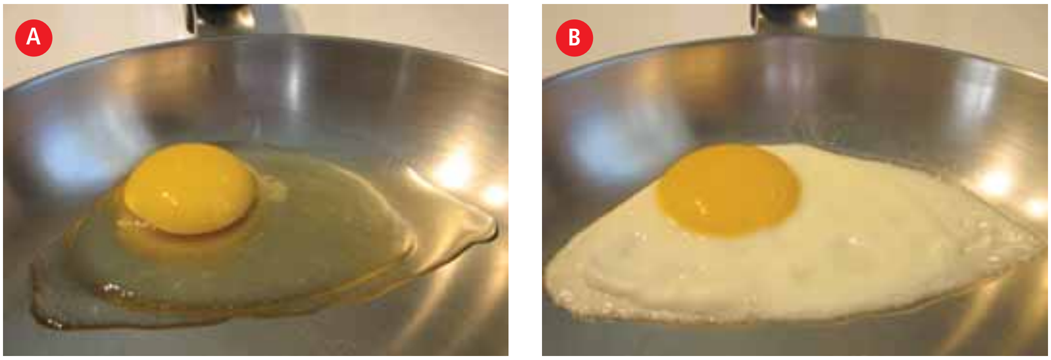

Figure 10.5 Heat transfers from the frying pan to the egg.

Reading Check

1. What term describes the total amount of energy of a solid, liquid, or gas?
2. How does temperature relate to thermal energy?
3. What is heat?

Heat Transfer

Heat can be transferred in three ways: conduction, convection, and radiation. Figure 10.6 shows a pot of boiling water on a stove. This figure illustrates all three types of heat transfer. The next three pages will describe the types of heat transfer in more detail.

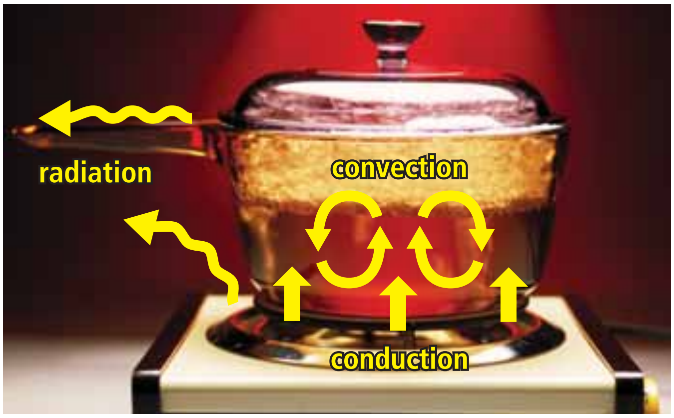

Figure 10.6 The stove element heats the pot and the pot heats the water by conduction. Water circulating in the pot transfers heat by convection. Near the stove, the air would feel warm due to heat transfer by radiation.

Conduction

Conduction is the transfer of heat from one substance to another or within a solid by direct contact of particles. Conduction transfers heat from matter with a higher temperature and greater kinetic energy to matter with a lower temperature and lower kinetic energy. This process explains why a metal spoon left in a pot of boiling water becomes hot to touch. The stove element heats the pot, which in turn heats the water. Heating increases the kinetic energy of the water molecules, which collide with particles in the spoon. The collisions transfer kinetic energy to the slower-moving particles of the spoon. As the collisions between particles continue, heat transfers to the spoon, making it feel hot.

Most materials can transfer heat by conduction, but they transfer it at different rates. Thermal conductors are materials that transfer heat easily. Metals, for example, are good thermal conductors. Materials that do not transfer heat easily are called insulators. Air, snow, wood, and Styrofoam® are examples of insulators (Figure 10.7).

Suggested Activity

Conduct an Investigation 10-1B on page 432

Did You Know?

On a cold winter day, if you touch anything metal, it feels very cold. However, the metal is not actually colder than the surrounding air. Most metals are excellent conductors and rapidly conduct thermal energy away from your hand. Your brain interprets the transfer of thermal energy to the metal as the sensation of cold.

Figure 10.7 Aluminum is a good thermal conductor (A). Styrofoam® is a good thermal insulator (B).

Reading Check

1. What term describes the transfer of heat by direct contact between particles?
2. What is the direction of heat transfer: higher temperature areas to lower temperature areas, or lower temperature area to higher temperature areas?
3. What is a conductor?
4. What is the term for a substance with low conductivity?

Convection

Liquids and gases are fluids. **Fluids** are substances in which the particles can flow freely. This characteristic allows for a second type of heat transfer, called convection. **Convection** is the transfer of heat within a fluid and with the movement of fluid from one place to another. Unlike conduction, convection transfers matter as well as heat.

The movement of liquid in a lava lamp occurs by convection. Melted rock under Earth's surface and clouds in the sky also move by convection (Figure 10.8).

internet connect

The horizontal transfer of heat in a fluid is called advection. To find out how ocean currents transfer heat by advection go to **www.bcscience10.ca**.

Figure 10.8 Convection currents are responsible for heat transfer in the lava lamp (A) and the lake of melted rock (B). Convection currents also produced the storm cloud (C).

Convection can be explained by the kinetic molecular theory. As particles move faster and their kinetic energy increases, they move farther apart. As the particles in a fluid move farther apart, the fluid itself expands and its density decreases. As you may have learned in earlier science courses, density is mass divided by volume. Therefore, if the mass of a sample of material remains the same but the volume increases, the density decreases.

Heating the air in a hot air balloon causes the air to expand. Because the air expands, it becomes lighter and the balloon can rise off the ground. Similarly, in a bubbling pot of water on the stove, the warmer water at the bottom of the pot rises because it is less dense than the surrounding water. At the surface, the water cools, contracts, and sinks—only to be reheated and recirculated. The movement of the water, caused by continuous cycling of heating, cooling, and reheating, is called a convection current. A **convection current** is the movement of a fluid caused by density differences.

Convection is used in a variety of household tools. Convection ovens use convection currents to transfer heat to food. Some home-heating systems also use convection (Figure 10.9). For example, a hot air furnace supplies warm air to a room through hot air vents. The warm air rises and then cools as it loses heat to surrounding air. The cooled air contracts and sinks, only to be reheated or replaced by incoming warm air. The convection current can therefore be used to warm an entire room.

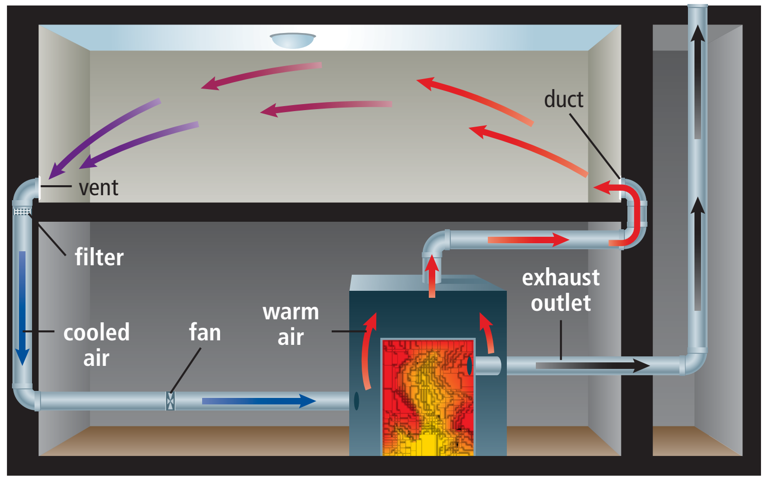

Figure 10.9 Hot air furnaces rely on convection currents to transfer heat throughout a room.

Suggested Activity

Conduct an Investigation 10-1C on page 433

Reading Check

1. What is the term for matter that can flow freely?
2. Does convection transfer heat or both heat and matter?
3. What happens to the density of an uncontained fluid when it is heated?
4. What is a convection current?

Radiation

Without heat transfer from the Sun, life on Earth would not exist as we know it. But how can heat be transferred through space, where particles are spread so far apart that there is little chance they will collide? **Electromagnetic radiation**, is the transfer of energy by waves travelling outward in all directions from a source. Electromagnetic waves radiate (travel by radiation) through space even though there is no matter there. **Radiant energy** is the energy carried by electromagnetic waves.

The only electromagnetic radiation we can see is visible light. Most of the electromagnetic spectrum is invisible to the unaided human eye. However, if you stand too close to a campfire, you will experience the reality of **infrared radiation**, also known as heat radiation (Figure 10.10). When you stand in sunlight, your skin feels warm due to solar radiation, the transfer of radiant energy from the Sun (Figure 10.11 on the next page). **Solar radiation** is made up of visible light as well as infrared and other types of radiation (Figure 10.12 on the next page).

Figure 10.10 Your body is a source of infrared radiation.

Any material with a temperature greater than absolute zero radiates some heat, including bicycle tires, baby diapers, ice cubes, oceans, and even you. Some materials transfer more heat than others. As you will read in Chapter 12, volcanic eruptions are a result of the release of thermal energy under Earth's surface. Scientists think that a great deal of thermal energy was stored as Earth formed from the build-up of dust into a bigger and bigger rocky lump. Some of this thermal energy was released over time. Residual thermal energy from Earth's formation continues to heat the planet. The decay of radioactive elements underground is another source of thermal energy on Earth.

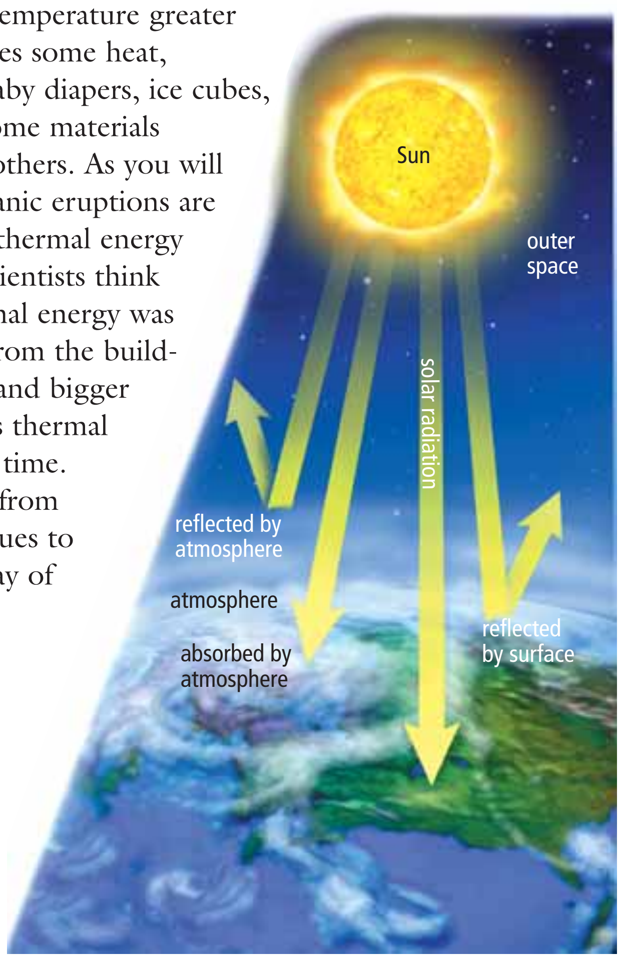

Figure 10.11 Solar radiation accounts for much of the thermal energy at Earth's surface.

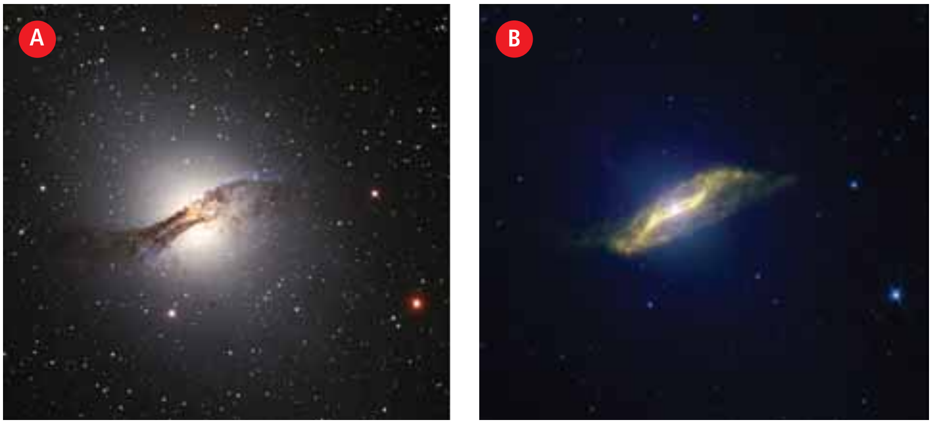

Figure 10.12 Like the Sun, this newly forming star is a source of both visible light (A) and infrared radiation (B).

Materials absorb, reflect, or transmit radiation. Heat is transferred when a substance absorbs radiation, causing it to increase in temperature, melt, or evaporate. Section 10.2 explores what happens to solar radiation and how the transfer of thermal energy affects the atmosphere.

Connection

Chapter 7 has more information on radiation.

Explore More

Find out more about scientists' hypotheses to explain how thermal energy became trapped in the newly formed Earth. Start your search at **www.bcscience10.ca**.