CHAPTER 6

Thermal Energy and Society

KEY CONCEPTS

After completing this chapter you will be able to

- describe the differences between temperature, thermal energy, and heat.
- solve problems involving the quantity of heat and apply the concept to situations involving heat exchange.
- explain the temperature changes involved in changes of state, and mathematically determine the energy involved
- describe the impact of heating and cooling systems on society and the environment

How Can People Utilize Thermal Energy?

The sight of steaming hot water shooting like a fountain out of Earth is impressive; it serves as an indicator of the potential that lies below the surface of Earth. Geothermal energy can be captured from deep within Earth's crust and employed for useful purposes. At a depth of 6000 km, water temperatures can be close to 5000 °C. Of course the water cools significantly as it rises, but it is often still over 150 °C when it reaches the surface, a temperature still warm enough to generate electricity or heat a home. Furthermore, as you will learn in this chapter, thermal energy that is even a short distance below Earth's surface can be effectively utilized for heating and cooling systems.

At the edges of Earth's tectonic plates, hot magma is much closer to the surface than it is in other areas of Earth's lithosphere, which comprises Earth's crust and the upper portion of the mantle. This results in concentrations of volcanoes, hot springs, and geysers such as those in the "Ring of Fire" in the Pacific Ocean. In the past, the Ring of Fire encompassed many of the areas where people tapped into Earth's geothermal energy: the people of New Zealand and some parts of North America used thermal pools to cook their food. Inhabitants of other areas, such as Iceland, utilized the same types of thermal pools, and the Romans used geothermally-heated water both in bathhouses for washing and treating illness, as well as to heat their homes.

Humans are now developing new ways to heat water and other liquids by pumping them down into Earth's hot interior and then bringing them to the surface for useful purposes. The development of such techniques is important in the reduction of greenhouse gases because, unlike the burning of fossil fuels that characterizes much of today's energy consumption, these processes that utilize geothermal energy do not directly release pollutants into the air.

In this chapter, you will explore the differences between thermal energy, temperature, and heat. You will learn how to calculate quantities of thermal energy gained or lost by an object as it changes temperature or during changes in states of matter. You will gain an understanding of how thermal energy transfer is involved in heating and cooling systems, including geothermal systems, and you will explore the environmental and societal impacts of these systems.

STARTING POINTS

Answer the following questions using your current knowledge. You will have a chance to revisit these questions later, applying concepts and skills from the chapter.

1. Define the terms "hot" and "cold" by relating them to the concept of energy that you learned in Chapter 5.
2. What does temperature really tell you about a substance?
3. What happens to the particles of a substance as they change states? How is energy involved in the process?

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Figure 1 Water from beneath Earth's surface erupts in the form of a geyser at temperatures that can exceed 150 °C.

Mini **Investigation**

Will It Pop?

Skills: Predicting, Performing, Observing, Analyzing, Communicating

SKILLS HANDBOOK T/K

Different substances react to thermal energy in different ways. In this experiment you will think about the differences between air and water and the ability of each to absorb thermal energy.

Equipment and Materials: bunsen burner, retort stand, 2 balloons, water

Tie back long hair during the experiment

1. Predict what will happen when a flame is touched to an air-filled balloon, and when a flame is touched to a water-filled balloon.
2. Fill one balloon with water. Do not make it too big, or else it may be difficult to handle. Tie off the water balloon.
3. Blow up the second balloon with air. Try to make it approximately the same size as the water balloon.
4. Clamp a Bunsen burner to a retort stand and light it with a spark lighter.
5. Briefly touch the surface of the air-filled balloon to the flame from the Bunsen burner (a reaction should occur immediately). Write down your observations.
6. While holding the water balloon over a sink or other large container, briefly touch the water-filled balloon to the flame of the Bunsen burner. Do not hold the flame against the balloon; it will react immediately. Extinguish the flame and write down your observations.
7. Pop any balloons that did not break and dispose of all materials in the garbage.

A. Where did the thermal energy from the flame go in the case of the air-filled balloon? Where did the thermal energy of the flame go in the case of the water balloon? Why is there a difference?

B. Comment on the accuracy of your prediction.

[ANS: A. The thermal energy from the flame goes into melting the rubber of the air-filled balloon, so the balloon pops. The water in the water-filled balloon absorbs the thermal energy, so the rubber does not melt and it does not pop. The difference is based on the substance inside the balloon and how it absorbs thermal energy. B. This answer will vary based on the students' personal hypotheses.]

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6.1 Warmth and Coldness

When you dip your toe into a swimming pool to test the warmth of the water before jumping in, or cautiously sip a spoonful of soup to determine if it is too hot to eat, you are using your sense of touch to determine how hot or cold something is. While touch helps us sense large differences in warmth or coldness, small differences can go unnoticed. For example, you might be able to feel the difference in warmth between an egg in the refrigerator and an egg frying in a skillet, but you might not notice the difference an egg in the refrigerator and the same egg left on a kitchen counter for a minute or two. What is the difference between a cold egg and a hot egg? Why is a cold egg cold and a hot egg hot? How can we accurately measure the warmth and coldness of objects?

Warmth and Coldness Are Produced by the Vibrations of Atoms and Molecules

During the eighteenth century, scientists believed that warmth and coldness were produced by a massless fluid known as "caloric." Scientists believed that the amount of this fluid in the universe was constant and that it flowed naturally from warmer objects to colder objects. In 1798, English scientist Benjamin Thompson (known as Count Rumford) conducted investigations showing that caloric did not exist. Count Rumford noticed that when holes were drilled into large, solid iron cylinders used to build cannons, the drilling apparatus and the iron cylinders would become very hot even though both had been lukewarm at the beginning of the process. This seemed to imply that caloric was not flowing from a warmer object to a colder one, but was being created by rubbing two objects together. You might experience the same effect by rubbing the palms of your hands together very rapidly (**Figure 1**).

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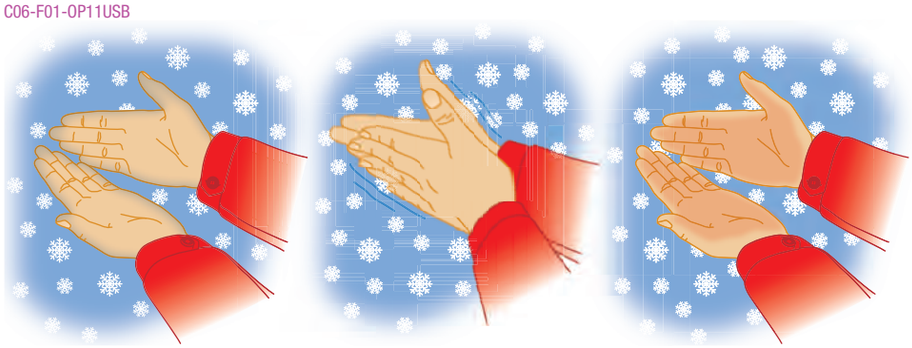

Figure 1 Your bare hands become cold outside in the winter. When you rubs your hands together, they warm up. What causes your hands to become warm?

Up until this time, it was believed that materials could become hotter only if they came into contact with even hotter materials that could transfer caloric to them. Count Rumford's investigations caused scientists to lose confidence in the caloric theory's explanation of why hot objects are hot and cold objects are cold, and how colder objects become warmer and warmer objects become colder. Instead, scientists began to explain warmth and coldness using a theory called the kinetic molecular theory.

kinetic molecular theory (KMT) the theory that describes the motion of molecules or atoms in a substance; in a solid, the particles vibrate around a fixed point; as energy is continuously added, the intensity of the particle movement increases, and the substance changes to a liquid and eventually a gas

The **kinetic molecular theory (KMT)** is based on the idea that matter is composed of particles (atoms and molecules) that attract each other and possess kinetic energy that causes them to be in a state of constant motion. In a solid, such as ice, the particles are held in fixed positions by the forces of attraction between them and vibrate because of the kinetic energy that they possess (**Figure 2(a)**). If a solid is warmed up, the particles remain in fixed positions but begin to vibrate more rapidly. According to the kinetic molecular theory, an increase in the motion of a substance's particles

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makes the substance feel warmer; a decrease in the motion makes the substance feel colder.

In a liquid, such as liquid water, the particles possess more kinetic energy than do those of a solid. This causes the particles to vibrate even more rapidly and also to move from place to place, although not very far from each other. This additional motion gives liquids their ability to flow (**Figure 2(b)**).

The particles of a gas possess more kinetic energy than those of liquids or solids. This causes them to vibrate and move from place to place much farther and more rapidly than the particles of liquids or solids (**Figure 2(c)**).

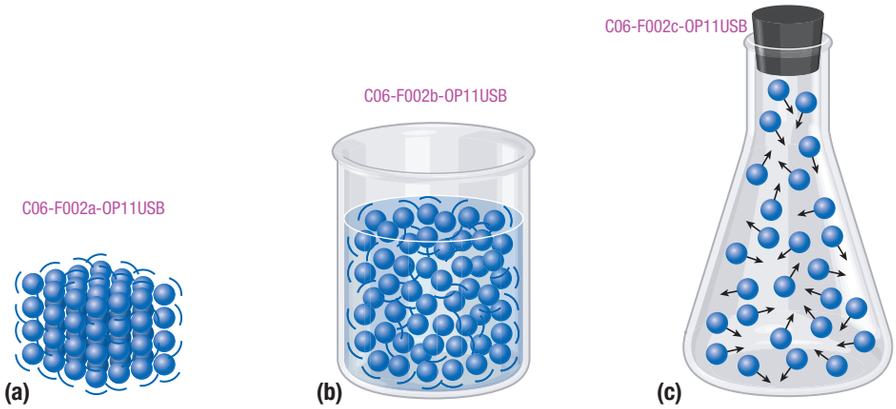

Figure 2 (a) Particles in solids are very close together and can only move back and forth within a very limited range. (b) Particles in liquids are very close together but are able to move and slide past one another. (c) The relatively large spaces between gas particles allow them to move freely past each other.

Thermal Energy

Particles of matter possess many forms of kinetic energy and potential energy. Much of the kinetic energy is associated with the motion of the substance's atoms or molecules while much of the potential energy is associated with the force of attraction between these particles. The total amount of kinetic and potential energy possessed by the particles of a substance is called **thermal energy**.

thermal energy the total quantity of kinetic and potential energy possessed by the atoms or molecules of a substance

In general, the amount of thermal energy possessed by an object determines how fast the object's particles move (vibrate) and, therefore, how hot or cold the object is. When a substance absorbs thermal energy, it warms up; when it loses thermal energy, it cools down. Under certain conditions (to be described later in this chapter), thermal energy can be transferred from a warmer object to a colder object, but not from a colder object to a warmer object. The thermal energy of an object can also be transformed into other forms of energy. Thermal energy, like all other types of energy, is measured using the SI unit of joules.

Temperature and Thermometers

If thermal energy is responsible for the warmth or coldness of an object, then how can we measure the amount of thermal energy that an object possesses? As it turns out, there is no way to measure the total amount of thermal energy in an object, primarily because it is impossible to measure the kinetic energy and potential energy of every particle (atom or molecule) in an object. However, there is a way to measure the kinetic energy component of thermal energy and, in this way, obtain a measurement that indicates how hot or cold an object is.

Temperature is a measure of the average kinetic energy of the particles in a substance. Notice that temperature is a measure of *average* kinetic energy, not total kinetic energy. This is because scientists have found that the particles of an object at a particular temperature possess different amounts of kinetic energy; some particles

temperature a measure of the average kinetic energy of the particles in a substance

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Figure 3 As the particles surrounding the thermometer warm up, they vibrate with greater intensity and bump into the thermometer with greater amounts of energy.

Celsius scale the temperature scale originally based on the boiling point and freezing point of water

Fahrenheit scale the temperature scale originally based on the boiling point and freezing point of brine

Kelvin scale the temperature scale developed using absolute zero as the point at which there is no motion in the particles of a substance

move faster than others. However, the majority of the particles of a warmer object move faster than the majority of the particles of a colder object. Thus, the temperature of a warmer object is higher than the temperature of a colder object. Temperature can be measured in degrees Celsius or kelvins.

Temperature is often measured using a glass-and-mercury or glass-and-alcohol thermometer. These thermometers consist of a narrow, sealed glass tube containing liquid mercury or alcohol. As the temperature of the substance surrounding the thermometer increases, its particles move with greater amounts of kinetic energy, which increases the energy with which the particles bump into the glass of the thermometer. These collisions cause the particles of the glass to vibrate with greater intensity. In turn, the fast-moving particles of the glass tube collide with the slower-moving particles of the mercury or alcohol inside the tube, making these particles move faster as well. The faster-moving particles of the mercury or alcohol take up more space and spread out. This causes the liquid in the thermometer to move higher in the tube and give a higher temperature reading (**Figure 3**).

If the thermometer is placed in a substance that is colder than the thermometer, the glass particles of the thermometer collide with the slower-moving particles of the substance, losing some of their kinetic energy. In turn, the particles of the mercury or alcohol in the thermometer collide with the slower-moving particles of the glass, losing kinetic energy in the process. The slower-moving particles of the mercury or alcohol now move more slowly and take up less space. This causes the liquid in the thermometer to move lower in the tube and give a lower temperature reading.

Temperature Scales

You are familiar with the Celsius scale for temperature: it is used by weather forecasters to report air and water temperatures, and we measure the temperature of our bodies using a Celsius thermometer when we are sick. The **Celsius scale** is named after Anders Celsius, a Swedish scientist who based the scale on the temperature at which water boils and freezes. On the Celsius scale, pure water freezes at 0 °C and boils at 100 °C.

Another commonly used temperature scale is the Fahrenheit scale. The **Fahrenheit scale** was invented by Daniel Gabriel Fahrenheit and is based on the temperature at which a brine solution (salt-water solution) freezes and boils. On the Fahrenheit scale, pure water freezes at 32 °F and boils at 212 °F. Although the Fahrenheit scale is still used in the United States and sometimes in Canada, it is not an SI unit.

Scientists often use the **Kelvin scale**, instead of the Celsius scale, to measure temperature. The Kelvin scale was created by Irish scientist William Thomson, also known as Lord Kelvin. The Kelvin scale is not based on the freezing and boiling points of water, but on the total amount of thermal energy that substances possess. The lowest point on the Kelvin scale, called absolute zero, is the temperature at which the particles of a substance have slowed down so much that they do not move at all. At this point, the kinetic energy of the particles approaches zero. Absolute zero, or 0 K, occurs at −273 °C (**Figure 4**). You can convert from the Kelvin scale to the Celsius scale (and vice versa) using the following conversion equations, where T_C is the temperature in degrees Celsius and T_K is the temperature in kelvins:

$$T_C = T_K - 273$$

$$T_K = T_C + 273$$

In the following Tutorial, you will use these equations to convert a given temperature from one scale to the other.

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Tutorial 1 Converting between Celsius and Kelvin Temperature scales

In the following Sample Problems you will convert degrees Celsius to kelvins, and kelvins to degrees Celsius.

Sample Problem 1

Ethyl alcohol boils at a temperature of 78.3 °C. What is this temperature in kelvins?

Given: $T_C = 78.3$ °C

Required: T_K

Analysis: $T_K = T_C + 273$

Solution: $T_K = T_C + 273$

$= 78.3° + 273$

$T_K = 351\text{K}$

Statement: Ethyl alcohol boils at a temperature of 351 K.

Sample Problem 2

Ethyl alcohol freezes at 159 K. What is this temperature in degrees Celsius?

Given: $T_K = 159$ K

Required: T_C

Analysis: $T_C = T_K - 273$

Solution: $T_C = T_K - 273$

$= 159° - 273$

$T_C = -114$ °C

Statement: Ethyl alcohol freezes at a temperature of −114 °C.

Practice

1. Convert each temperature to kelvins. T/I
   (a) 32 °C [ans: 305 K]
   (b) −10 °C [ans: 263 K]
   (c) 95 °C [ans: 368 K]
   (d) 0 °C [ans: 273 K]
2. Convert each temperature to degrees Celsius. T/I
   (a) 200 K [ans: −73 °C]
   (b) 373 K [ans: 100 °C]
   (c) 298 K [ans: 25 °C]
   (d) 10 K [ans: −263 °C]
3. Copy the table and fill in the missing values.

Table 1 Freezing points of various substance

Substance	Freezing point (°C)	Freezing point (K)
mercury	−38.7	
sea water		271
carbon dioxide		194

[ans: 234 K; −2.00 °C; : −79.0 °C]

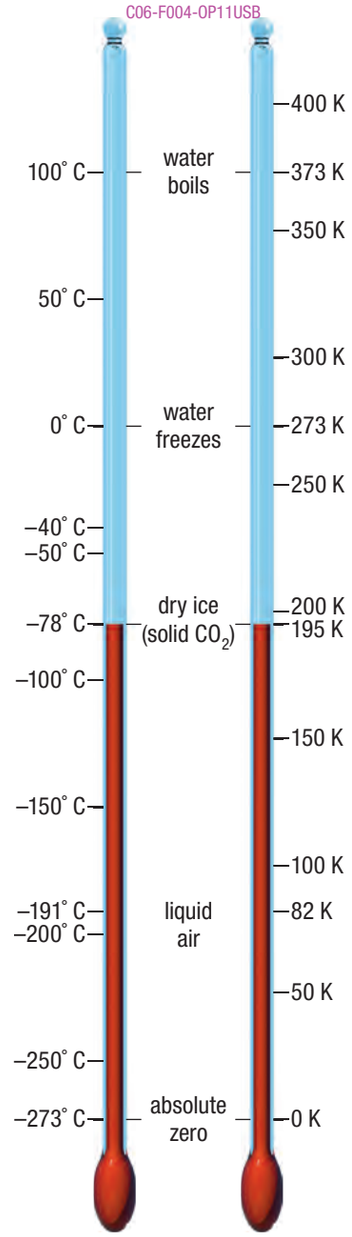

Figure 4 Common values on both the Celsius and Kelvin temperature scales

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Mini **Investigation**

Film Canister Thermometer

Skills: Observing, Analyzing

SKILLS HANDBOOK T/K

In this activity you will construct a film canister thermometer and compare its accuracy with that of a regular thermometer.

Equipment and Materials: thermometer; film canister with hole in its lid; straw; fine-tipped marker; ice water; food colouring; white glue

1. Push the straw through the hole in the lid of the film canister. The straw should be positioned so it is just above the bottom of the canister, but it should not touch the bottom (**Figure 5**).

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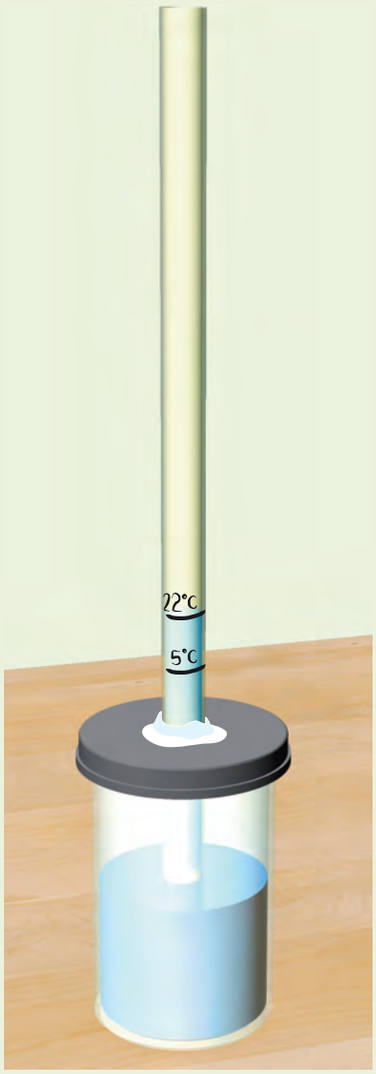

Figure 5 A film canister thermometer

2. Apply glue around the straw where it meets the canister lid to create a seal.
3. Use the regular thermometer to measure the temperature of the ice water.
4. Fill the canister half-full with ice water and add a drop or two of food colouring. Put the lid back on the canister.
5. Use the marker to mark the level of the water on the straw. Label this mark with the temperature of the ice water that you measured in Step 3.
6. Allow the canister thermometer to sit and warm up to room temperature. This can take some time, so you might want to wait overnight. As the canister thermometer warms up, the level of the coloured water in the straw will rise.
7. Find the room temperature using the regular thermometer. Mark this temperature on the straw at the level that the liquid has risen to.
8. Measure the distance between the two marks. Determine the number of degrees Celsius between the marks.
9. Create a scale that allows you to place 1 °C increments on the straw of the canister thermometer.
10. Put some cold water from the tap in a beaker. Use the canister thermometer to measure the temperature of the cold water. Check the reading by comparing it to the temperature you get using the regular thermometer.

A. Discuss the accuracy of this type of thermometer. K/U

B. What might scientific errors in this exercise be attributed to? T/I

C. How practical is the canister thermometer when measuring the temperature of another liquid? A

D. Explain how the canister thermometer works. K/U T/I

see OVERMATTER

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Thermal Energy, Temperature, and Physical State

melting point the temperature at which a solid changes into a liquid; equal to the freezing point for the liquid

freezing point the temperature at which a liquid changes into a solid; equal to the melting point for a given substance

boiling point the temperature at which a liquid changes to a gas; equal to the condensation point for a given substance

condensation point, the temperature at which a gas changes into a liquid; equal to the boiling point for a given substance

Substances increase in temperature (warm up) when they absorb thermal energy and decrease in temperature (cool down) when they lose thermal energy. When thermal energy is absorbed by a solid substance, the solid eventually melts into a liquid. The temperature at which a solid melts into a liquid is called the **melting point**. Conversely, when a liquid is cooled down, there is a temperature called the **freezing point** at which the liquid begins to freeze into a solid. For most substances, the melting point of the solid is the same as the freezing point of the liquid.

If a liquid absorbs enough thermal energy, it eventually changes into a gas. The temperature at which a liquid changes to a gas with the addition of thermal energy is called the **boiling point**. Conversely, when a gas loses thermal energy, it cools down and eventually condenses into a liquid. The temperature at which a gas changes into a liquid with the loss of thermal energy is called the **condensation point**. For most substances, the boiling point of the liquid is the same as the condensation point of the gas.

6.1 Summary

- Thermal energy is the potential and kinetic energy possessed by the randomly moving particles of a substance.
- Temperature is a measure of the average kinetic energy of the particles in a substance.
- The kinetic molecular theory (KMT) explains that as particles of matter move faster, their temperature increases because they gain kinetic energy; similarly, as particles of matter move more slowly, their temperature decreases because they lose kinetic energy.
- A glass-and-mercury thermometer or a glass-and-alcohol thermometer can be used to measure temperature.
- Temperature can be measured using the Celsius, Fahrenheit, or Kelvin scale. Scientists typically use the Celsius and Kelvin scales because they use SI units.
- The equations $T_C = T_K - 273$ and $T_K = T_C + 273$ can be used to convert temperatures from one scale to the other.

6.1 Questions

1. Differentiate between temperature and thermal energy. K/U
2. Describe how the kinetic molecular theory explains the changes of state in substances. K/U
3. How does a mercury or alcohol thermometer work? K/U
4. Copy **Table 2** and fill in the missing values. K/U T/I

Table 2 Boiling points of various substances

Substance	Boiling point (°C)	Boiling point (K)
sodium	882.9	
helium		4.22
copper	2567	
mercury		630

5. Research to find out more about how the caloric theory was disproved.
6. Based on the information you learned in this section, predict whether the statement "previously boiled water boils faster than tap water of the same temperature" is true or false.

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Heat and Heat Capacity

6.2

In Section 6.1 you learned that thermal energy is responsible for an object's warmth or coldness; thermal energy affects an object's temperature. When an object absorbs thermal energy, its temperature rises; when the object loses thermal energy, its temperature falls. This occurs because a large component of the thermal energy of an object is the kinetic energy of its particles. However, the thermal energy of an object not only includes the kinetic energy of its particles but also the potential energy associated with the particles. How do the kinetic energy and potential energy components of thermal energy affect the warmth and coldness (temperature) of objects?

Thermal Energy and Temperature

Since the amount of thermal energy in an object determines the object's temperature, it follows that two identical objects at the same temperature contain the same amount of thermal energy. However, this is only true if the two objects are made of the same substance and have the same mass. For example, two iron nails, both with a mass of 1.0 g and both with a temperature of 22 °C, have the same amount of thermal energy (**Figure 1(a)**). However, if two objects are made of the same substance but their masses are different, then the amount of thermal energy they contain is different (**Figure 1(b)**). For example, if an iron nail with a mass of 1.0 g and an iron nail with a mass of 2.0 g are both at a temperature of 22 °C, they do not have the same amount of thermal energy. The more massive nail has more thermal energy in it than the less massive nail even though both nails have the same temperature.

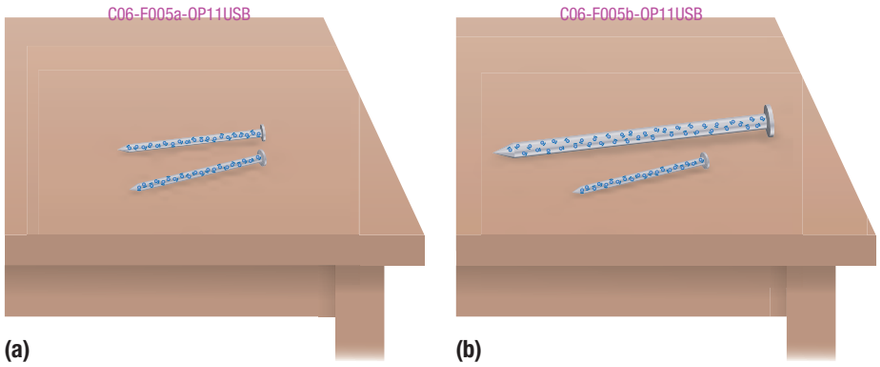

Figure 1 (a) Two 1.0 g iron nails at room temperature (22 °C) have the same amount of thermal energy. (b) A 1.0 g iron nail and a 2.0 g iron nail at the same temperature do not have the same amount of thermal energy. The 2.0 g iron nail has twice as many vibrating iron atoms as the 1.0 g iron nail so it has twice the thermal energy of the 1.0 g nail (even though both nails have the same temperature).

This difference in thermal energy occurs because the more massive nail has more vibrating atoms of iron (twice as many). Since both nails are at the same temperature, their atoms are vibrating with the same average kinetic energy. However, the 2.0 g nail has twice as many vibrating atoms as the 1.0 g nail. Thus, the 2.0 g nail has twice as much *total* kinetic energy (and thermal energy) as the 1.0 g nail.

If two objects have the same mass and the same temperature, but they are made of two different substances, then the amount of thermal energy they contain is different as well. For example, an iron nail with a mass of 1.0 g and a temperature of 22 °C does *not* have the same amount of thermal energy as an aluminum nail with the same mass and temperature. This occurs because (as mentioned earlier) thermal energy includes the kinetic *and* potential energy of a substance's particles. As a substance absorbs energy from its surroundings, part of this energy increases the kinetic energy of the substance's particles (which increases the substance's temperature), and part of the energy increases the potential energy of the particles (which does not increase the substance's temperature). The proportion of the absorbed energy that goes toward increasing the potential energy of the particles is different in different substances.

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Consider any two objects, such as the iron nail and the aluminum nail, that have the same mass and the same temperature but are made of different materials. These two objects likely have different amounts of thermal energy because, while their particles have the same average kinetic energy (their temperature is the same), they do not have the same average potential energy: the two substances have different particles with different forces of attraction between them.

Thermal Energy and Heat

heat to transfer thermal energy from a substance with a higher temperature to a substance with a lower temperature.

While thermal energy is the sum of the potential and kinetic energies possessed by the particles (atoms or molecules) of an object, **heat** is a term used in science to describe the transfer of thermal energy from a warmer object to a colder one. The word "heat" has many meanings in the English language, and it is commonly used to describe what makes objects become warmer. For example, in the phrase, "a teaspoon of hot water has more heat in it than a teaspoon of cold water" the word "heat" is being used in a non-scientific way. In science, we know that thermal energy, not heat, is responsible for an object's warmth or coldness. Thus, we can say "a teaspoon of hot water has more *thermal energy* in it than a teaspoon of cold water."

In most cases (in science) it is preferable to use the word "heat" as a verb, not a noun. For example, in an investigation, you might be asked to use a hot plate *to heat* 250 mL of water to a temperature of 80 °C. This is the same as saying use a hot plate *to transfer thermal energy* to 250 mL of water until the water's temperature reaches 80 °C. Always use the word "heat" to mean the transfer of thermal energy, not the thermal energy itself.

Methods of Transferring Thermal Energy

WEB **LINK**

To learn more about the methods of heat transfer,

GO TO NELSON SCIENCE

Since heat is the transfer of thermal energy from a substance with a higher temperature to a substance with a lower temperature, there must be a method by which thermal energy moves from one object to another. In fact, there are several ways in which thermal energy can be transferred from one object to another. We will discuss three methods: thermal conduction, convection, and radiation.

TRANSFER OF THERMAL ENERGY BY CONDUCTION

thermal conduction the transfer of thermal energy that occurs when warmer objects come into physical contact with colder objects

Thermal energy can move from one substance to another by a process called **thermal conduction** if the substances come into physical contact with each other (if they touch). Thermal conduction occurs when the fast-moving particles of a warmer material collide with the slower-moving particles of a colder material. These collisions cause the slower-moving particles of the colder object to speed up and the faster-moving particles of the warmer object to slow down. As a result, the warmer object cools down (its temperature falls) as the colder object warms up (its temperature rises) (**Figure 2**). Eventually, both objects will be at the same temperature.

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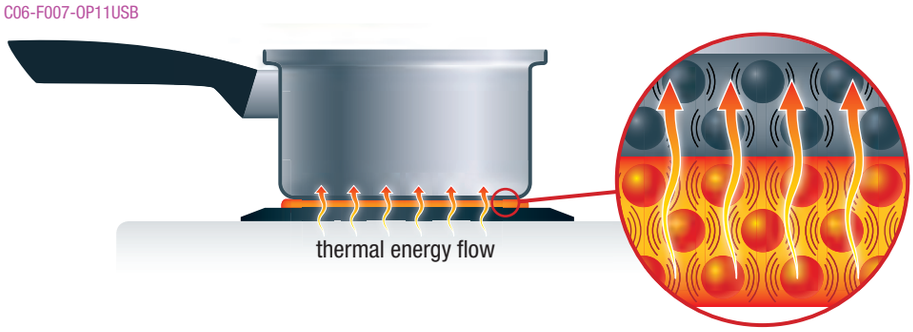

Figure 2 The transfer of thermal energy from an electric stove element to a metal pot.

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You might notice this type of thermal energy transfer if you place a cold metal spoon in a cup of hot chocolate (**Figure 3**). In this case, the fast-moving particles of the hot chocolate collide with the slower-moving particles of the cold teaspoon, transferring thermal energy to them in the process. In turn, the fast-moving particles of the spoon's ladle (the part in the hot chocolate) collide with the slower-moving particles in the spoon's handle, causing the particles in the handle to move faster. Thus, the thermal energy is transferred from the spoon's ladle to the spoon's handle until the thermal energy is evenly distributed throughout the spoon.

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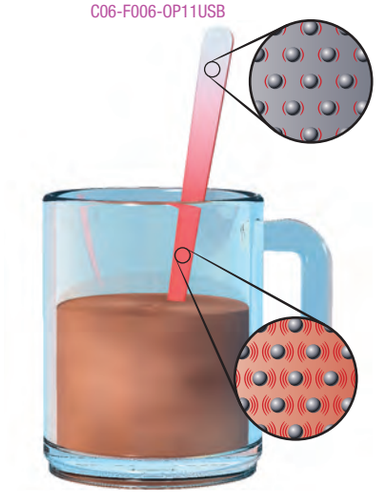

Figure 3 Thermal energy slowly moves up the spoon by conduction as it sits in a hot liquid.

TRANSFER OF THERMAL ENERGY BY CONVECTION

In fluids (liquids and gases), thermal energy can be transferred by convection. **Convection** occurs when colder, denser fluid falls and pushes up less dense, warmer fluid. We can illustrate thermal energy transfer by convection by analyzing the changes that occur in a pot of water that is being heated on a stovetop (**Figure 4**). In this case, when the particles of the liquid nearest to the heat source absorb thermal energy, they move faster and spread farther apart. This means that the water near the bottom of the pot becomes less dense. As a result, the colder, denser water above the warmer water sinks and pushes the warmer, less dense water upward. As the warmer water moves upward and father away from the heat source, it cools down, increases in density, and falls into the warmer, less dense water below. This process repeats itself, resulting in a continuous **convection current** in which colder water moves downward (toward the heat source) and warmer water moves upward (away from the heat source). In this way, thermal energy spreads throughout the liquid in a cooking pot on a stove.

convection the transfer of thermal energy through a fluid (liquid or gas) that occurs when colder, denser fluid falls and pushes up less dense warmer fluid

convection current a current that occurs when a fluid (liquid or gas) is continuously heated by convection; cold fluid constantly pushes up warmer fluid, causing the fluid to circulate

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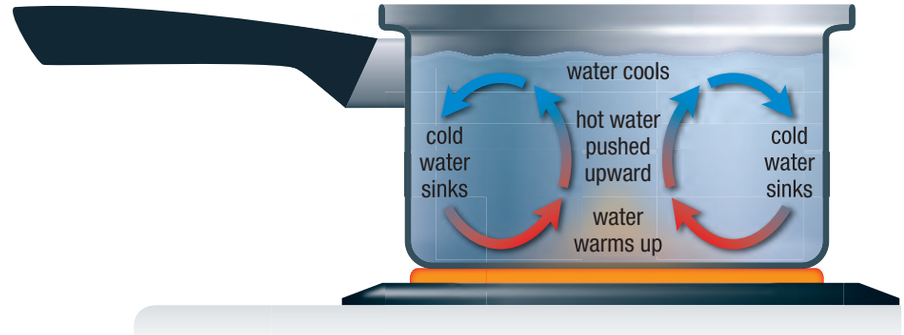

Figure 4 Convection currents cause the liquid in the pot to move around, spreading the thermal energy evenly.

Convection currents can also form in gases such as air, and are responsible for ocean breezes and other winds in the atmosphere. When the Sun's rays strike land, the air immediately above the land warms up and becomes less dense. As a result, colder, heavier air that is higher in the atmosphere falls downward, pushing the warmer air upward (**Figure 5**). This process repeats itself as the Sun continues to warm up the land, setting up continuous convection currents. People on the shore feel part of these currents as winds or breezes that move toward the shore.

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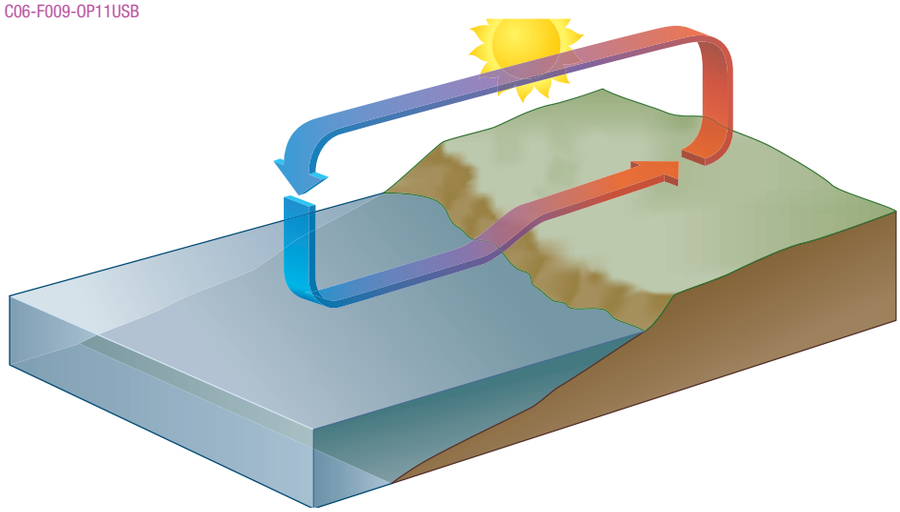

Figure 5 During the day, ocean breezes are created when cool air from above the ocean pushes up on the warm air over the land.

TRANSFER OF THERMAL ENERGY BY RADIATION

Thermal energy can also be transferred from place to place by radiation. Thermal energy is transferred by **radiation** when electromagnetic waves that are emitted from sources such as lamps, flames, and the Sun travel through materials such as air or glass or even through empty space, and interact with matter (**Figure 6**).

radiation the movement of thermal energy as infrared radiation, a type of electromagnetic wave.

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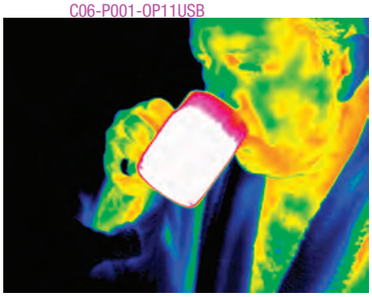

Figure 6 Thermal energy from a campfire radiates in all directions as electromagnetic waves.

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Figure 7 Place the bottle of blue, cold water on top of the bottle of yellow, hot water.

Mini Investigation

Observing Convection

Skills: Performing, Observing, Analyzing

SKILLS HANDBOOK 3.B., 10.

This investigation will allow you to observe convection between warm and cold water.

Equipment and Materials: 4 identical bottles; blue food colouring; yellow food colouring; index card

1. Fill two of the bottles with hot tap water. Add 2 drops of yellow food colouring to each bottle.
2. Fill the other two bottles with cold tap water. Add 2 drops of blue food colouring to each bottles.
3. Use an index card to cover the top of one of the bottles of blue, cold water. Make sure there is a good seal between the card and the bottle, and then flip the bottle over. Place this bottle of blue, cold water on top of one of the bottles of yellow, hot water. Hold onto the top bottle and slide the index card out, making sure the mouths of both bottles stay overlapped (**Figure 7**). Water should not spill out of the bottles if they are properly aligned; water will move back and forth between the bottles.
4. Observe what happens.
5. Repeat the activity, only this time put the bottle of yellow, hot water on top of the bottle of cold, blue water. Observe what happens.

A. Use the concept of convection to explain what you observed when you put the bottle of cold water on top of the bottle of hot water. K/U T/I

B. Explain why your observations were different when you placed the bottle of hot water on top of the bottle of cold water. T/I

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THERMAL CONDUCTORS AND THERMAL INSULATORS

Have you ever touched a metal object and been surprised at how much colder it feels than a non-metal object under the same conditions? For example, a metal sink feels colder than a plastic kitchen countertop even though both are at room temperature. Why does this occur? It occurs because most metals are good conductors of thermal energy while many non-metals are poor conductors of thermal energy. Metals are called **thermal conductors** because they allow thermal energy to pass through them relatively easily and quickly. Thus, when your hand touches a metal sink, thermal energy moves easily and quickly from your hand into the metal sink. This makes the metal sink feel cold. The plastic countertop does not allow thermal energy to pass through it easily, so the thermal energy stays in your hand longer, and the countertop does not feel as cold as the sink. Since metals conduct thermal energy so well, we commonly make pots and pans out of metals so that thermal energy can be transferred easily and quickly from a hot stove or oven into raw food during cooking and baking.

thermal conductor a material that is a good conductor of thermal energy; a metal

Some materials, called **thermal insulators**, do not conduct thermal energy very well. These materials include many types of plastic. You might have noticed that the handles of many pots and pans and other kitchen utensils are made of plastic. The plastic handles prevent thermal energy from moving quickly from the metal pot into your hand. Still air (also called dead air) is also a very good thermal insulator. The atoms and/or molecules in gases such as air are farther apart than the particles in solids and liquids. Thus, gases tend to be poor conductors of thermal energy (good insulators). Animals make good use of this form of thermal insulation. Hair, fur, and feathers trap air between strands of matter (**Figure 8(a)**). The trapped air makes it difficult for thermal energy to move from the external environment into the animal's body or from the animal's body into the external environment (by thermal conduction or convection). Since hair, fur, and feathers help prevent the transfer of thermal energy, they are good thermal insulators.

thermal insulator a material that is a poor conductor of thermal energy; some types of plastic and glass

A good way to add thermal insulation to the walls of a house is by placing fibreglass batting (**Figure 8(b)**) or sheets of plastic foam (**Figure 8(c)**) in the wall spaces. Both of these materials contain trapped air that makes it difficult for thermal energy to pass from the outside environment into the house or from inside the house into the external environment. Understanding which materials reduce the transfer of thermal energy can help people develop better building materials. New programs such as R-2000 and LEED (Leadership in Energy and Environmental Design) focus on helping Canadians create more energy efficient homes by promoting the use of effective thermal insulation.

WEB LINK

To learn more about the R-2000 and LEED programs, go to

GO TO NELSON SCIENCE

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(a)

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(b)

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(c)

Figure 8 Thermal insulators include (a) fur, (b) fibreglass, and (c) plastic foam. All of these materials trap air and help to prevent the movement of thermal energy in and out of an environment or an object.

The best thermal insulator of all is empty space, or vacuum. A vacuum contains no particles or very few particles. Thus, thermal energy cannot be transferred by conduction or convection. A Thermos bottle (**Figure 9**) is an example of a device used to keep hot materials hot and cold materials cold by having a vacuum between an inner flask and an outer flask (usually made of glass). The inner glass flask is usually coated with a shiny, mirror-like layer to reflect any thermal energy that is transferred by radiation.

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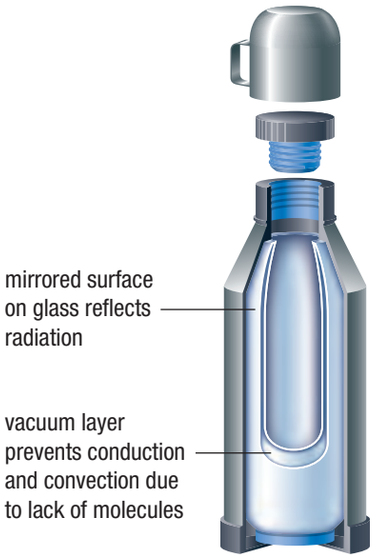

Figure 9 The layers of a Thermos bottle stop conduction, convection, and radiation of thermal energy, keeping the contents cool or hot.

Thermal Energy Transformations

Furnaces, car engines, and incandescent lamps are all devices that transform one form of energy into another. For example, the internal combustion engine of a car is designed to transform the chemical energy in gasoline (input energy) into kinetic energy and thermal energy (output energies). The kinetic energy moves the car and the thermal energy is transferred to the environment. Although some of the thermal energy may be used to heat the interior of the car in cold weather, most of the thermal energy is considered waste since it does not contribute to the car's motion. Thus, scientists and engineers try to design energy efficient devices—devices that transform as much input energy as possible into desired output energy.

THERMAL ENERGY TRANSFORMATION EFFICIENCY

The internal combustion engine is a device in which we would like to maximize the kinetic energy output and minimize the thermal energy output. However, in other devices, we would like to maximize the thermal energy output. For example, a furnace is used to heat a home or other building. In most furnaces, electrical energy or the chemical energy in fossil fuels (natural gas, propane, or oil) is the input energy and thermal energy is the desired output energy. A high efficiency furnace is one that transforms a relatively small amount of input energy into a relatively large amount of thermal energy. An electric furnace is essentially 100 % efficient, meaning that virtually all of the input electrical energy is transformed into thermal energy. The most efficient high natural gas furnaces are approximately 96 % efficient while older, less efficient versions are about 60 % efficient.

Specific Heat Capacity (*c*)

specific heat capacity (*c*) the amount of energy, in joules, required to increase the temperature of 1 kg of a substance by 1 °C; units are J/(kg • °C)

Every substance requires a particular amount of energy to heat up by the same amount. For example, it takes more energy to increase the temperature of 1.0 kg of water by 1 °C than it takes to increase the temperature of 1.0 kg of vegetable oil by 1 °C. The amount of energy needed to raise the temperature of 1 kg of a substance by 1 °C is called the substance's **specific heat capacity (*c*)**.

The specific heat capacity of water is 4.18×10^3 J/(kg · °C), which is high in comparison with many other common liquids. The specific heat capacity of water indicates that it takes 4.18×10^3 J of energy to raise the temperature of 1 kg of water by 1 °C. Vegetable oil has a specific heat capacity of 2.0×10^3 J/(kg · °C), indicating that it takes approximately half as much energy to heat up 1 kg of vegetable oil by 1 °C than it takes to heat up 1 kg of water by 1 °C. So, a pot containing 1 kg of water at 10 °C uses a little more than twice as much energy to reach 100 °C as a pot containing 1 kg of vegetable oil at 10 °C. This difference is because water and vegetable oil are composed of different types of molecules. Different molecules require different amounts of energy to increase their kinetic energies by the same amount. Specific heat capacity also represents how much thermal energy is released when a substance cools down by 1 °C. **Table 1** gives the specific heat capacities of some common substances.

Table 1 Specific heat capacities of common substances

Substance	Specific heat capacity (J/(kg • °C))
water	4.18×10^3
ethyl alcohol	2.46×10^3
ice	2.1×10^3
aluminum	9.2×10^2
glass	8.4×10^2
iron	4.5×10^2
copper	3.8×10^2
silver	2.4×10^2
lead	1.3×10^2

Quantity of Heat (*Q*)

quantity of heat (*Q*) the amount of thermal energy transferred from one object to another

The total amount of thermal energy transferred from a warmer substance to a colder substance is called the **quantity of heat (*Q*)**. A quantity of heat calculation takes into account the mass (m) of the substance, the specific heat capacity (c) of the substance, and the change in the temperature (ΔT) that the substance undergoes as it heats up or cools down. The quantity of heat is measured in joules and can be calculated using the equation

$$Q = mc\Delta T$$

In this equation, Q is the quantity of heat in joules, m is the mass of the object in kilograms, c is the specific heat capacity of the substance the object is made of in

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joules per kilogram per degree Celsius, and ΔT is the change in temperature that occurs as the object absorbs or releases thermal energy in degrees Celsius. The change in temperature, ΔT, is calculated by subtracting the object's initial temperature (T_1) from its final temperature (T_2) as follows:

$$\Delta T = T_2 - T_1$$

Note that if an object absorbs energy, its final temperature is greater than its initial temperature, and the value of ΔT is positive. However, if an object loses thermal energy, its final temperature is lower than its initial temperature, and the value of ΔT is negative. The following tutorial demonstrates how to use the quantity of heat equation to calculate the amount of thermal energy lost or gained by an object. The tutorial also shows how you can use the quantity of heat equation to calculate the mass of an object or the specific heat capacity of an unknown object.

Tutorial 1 quantity of heat Calculations

The equation $Q = mc\Delta T$ can be used to calculate the quantity of thermal energy gained or lost by an object.

Sample Problem 1

When 200.0 mL of water is heated from 15.0 °C to 40.0 °C, how much thermal energy is gained by the water?

Since the quantity of heat equation is based on the mass of an object, we must first determine the mass, in kilograms, of 200.0 mL of water. To do this, we use the density of water, which is 1.0 g/mL. We then calculate the change in the temperature of the water using the equation $\Delta T = T_2 - T_1$. Finally, we use the quantity of heat equation, $Q = mc\Delta T$, along with the mass of the water, m, the specific heat capacity of water, c, and the change in temperature of the water, ΔT.

Given: $v = 200.0$ mL; $T_1 = 15.0$ °C; $T_2 = 40.0$ °C; $c = 4.18 \times 10^3$ J/(kg · °C).

Required: ΔT, change in temperature; Q, quantity of heat

Analysis: $\Delta T = T_2 - T_1$; $Q = mc\Delta T$

Solution:

$$m = 200.0\ \cancel{\text{mL}} \times \frac{1\ \cancel{\text{g}}}{1\ \cancel{\text{mL}}} \times \frac{1\ \text{kg}}{1000\ \cancel{\text{g}}}$$

$$= 0.2000\ \text{kg}$$

$$\Delta T = T_2 - T_1$$

$$= 40.0\ °\text{C} - 15.0\ °\text{C}$$

$$\Delta T = 25.0\ °\text{C}$$

Now that we have calculated the change in temperature, we can use that value to calculate the quantity of heat:

$$Q = mc\Delta T$$

$$= (0.2000\ \text{kg})\left(4.18 \times 10^3\ \frac{\text{J}}{\text{kg} \cdot °\text{C}}\right)(25\ °\text{C})$$

$$= 2.09 \times 10^4\ \text{J}$$

Statement: The water gains 2.09 × 104 J of thermal energy.

Sample Problem 2

An empty copper pot is sitting on a burner. The pot has a mass of 1.2 kg and is at a temperature of 130.0 °C. If the pot cools to a room temperature of 21.0 °C, how much thermal energy does it lose?

By looking back at Table 1 on page xxx, we can determine that the specific heat capacity of copper is 3.8×10^2 J/(kg · °C). As in Sample Problem 1, we need to find the

LEARNING TIP

Quantity of Heat Can Be Positive or Negative

When you calculate the thermal energy gained by a substance that gets warmer, ΔT is a positive value, so the quantity of heat (Q) is also positive.

If the substance loses thermal energy (cools down), then ΔT is negative, and so is the value for quantity of heat, Q. It is important to subtract the initial temperature (T_1) from the final temperature (T_2) when calculating the change in temperature, ΔT. If you reverse the operation, you will not get the correct value for ΔT!

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LEARNING **TIP**

Mass Must Be in Kilograms When Using the Quantity of Heat Equation
Because the units for specific heat capacity are joules per kilogram per degree Celsius, mass must be expressed in kilograms when using the quantity of heat equation.

change in temperature before calculating the quantity of thermal energy lost by the pot using the quantity of heat equation.

Given: $m = 1.2\ \text{kg}$; $T_1 = 130.0\ °\text{C}$; $T_2 = 21.0\ °\text{C}$; $c = 3.8 \times 10^2\ \text{J/(kg} \cdot °\text{C)}$.

Required: ΔT, change in temperature; Q, quantity of heat

Analysis: $\Delta T = T_2 - T_1$; $Q = mc\Delta T$

Solution:

$$\begin{aligned} \Delta T &= T_2 - T_1 \\ &= 21.0\ °\text{C} - 130.0\ °\text{C} \\ \Delta T &= -109.0\ °\text{C} \\ Q &= mc\Delta T \\ &= (1.2\ \cancel{\text{kg}})\left(3.8 \times 10^2\ \frac{\text{J}}{\cancel{\text{kg}} \cdot \cancel{°\text{C}}}\right)(-109.0\ \cancel{°\text{C}}) \\ &= -5.0 \times 10^4\ \text{J} \end{aligned}$$

Statement: The copper pan looses 5.0×10^4 J of thermal energy as it cools to 21.0 °C.

Sample Problem 3

A block of iron with an unknown mass starts off at a room temperature of 22.0 °C. It is heated to a temperature of 100.0 °C by placing it in boiling water. The quantity of thermal energy required for this temperature change to occur is 4.91×10^5 J. Calculate the mass of the iron block.

By looking at **Table 1** on page xxx, we can determine that the specific heat capacity of iron is $4.5 \times 10^2\ \text{J/(kg} \cdot °\text{C)}$. As in Sample Problems 1 and 2, we need to find the change in temperature before we can calculate the mass of the iron block using the quantity of heat equation.

Given: $T_1 = 22.0\ °\text{C}$; $T_2 = 100.0\ °\text{C}$; $c = 4.5 \times 10^2\ \text{J/(kg} \cdot °\text{C)}$, $Q = 4.91 \times 10^5$ J

Required: ΔT, change in temperature; m, mass of iron

Analysis: $\Delta T = T_2 - T_1$; $Q = mc\Delta T$

Solution:

$$\begin{aligned} \Delta T &= T_2 - T_1; \\ &= 100.0\ °\text{C} - 22.0\ °\text{C} \\ &= 78.0\ °\text{C} \end{aligned}$$

Rearrange the quantity of heat equation to solve for mass:

$$\begin{aligned} Q &= mc\Delta T \\ m &= \frac{Q}{c\Delta T} \\ m &= \frac{4.91 \times 10^5\ \cancel{\text{J}}}{\left(4.5 \times 10^2\ \frac{\cancel{\text{J}}}{\text{kg} \cdot \cancel{°\text{C}}}\right)(78.0\ \cancel{°\text{C}})} \\ m &= 14\ \text{kg} \end{aligned}$$

Statement: The iron block has a mass of 14 kg.

Practice

1. How much thermal energy is required to raise the temperature of 2.0 kg of water by 10.0 °C? T/I [ans: 8.4×10^4 J]
2. A glass window with a mass of 20.0 kg is heated to a temperature of 32.0 °C by the Sun. How much thermal energy is lost by the window as it cools to 5.0 °C at night? T/I [ans: -4.5×10^5 J]
3. 1.0×10^4 J of energy is gained by an aluminum block as the Sun raises its temperature by 5.0 °C. What is the mass of the block? T/I [ans: 2.2 kg]

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The Principle of Thermal Energy Exchange

The **principle of thermal energy exchange** states that when a warmer object comes in contact with a colder object, thermal energy is transferred from the warmer object (the object with the higher temperature) to the colder object (the object with the lower temperature) until all of the thermal energy is evenly distributed in both objects (a constant temperature is reached) (**Figure 10**). If you use the quantity of heat equation to calculate the thermal energy lost by the warmer object (Q_{lost}) and the thermal energy gained by the colder object (Q_{gained}), the two values are equal in magnitude but opposite in sign; Q_{lost} is a negative value since ΔT is negative, and Q_{gained} is a positive value since ΔT is positive. Considering the law of conservation of energy, this makes sense; thermal energy, like all other forms of energy, cannot be destroyed; it can only be transferred from one place or object to another or transformed into other forms of energy. In this case, the thermal energy is simply transferred from a warmer object to a colder object.

This, of course, assumes that the thermal energy remains in the system (in one of the two objects being studied) and none is lost to the surroundings. Practically, we must realize that in most circumstances some thermal energy will be lost to the surrounding air, container, or surfaces.

Mathematically, Q_{lost} and Q_{gained} should add to zero, since they represent equal amounts, but have opposite signs:

$$Q_{lost} + Q_{gained} = 0$$

The following tutorial demonstrates how the quantity of heat equation and the principle of thermal energy exchange can be used to calculate the specific heat capacities, masses, or temperatures of various substances and objects.

principle of thermal energy exchange the property that when thermal energy is transferred from a warmer object to a colder object, the amount of thermal energy lost by the warmer object is equal to the amount of thermal energy gained by the colder object

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Figure 10 Thermal energy flows from substances with higher temperatures to substances with lower temperatures. In this photo, thermal energy moves from the liquid water (higher temperature) to the ice (lower temperature). This causes the liquid water to cool down and the ice to warm up. Eventually, the water will have the same temperature everywhere.

Tutorial 2 Using the Principle of Thermal Energy Exchange to Determine Mass, Temperature, and Specific Heat Capacity

By mathematically combining the quantity of heat equation, $Q = mc\Delta T$, with the principle of thermal energy exchange, $Q_{lost} + Q_{gained} = 0$, we can calculate the specific heat capacity, mass, or temperature of a substance.

Sample Problem 1

A 60.0 g sample of an unknown metal is heated to a temperature of 100.0 °C before being placed in 200.0 mL of water with an initial temperature of 10.0 °C. The metal-water combination reaches a final temperature of 15.6 °C. Identify the metal using its specific heat capacity and the values of specific heat capacity provided in **Table 1** on page xxx.

In this situation, the metal loses thermal energy and the water gains thermal energy. Use the data given to calculate the specific heat capacity, and then use the values of specific heat capacity in **Table 1** to identify the metal.

Given: We will use the subscripts "m" for metal and "w" for water and let v_w represent the volume of the water.

Metal: $m_m = 60.0$ g; $T_{1m} = 100.0$ °C; $T_{2m} = 15.6$ °C

Water: $v_w = 200.0$ mL; $T_{1w} = 10.0$ °C; $T_{2w} = 15.6$ °C; $c_w = 4.18 \times 10^3$ J/(kg · °C)

Required: c_m, specific heat capacity of the metal

Analysis: $Q_{lost} + Q_{gained} = 0$; $Q = mc\Delta T$

Solution: Since the quantity of heat equation is based on the mass of a substance, we must first calculate the mass of water, m_w, in kilograms, using the volume of water, v_w, provided.

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$$m_w = 200.0\ \cancel{mL} \times \frac{1\ \cancel{g}}{1\ \cancel{mL}} \times \frac{1\ kg}{1000\ \cancel{g}}$$
$$= 0.2000\ kg$$

The specific heat capacity of the metal, c_m, can be calculated by mathematically combining the quantity of heat equation, $Q = mc\Delta T$, and the principle of thermal energy exchange equation, $Q_{lost} + Q_{gained} = 0$, as follows. Substitute $Q = mc\Delta T$ for both the metal and the water into $Q_{lost} + Q_{gained} = 0$:

$$m_m c_m \Delta T_m + m_w c_w \Delta T_w = 0$$
$$(0.0600\ kg)(c_m)(15.6\ °C - 100\ °C) + (0.2000\ kg)\left(4.18 \times 10^3 \frac{J}{kg \cdot °C}\right)(15.6\ °C - 10.0\ °C) = 0$$
$$(0.0600\ kg)(c_m)(-84.4\ °C) + (0.2000\ \cancel{kg})\left(4.18 \times 10^3 \frac{J}{\cancel{kg} \cdot \cancel{°C}}\right)(5.6\ \cancel{°C}) = 0$$
$$(-5.064\ kg \cdot °C)(c_m) + 4681.6\ J = 0 \text{ (two extra digits carried)}$$
$$(-5.064\ kg \cdot °C)(c_m) = -4681.6\ J$$
$$c_m = \frac{-4681.6\ J}{-5.064\ kg \cdot °C}$$
$$c_m = 9.24 \times 10^2\ J/(kg \cdot °C)$$

Statement: The specific heat capacity of the metal is 9.24×10^2 J/(kg · °C), so it must be aluminum.

Sample Problem 2

A sample of iron is heated to 80.0 °C and placed in 100.0 mL of 20.0 °C water. The final temperature of the mixture is 22.0 °C. What is the mass of the iron?

Find the heat capacities of the substances in Table 1, decide which substances gain and lose heat, and then use the combined quantity of heat and principle of thermal energy exchange equation to calculate the mass of the iron.

Given: Iron: $T_{1i} = 80.0$ °C; $T_{2i} = 22$ °C; $c_i = 4.5 \times 10^2$ J/(kg · °C)

Water: $m_w = 100.0$ mL $= 100.0$ g $= 0.1000$ kg; $T_{1w} = 20.0$ °C; $T_{2w} = 22$ °C; $c_w = 4.18 \times 10^3$ J/(kg · °C)

Required: m_i, mass of the iron

Analysis: $Q_{lost} + Q_{gained} = 0$; $Q = mc\Delta T$

Solution:

$$Q_{lost} + Q_{gained} = 0$$
$$m_i c_i \Delta T_i + m_w c_w \Delta T_w = 0$$
$$(m_i)\left(4.5 \times 10^2 \frac{J}{kg \cdot °C}\right)(22.0\ °C - 80.0\ °C) + (0.1000\ kg)\left(4.18 \times 10^3 \frac{J}{kg \cdot °C}\right)(22.0\ °C - 20.0\ °C) = 0$$
$$(m_i)\left(4.5 \times 10^2 \frac{J}{kg \cdot \cancel{°C}}\right)(-58.0\ \cancel{°C}) + (0.1000\ \cancel{kg})\left(4.18 \times 10^3 \frac{J}{\cancel{kg} \cdot \cancel{°C}}\right)(2\ \cancel{°C}) = 0$$
$$(m_i)\left(-2.61 \times 10^4 \frac{J}{kg}\right) + 8.36 \times 10^2\ J = 0$$

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$$(m_i)\left(-2.61 \times 10^4 \frac{\text{J}}{\text{kg}}\right) = -8.36 \times 10^2 \text{ J}$$

$$m_i = \frac{-8.36 \times 10^2 \text{ J}}{\left(-2.61 \times 10^4 \frac{\text{J}}{\text{kg}}\right)}$$

$$m_i = 3.20 \times 10^{-2} \text{ kg}$$

Statement: The mass of the iron is 3.2×10^{-2} kg.

Sample Problem 3

During an investigation, 200.0 g of silver is heated to a temperature of 90.0 °C. The hot silver is moved into 300.0 g of ethyl alcohol that has a temperature of 5.0 °C. Determine the final temperature of the silver-alcohol mixture.

Given: silver: $m_s = 200.0 \text{ g} = 0.2000 \text{ kg}$; $T_{1s} = 90.0 \text{ °C}$; $c_s = 2.4 \times 10^2 \text{ J/(kg} \cdot \text{°C)}$

ethyl alcohol: $m_a = 300.0 \text{ g} = 0.3000 \text{ kg}$; $T_{1a} = 5.0 \text{ °C}$; $c_a = 2.46 \times 10^3 \text{ J/(kg} \cdot \text{°C)}$

Required: T_2, final temperature of the silver-ethyl alcohol mixture

Analysis: $Q_{lost} + Q_{gained} = 0$; $Q = mc\Delta T$

Solution:

$$Q_{lost} + Q_{gained} = 0$$

$$m_s c_s \Delta T_s + m_a c_a \Delta T_a = 0$$

$$(0.2000 \text{ kg})\left(2.4 \times 10^2 \frac{\text{J}}{\text{kg} \cdot \text{°C}}\right)(T_2 - 90.0 \text{ °C})$$

$$+ (0.3000 \text{ kg})\left(2.46 \times 10^3 \frac{\text{J}}{\text{kg} \cdot \text{°C}}\right)(T_2 - 5.0 \text{ °C}) = 0$$

$$\left(48 \frac{\text{J}}{\text{°C}}\right)(T_2 - 90.0 \text{ °C}) + \left(738 \frac{\text{J}}{\text{°C}}\right)(T_2 - 5.0 \text{ °C}) = 0$$

$$\left(48 \frac{\text{J}}{\text{°C}}\right)T_2 - 4320 \text{ J} + \left(738 \frac{\text{J}}{\text{°C}}\right)T_2 - 3690 \text{ J} = 0$$

$$\left(786 \frac{\text{J}}{\text{°C}}\right)T_2 - 8010 \text{ J} = 0$$

$$\left(786 \frac{\text{J}}{\text{°C}}\right)T_2 = 8010 \text{ J}$$

$$T_2 = \frac{8010 \text{ J}}{786 \frac{\text{J}}{\text{°C}}}$$

$$T_2 = 1.0 \times 10^1 \text{ °C}$$

Statement: The final temperature of the ethyl alcohol-silver mixture is 1.0×10^1 °C.

Practice

1. A gold-coloured bar with a mass of 4.0 kg is placed in boiling water until its temperature stabilizes at 100.0 °C. The bar is then immersed in 500.0 mL of water with an initial temperature of 20.0 °C. The mixture reaches a temperature of 35.0 °C. What is the specific heat capacity of the gold-coloured bar? T/I [ans: 1.2×10^2 J/(kg · °C)]
2. Clifford places a 1.13 kg copper bar that is at 92.0 °C in a container of water with an initial temperature of 20.8 °C. If the final temperature is 26.0 °C, what volume of water was used? T/I [ans: 1.3 L]
3. Sun-Young places a 2.0 kg block of aluminum that had been heated to 100.0 °C in 1.5 kg of ethyl alcohol with an initial temperature of 18.0 °C. What is the final temperature of the mixture? T/I [ans: 45 °C]

Investigation 6.2.1

Specific Heat Capacity of Brass

In this investigation you will use the equations $Q = mc\Delta T$ and $Q_{lost} + Q_{gained} = 0$ to calculate the specific heat capacity in a laboratory setting.

see OVERMATTER

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THERMAL EXPANSION AND CONTRACTION

As a substance gains thermal energy, its particles gain kinetic energy, spread out, and increase in volume. The increase in an object's volume due to an increase in its temperature is called **thermal expansion**.

thermal expansion the expansion of a substance as it heats up

An understanding of thermal expansion is important to engineers designing building materials. For example, metal-framed windows require rubber spacers to accommodate any changes in size brought about by changes in temperature. Bridges require special joints called expansion joints to prevent pressure from bending the metal components of the bridge on hot summer days (**Figure 11(a)**), and concrete sidewalks have spaces between the slabs to make room for expansion that occurs as temperatures rise (**Figure 11(b)**).

Likewise, when substances cool down, their particles lose kinetic energy and the substance decreases in volume, resulting in **thermal contraction**. All substances that expand in warmer weather contract during colder weather. Engineers must keep this in mind.

thermal contraction the contraction of a substance when it cools down

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Figure 11 (a) Bridges include expansion joints, areas where space is left to allow expansion in hot temperatures and contraction during cold temperatures. (b) Likewise, space must be left between concrete slabs to keep sidewalks from cracking when they expand in the heat and contract in the cold.

6.2 Summary

- Thermal energy includes the kinetic energy of the particles in a substance, the number of particles, and the chemical makeup of the substance.
- Heat is the transfer of thermal energy from a warmer object to a cooler one.
- Thermal energy can be transferred in three different ways: thermal conduction, convection, and radiation.
- Specific heat capacity is the amount of heat needed to raise the temperature of a 1 kg sample of a substance by 1 °C.
- The quantity of heat, or amount of thermal energy gained or lost by an object, can be calculate using the equation $Q = mc\Delta T$.
- The principle of heat exchange states that thermal energy moves from a warm object to a cooler one until they reach the same temperature. This can be demonstrated by the equation $Q_{lost} + Q_{gained} = 0$.
- The gain or loss of thermal energy results in thermal expansion or contraction.

see OVERMATTER

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6.2 Questions

1. Differentiate between thermal energy, temperature, and heat. K/U
2. Describe thermal conduction, convection, and radiation. Be sure to include the type of particles involved in each type of thermal energy transfer. K/U
3. What is specific heat capacity? What does it tell you? K/U
4. Find the amount of thermal energy required for 25.0 g of silver to change from 50.0 °C to 80.0 °C. K/U T/I
5. Find the amount of thermal energy lost when 260.0 g of ice cools from −2.0 °C to −20.0 °C. K/U T/I
6. A 50.0 g sample of metal loses 1520 J of thermal energy when it starts at a temperature of 100.0 °C and ends up at a temperature of 20.0 °C. What is the metal? K/U T/I
7. A 60.0 g sample of calcium has a specific heat capacity of 6.3×10^2 J/(kg · °C). Find its final temperature if it starts at 10.0 °C and gains 302 J of thermal energy. K/U T/I
8. A 170.0 g sample of an unknown substance is heated to 120.0 °C and then plunged into 200.0 mL of 10.0 °C water. The resulting mixture has a temperature of 12.6 °C. What is the specific heat capacity of the unknown substance? K/U T/I
9. An unknown amount of pure gold is heated to 95.0 °C. The specific heat capacity of gold is 1.29×10^2 J/(kg · °C). The gold is placed into 500.0 mL of ethyl alcohol at a temperature of 25.0 °C. The final temperature of the mixture is 27.0 °C. What is the mass of the gold bar? K/U T/I
10. Danielle cools a 2.0 kg metal object to a temperature of −25.0 °C. She places the metal in 3.0 L of pure water with a temperature of 40.0 °C. The final temperature of the mixture is 36.0 °C. What is the specific heat capacity of the metal? K/U T/I
11. When you mix 100.0 g of a liquid at 100.0 °C with 90.0 mL of water at 15.0 °C, the mixture reaches a final temperature of 45.0 °C. What is the specific heat capacity of the liquid? K/U T/I
12. A 1.50×10^2 g piece of brass (specific heat capacity 3.80×10^2 J/(kg · °C)) is submerged in 400.0 mL of 27.7 °C water. What is the original temperature of the brass if the combination has a temperature of 28.0 °C? K/U T/I
13. Explain how temperature changes are important for contractors and engineers to consider while building structures. K/U A
14. Research more about thermal expansion and contraction and how it is dealt with in the design of homes, schools, or other structures. Pick one innovation related to this topic and write a brief report. K/U C A

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6.3 States of Matter and Changes of State

Glaciers are huge masses of ice and snow that once covered most of Earth's surface. Many of the world's glaciers are retreating. This means that they are getting smaller with time. The Athabasca glacier near Banff, Alberta, has retreated over 1.5 km in the last 120 years (**Figure 1(a)**)! Scientists believe that global warming is responsible for the retreat of the glaciers. Warm temperatures cause the ice and snow of a glacier to melt into liquid water (**Figure 1(b)**). The liquid water flows away from the glacier, forming rivers, lakes, and streams that make their way to the oceans. If the molten ice is not replaced by new snowfall, the glacier will recede. Water in all its forms is important to the existence of glaciers.

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Figure 1 (a) This photo, taken in 2005, shows how far the Athabasca glacier has retreated since 1992, which is about 200 m. (b) Glacier ice melting into liquid water

States of Matter

Water, and all other forms of matter, can exist in three different physical states, or phases: solid, liquid, and gas. The kinetic molecular theory described in Section 6.1 explains the differences between these physical states. In a solid, strong forces of attraction (bonds) hold the particles in fixed positions. The particles of a solid vibrate, but they cannot easily slide past each other or move from place to place. This gives solids their rigidity and allows them to maintain their shape. The particles of a liquid are also attracted to each other. However, in liquids, the particles have more kinetic energy than the particles of a solid. This causes the liquid's particles to vibrate more vigorously than the particles of a solid, and also to slide and tumble past each other and move from place to place. This gives liquids the ability to flow and pour. Like solids and liquids, the particles of a gas are attracted to each other. However, gas particles have much more kinetic energy than the particles of solids and liquids. The particles of a gas vibrate more vigorously than the particles of solids and liquids, and they move large distances past each other. This gives gases their ability to flow and to fill expandable containers like balloons and tires with great pressure

Changes of State

When solids, liquids, or gases absorb or release enough thermal energy, they may change state (**Figure 2**). For example, a solid can change into a liquid and a liquid can change into a gas. When a substance absorbs thermal energy, the particles of the substance begin to move faster (their kinetic energy increases) and farther apart (their potential energy increases). Note that the thermal energy is not really "absorbed"; it is transformed into kinetic energy and potential energy of the substance's particles. Remember that energy is always conserved. It can be changed from one form into another (transformed), but it cannot disappear or be destroyed.

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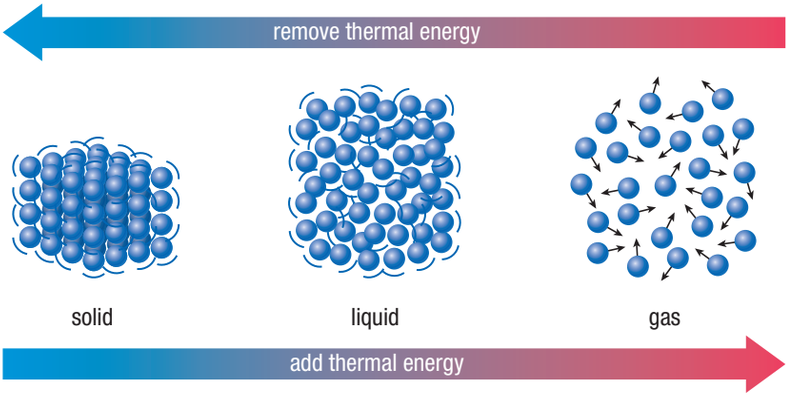

Figure 2 [TO COME]

Let us consider what happens to ice when it is continuously heated (**Figure 3**):

When the ice is placed on the hot plate it is at a temperature of −10 °C (**Figure 3(a)**). As the ice absorbs thermal energy, its particles begin to vibrate more vigorously. This warms up the ice and increases its temperature. As the particles absorb more thermal energy, the forces of attraction become less effective at holding the particles in fixed positions. Eventually, the solid reaches its melting point, where the particles begin to slide past each other and move from place to place. At this point, the solid begins to change into a liquid. The melting point of water is 0 °C (**Figure 3(b)**). This change of state is called melting, or **fusion**. Eventually, all of the ice becomes liquid water (**Figure 3(c)**). Notice that thermal energy continues to be absorbed during the melting process, but the temperature does not change—it remains at 0 °C until the last crystal of ice has melted into liquid water.

fusion the process by which a solid changes to a liquid

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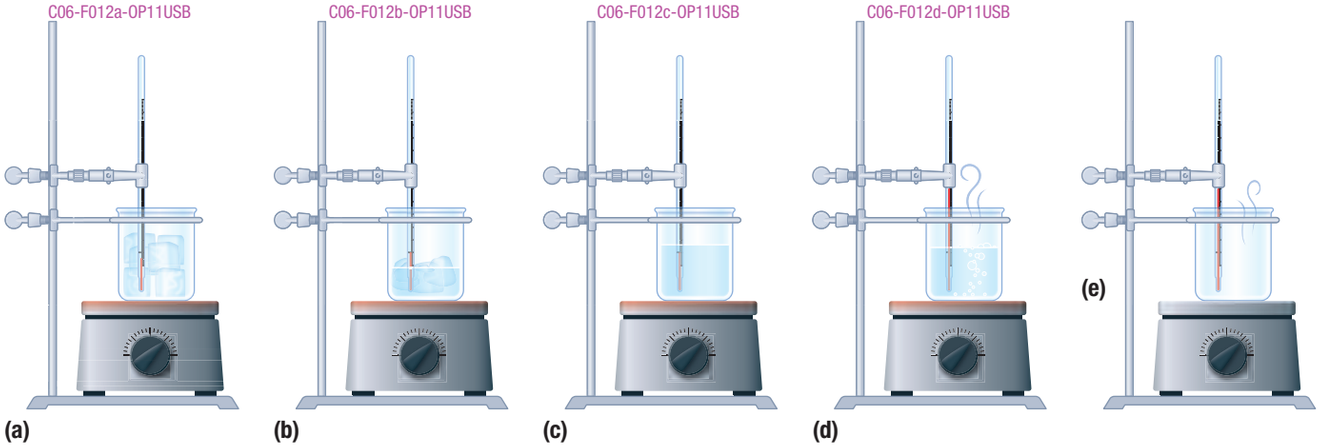

Figure 3 (a) Ice is heated. (b) As it reaches its melting point of 0 °C, it begins to change into a liquid because of the absorption of thermal energy. (c) As the ice/liquid water mixture is continuously heated, it continues to absorb thermal energy but stays at a temperature of 0 °C until the ice has completely melted. (d) The liquid water continues to heat up until its temperature reaches its boiling point of 100 °C, at which point enough thermal energy has been absorbed for it to begin to change into its gas, water vapour. (e) The temperature remains at 100 °C until all of the liquid has changed to water vapour.

As the liquid water absorbs thermal energy, its particles move faster and farther apart. This warms up the liquid and increases its temperature. As the particles increase in speed, the forces of attraction become less effective at holding the particles together. Eventually, the liquid reaches its boiling point, at which the particles have enough kinetic energy to completely break away from each other. At the boiling point, the liquid water changes into a gas called water vapour (**Figure 3(d)**). The boiling point of water is 100 °C. This change of state is called evaporation or vaporization. Eventually, all of the liquid evaporates into a gas (**Figure 3(e)**). Notice that

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thermal energy continues to be absorbed during the boiling process, but the temperature does not change—it remains at 100 °C until the last drop of liquid water has changed into water vapour. These changes of state occur whenever any material is heated from a solid to a liquid to a gas. The only difference is that every material has a different melting point and boiling point.

Removal of thermal energy reverses this process. In this case, a gas cools down and changes into a liquid and the liquid cools down and changes into a solid. The change of a gas into a liquid is called condensation, and the change of a liquid into a solid is called freezing, or solidification. Two other changes of state are possible: solid-to-gas sublimation and gas-to-solid sublimation. Solid-to-gas sublimation occurs when a solid changes directly into a gas (without becoming a liquid first), and gas-to-solid sublimation occurs when a gas changes directly into a solid (without becoming a liquid first). When ice cubes are kept in a freezer for a long period of time, they become smaller and smaller as they sublimate into water vapour. This is an example of solid-to-gas sublimation.

heating graph a graph that shows the temperature changes that occur while thermal energy is absorbed by a substance

cooling graph a graph that shows the temperature changes that occur while thermal energy is being removed from a substance

Heating and Cooling Graphs

The changes in temperature that occur when a substance is heated (absorbs thermal energy) can be shown in a graph called a **heating graph**, and the changes in temperature that occur when a substance is cooled (releases thermal energy) can be shown in a graph called a **cooling graph**. In both graphs, the vertical axis (*y*-axis) represents temperature and the horizontal axis (*x*-axis) represents the amount of thermal energy absorbed or released. **Figure 4(a)** is the heating graph for water, and **Figure 4(b)** is the cooling graph for water. An artist's illustration of the state of the water particles is shown above each graph.

Notice the following key aspects of each graph:

- Thermal energy is being absorbed by the water particles throughout the heating process represented by the heating graph, and thermal energy is being removed from the water particles throughout the cooling process represented by the cooling graph.

Investigation 6.3.1

Heating Graph of Water

In this activity you will obverse the temperature change as ice changes to water and create your own heating graph of water.

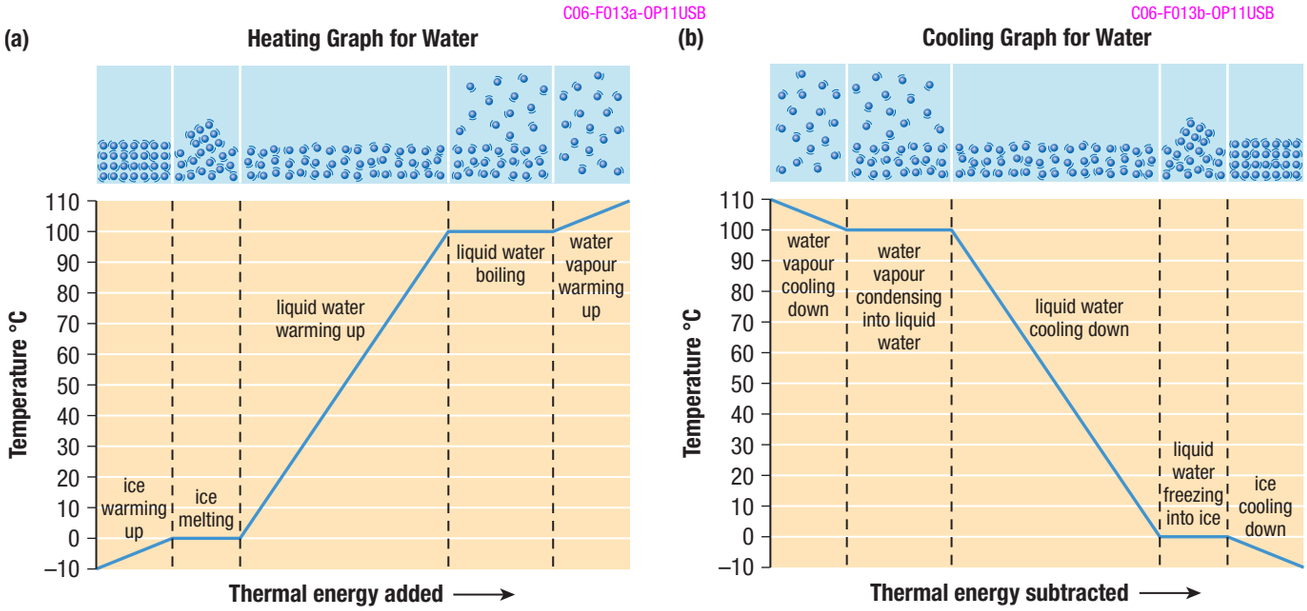

Figure 4 (a) A heating graph for water. The water temperature changes when the water is warming up, as shown by the angled parts of the graph. The temperature stays constant, as indicated by the flat parts of the graph, during changes of state (melting and boiling). (b) A cooling graph for water: The water temperature changes when the water is cooling down, as shown by the angled parts of the graph. The temperature stays constant, as indicated by the flat parts of the graph, during changes of state (condensation and freezing).

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- The heating graph shows a distinct melting point and boiling point and the cooling graph shows a distinct freezing point and condensation point. The melting and freezing points are the same (0 °C), and the boiling and condensation points are the same (100 °C). In general, melting and freezing occur at the same temperature, and boiling and condensation occur at the same temperature.
- Temperature does not change while ice melts into liquid water or liquid water freezes into ice and while liquid water boils to become water vapour or water vapour condenses into liquid water. This is represented by the flat parts of both graphs. In general, the temperature of a substance does not change while a change of state is occurring even though thermal energy continues to be absorbed or released by the substance.
- Temperature changes occur only when ice is warming up or cooling down; liquid water is warming up or cooling down; water vapour is warming up or cooling down. These changes are represented by the angled parts of each graph. In general, the temperature of a substance changes only when the substance is in a particular state (solid, liquid, or gas) and it is being heated or cooled. Temperature does not change while a change of state is occurring.

It might seem reasonable that the temperature of a substance should change while it is absorbing or releasing thermal energy because thermal energy affects the kinetic energy of particles. When particles of matter absorb thermal energy, their kinetic energy increases (their temperature increases), and when particles lose thermal energy, their kinetic energy decreases (their temperature decreases). The heating and cooling graphs above show that the temperature changes when thermal energy is added to or removed from ice, liquid water, or water vapour. But why does the temperature not change during melting, freezing, boiling, or condensation?

Temperature stays the same during melting and boiling because a certain amount of thermal energy is required to break the bonds that hold the water particles together as ice or liquid water. This thermal energy changes the potential energy of the particles, not their kinetic energy. Since temperature is a measure of the average kinetic energy of particles, temperature does not change during melting or boiling.

Temperature stays the same during freezing and condensation because during both of these changes of state, particles are becoming more organized. As a liquid cools down, its particles move more slowly and its temperature decreases. At the freezing point, the particles are moving slowly enough for them to start locking into fixed positions. This process changes the particles' potential energy, not their kinetic energy. Thus, the change of state occurs, but the temperature remains constant. Once all of the water particles are in fixed positions (all of the particles are in ice crystals), further cooling slows the particles down and reduces the temperature of the ice (the ice cools down). A similar process occurs when water vapour condenses into liquid water.

Latent Heat

As you have learned, a substance absorbs or releases thermal energy while it changes state, but its temperature remains constant. The total amount of thermal energy added or removed as a substance changes state is called the **latent heat (*Q*)** of the substance. The word "latent" means "hidden" and is used because thermal energy is absorbed when a substance changes from a liquid to a solid without a visible or measurable change in temperature. This thermal energy remains "hidden" in the substance until the opposite change of state occurs. For example, the thermal energy absorbed when ice melts remains in the liquid water until it is released when the liquid water freezes. Latent heat is measured in joules. Every substance has a latent heat of fusion and a latent heat of vaporization. The **latent heat of fusion** is the total thermal energy

latent heat (*Q*) the total amount of thermal energy added or removed as a substance changes state; measured in joules

latent heat of fusion the amount of thermal energy added or removed to convert a substance from a solid to a liquid or a liquid to a solid

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absorbed when a substance changes from a solid into a liquid (during melting, or fusion) or released when it changes from a liquid into a solid (during freezing). Note that these energy values are the same for a particular substance; the amount of energy absorbed when a solid melts into a liquid is the same as the amount of energy released when the same liquid freezes into a solid. We use the term "latent heat of fusion" for both values.

latent heat of vaporization the total amount of thermal energy added or removed to convert a substance from a liquid to a gas or a gas to a liquid

The **latent heat of vaporization** is the thermal energy absorbed when a substance changes from a liquid into a gas (during evaporation, or vaporization) or released when it changes from a gas into a liquid (during condensation). Note that these energy values are the same for a particular substance; the amount of energy absorbed when a liquid boils into a gas is the same as the amount of energy released when the same gas condenses into a liquid. We use the term "latent heat of vaporization" for both values.

specific latent heat (*L*) the amount of thermal energy added or removed to convert 1 kg of a substance from one state into another

specific latent heat of fusion (L_f) the amount of thermal energy added or removed to convert 1 kg of a substance from a solid to a liquid or a liquid to a solid; measured in joules per kilogram (J/kg)

specific latent heat of vaporization (L_v) the amount of thermal energy added or removed to convert 1 kg of a substance from a liquid to a gas or a gas to a liquid; measured in joules per kilogram (J/kg)

The **specific latent heat (*L*)** of a substance is the amount of thermal energy added or removed to convert 1 kg of the substance from one state into another. Every substance has a different specific latent heat because every substance is composed of different particles (atoms or molecules). The **specific latent heat of fusion (L_f)** is the thermal energy absorbed or released when 1 kg of a particular substance melts or freezes (**Table 1**). The **specific latent heat of vaporization (L_v)** is the thermal energy absorbed or released when 1 kg of a particular substance boils (vaporizes) or condenses (Table 1). The SI unit for specific latent heat (of fusion or vaporization) is joules per kilogram (J/kg).

Table 1 Specific latent heats for various substances

Substance	Specific latent heat of fusion (L_f) (J/kg)	Melting point (°C)	Specific latent heat of vaporization (L_v) (J/kg)	Boiling point (°C)
aluminum	6.6×10^5	2519	4.0×10^5	10 900
ethyl alcohol	1.1×10^5	−114	8.6×10^5	78.3
carbon dioxide	1.8×10^5	−78	5.7×10^5	−57
gold	1.1×10^6	2856	6.4×10^4	1 645
lead	2.5×10^4	327.5	8.7×10^5	1 750
water	3.4×10^5	0	2.3×10^6	100

The latent heat (Q), or total thermal energy involved in a change of state, can be calculated using the mass of the substance (m) and the specific latent heat of fusion (L_f) or specific latent heat of vaporization (L_v) in the following equations:

$$Q = mL_f \text{ (for substances that are melting or freezing)}$$
$$Q = mL_v \text{ (for substances that are boiling or condensing)}$$

LEARNING TIP

Remember Units
As with all questions in physics, make sure the units in your calculations of latent heat match. Mass must be expressed in kilograms, and latent heat is expressed in joules since the units for specific latent heat are joules per kilogram.

In the following tutorial, you will use the specific latent heat of fusion (L_f) and specific latent heat of vaporization (L_v) to calculate the latent heat (Q), or total amount of thermal energy absorbed or released when a substance changes state. In some of the sample problems, you will also determine the amount of thermal energy absorbed or released when a substance warms up or cools down but does not change state. In those cases, you will use the quantity of heat equation ($Q = mc\Delta t$) that you learned in Section 6.2. Note that Q is used to symbolize both latent heat and quantity of heat. This is because both are measures of the amount of thermal energy absorbed or released when a substance is heated or cooled. The only difference is that latent

Investigation 6.3.1

Specific Latent Heat of Fusion for Ice
In this investigation you will observe use the equations $Q = mc\Delta T$ and $Q = mL_f$ to determine the latent heat of fusion for melting ice.

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heat (Q) is the amount of thermal energy absorbed or released when a substance changes state (temperature remains constant) and quantity of heat (Q) is the amount of thermal energy absorbed or released when a substance in a particular state (solid or liquid or gas) warms up or cools down (temperature changes).

Tutorial 1 Calculating Latent Heat of Fusion or Vaporization

Remember that the latent heat equations $Q = mL_v$ and $Q = mL_f$ are used to calculate the amount of thermal energy absorbed or released during a change of state (when temperatures remain constant) and the equation $Q = mc\Delta T$ is used to calculate the amount of thermal energy absorbed or released when a solid, liquid, or gas warms up or cools down (during temperature changes).

Sample Problem 1

How much thermal energy is released by 652 g of molten lead when it changes into solid lead?

We start by deciding whether we should use the latent heat equations $Q = mL_f$ or $Q = mL_v$ or the quantity of heat equation $Q = mc\Delta T$ to solve this problem. Since lead is changing from a liquid to a solid, a change of state is occurring. Therefore, we should use the latent heat equation $Q = mL_f$ to solve this problem.

Given: $m = 652$ g or 0.652 kg; $L_f = 2.5 \times 10^4$ J/kg (from Table 1)

Required: Q, latent heat

Analysis: $Q = mL_f$

Solution: $Q = mL_f$

$= (0.652\text{ kg})(2.5 \times 10^4\text{ J/kg})$

$Q = 1.6 \times 10^4$ J

Statement: The 652 g of lead releases 1.6×10^4 J of thermal energy as it solidifies.

Sample Problem 2

Ethyl alcohol is a liquid at room temperature. How much thermal energy is absorbed when 125 g of ethyl alcohol at a temperature of 21.5 °C is heated until all of it boils and turns into vapour?

This is a two-step calculation because the ethyl alcohol will first warm up from 21.5 °C to its boiling point of 78.3 °C (see Table 1) and then change from a liquid into a gas while its temperature remains at 78.3 °C. Therefore, the entire process occurs in two phases: a warming phase and a change of state phase. We will symbolize the amount of thermal energy absorbed during the warming phase with Q_1, and the amount of thermal energy absorbed during the change of state phase with Q_2.

We will use the quantity of heat equation, $Q_1 = mc\Delta T$, to calculate the amount of thermal energy absorbed during the warming phase. For this calculation, we need to know the specific heat capacity, c, of ethyl alcohol; this value can be found in the specific heat capacity table in Section 6.2. We will use the latent heat equation, $Q_2 = mL_v$, to calculate the amount of thermal energy absorbed during the change of state phase. For this calculation, we need to know the specific latent heat of vaporization, L_v, of ethyl alcohol; this can be found in Table 1 (in this section).

The total amount of thermal energy absorbed in the entire process, Q_{total}, is calculated by adding Q_1 and Q_2.

Given: $m = 125$ g or 0.125 kg; $c = 2.46 \times 10^3$ J/(kg · °C); $T_1 = 21.0$ °C; $T_2 = 78.3$ °C; $L_v = 8.6 \times 10^5$ J/kg

Required: Q_{total}, total amount of thermal energy absorbed

Analysis: $Q_1 = mc\Delta T$; $Q_2 = mL_v$; $Q_{total} = Q_1 + Q_2$

Solution:

$Q_1 = mc\Delta T$

$= (0.125\text{ kg})(2.46 \times 10^3\text{ J/(kg}\cdot\text{°C)})(78.3\text{ °C} - 21.5\text{ °C})$

$= 1.747 \times 10^4$ J (one extra digit carried)

$Q_2 = mL_v$

$= (0.125\text{ kg})(8.6 \times 10^5\text{ J/kg})$

$= 1.075 \times 10^5$ J (two extra digits carried)

$Q_{total} = 1.747 \times 10^4\text{ J} + 1.075 \times 10^5\text{ J}$

$= 1.2 \times 10^5$ J

Statement: Ethyl alcohol absorbs a total of 1.2×10^5 J of energy when 125 g of the alcohol at 21.5 °C is heated until all of it boils and turns into vapour.

Practice

1. How much thermal energy is removed to freeze 2.0 L of water? T/I [ans: 6.8×10^5 J]
2. How much thermal energy is needed to melt a 350 g bar of gold? T/I [ans: 3.9×10^5 J]
3. How much thermal energy is given off when 500 g of steam at 100 °C condenses and then cools off to 50 °C? T/I [ans: 1.3×10^5 J]

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Water: A Special Liquid

Most solids sink in their respective liquids (**Figure 5(a)**). For example, solid iron sinks in liquid iron. This occurs because the particles of the solid are more closely packed than the particles of the liquid, making the solid denser.

This is true for most substances. However, water is different. Solid water (ice) floats on liquid water (**Figure 5(b)**).

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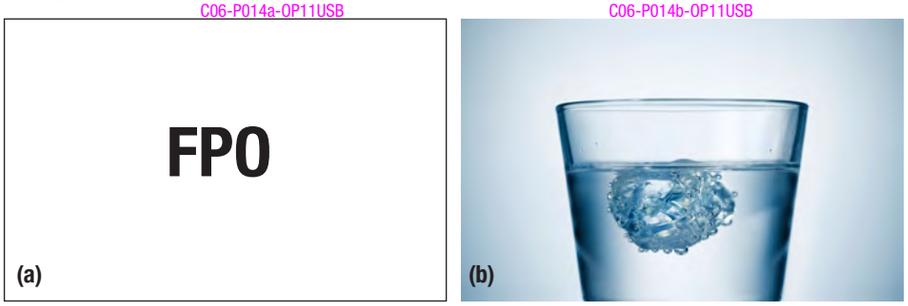

Figure 5 (a) Most solids sink in their respective liquids. (b) Ice, however, floats on liquid water.

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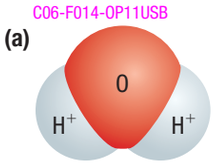

Figure 6 A water molecule has two hydrogen atoms with a slight positive charge and one oxygen atom with a slight negative charge.

This occurs because water is one of the few substances whose solid is less dense than its liquid. This is based on the water molecule's chemical structure. Water molecules are V-shaped and have two hydrogen atoms attached to one oxygen atom (**Figure 6**). The hydrogen atoms have a small positive charge, while the oxygen atom has a small negative charge. This causes water molecules to attract one another because opposite charges attract.

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However, at temperatures above 4 °C, molecules of water move too fast for these forces of attraction to pull the molecules together. At these temperatures, water molecules are relatively disorganized (**Figure 7(a)**). As the temperature decreases, the molecules move slowly enough for the forces of attraction to place the molecules into a more organized structure. The more organized molecules of water in ice take up more space than the more disorganized molecules in liquid water, so water expands as it freezes (**Figure 7(b)**).

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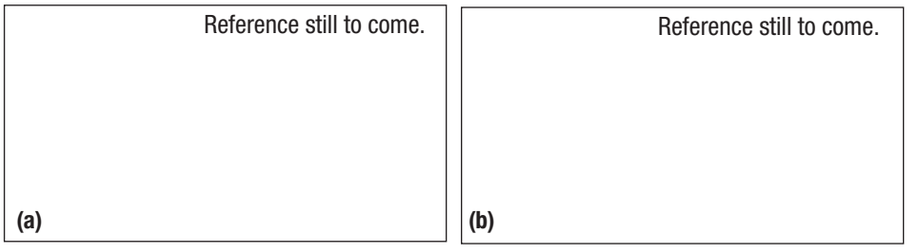

Figure 7 (a) At temperatures above 4 °C, water molecules are relatively disorganized. (b) As the temperature of the water decreases, the molecules move more slowly, forming a more organized structure, so that molecules of ice take up more space than those of liquid water.

The expansion of water as its temperature drops below 4 °C can cause a lot of problems. Pipes in homes or under the street can break under the pressure of the expanding, frozen water. When the water thaws it flows out of the broken pipes, causing flooding and damage (**Figure 8(a)**). Potholes in roads form when water under the pavement freezes and expands, weakening the pavement so that it crumbles after the ice thaws. (**Figure 8(b)**).

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Figure 8 (a) When pipes freeze and burst, it can be a big mess, both above ground on road surfaces and below ground in water and sewer systems (b) Potholes are created when water beneath the pavement freezes in the winter and expands, resulting in the crumbling of asphalt.

6.3 Summary

- When a solid absorbs thermal energy, its particles gain kinetic energy and move faster; when enough thermal energy is absorbed that the substance reaches its melting point, its particles begin to slide past each other as the substance changes from a solid to a liquid.
- When a liquid absorbs thermal energy, its particles gain kinetic energy and move even more quickly; when enough thermal energy is absorbed that the substance reaches its boiling point, the particles' movement is intense enough to overcome their forces of attraction, and they begin to move freely as the substance changes from a liquid to a gas.
- Removal of thermal energy reverses the process: a gas cools down and changes into a liquid when it reaches its condensation point (which is usually the same as its boiling point); likewise, a liquid cools down and changes into a solid when it reaches its freezing point (which is usually the same as its melting point).
- A solid can also change directly into a gas during solid-to-gas sublimation, and a gas can change directly into a solid during gas-to-solid sublimation.
- During a change in state, the temperature of an object does not change; the thermal energy that is added or released changes the potential energy, as opposed to the kinetic energy, of the particles.
- Latent heat is the total amount of thermal energy added or removed as a substance changes from one state to another.
- Every substance has a specific latent heat of fusion (L_f), which represents the amount of heat per kilogram needed to melt or freeze the substance. Every substance also has a specific latent heat of vaporization (L_v), which is the amount of heat needed per kilogram to evaporate or condense the substance.
- The equation $Q = mL_f$ is used to calculate the latent heat of fusion, and $Q = mL_v$ is used to calculate the latent heat of vaporization. The latent heat of fusion or latent heat of vaporization is the total thermal energy needed for the change of state.
- Ice is one of the few solids that float in their liquid (water in this case); this is due to its unique intermolecular forces that make its solid less dense than its liquid.

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6.3 Questions

1. What is happening at the plateau in the graph in **Figure 9**? How can you tell? K/U T/I

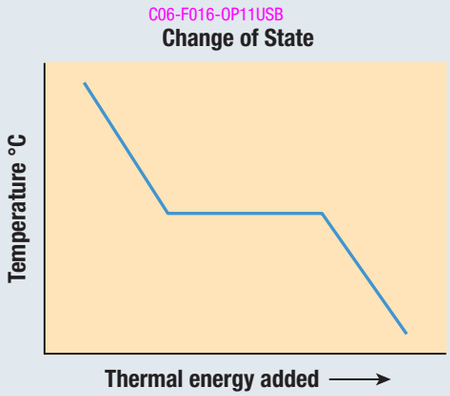

Figure 9

2. (a) Use **Table 2** to graph a heating curve for an unknown substance. T/I
   (b) Label the graph with the following: solid, liquid, gas, melting, evaporation. T/I
   (c) Determine the melting point and boiling point of the unknown substance. T/I
3. Why is it not possible to heat liquid water to a temperature of 110 °C? K/U
4. Explain the terms "latent heat of fusion" and "latent heat of vaporization." K/U
5. To prevent the fruit from freezing and becoming inedible, fruit farmers in Ontario often spray their crops with water if they know the temperatures are going to drop below zero. Use your knowledge of latent heat to explain why this works. K/U A
6. Calculate the latent heat of fusion for 2.40 kg of gold as it changes from a molten liquid to a solid bar. T/I
7. How much thermal energy is needed to change 100 g of ice at −20 °C into steam at 110 °C? T/I
8. While casting a 1.50 kg aluminum piece, a metal smith heats the aluminum to 2700 °C, pours it into a mould, and then cools it to a room temperature of 23.0 °C. Determine the total thermal energy lost by the aluminum. T/I
9. What makes water different from most other substances? Include a description of the physical characteristics that make water special. K/U

Table 2 Data collected during the heating of an unknown substance

Time (min)	0.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5
Temperature (°C)	37	43	49	55	55	55	56	64	70	80	86	90	90	90	100

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6.4 Heating and Cooling Systems

Canadians depend on heating systems to keep homes, schools, and other buildings comfortable during the winter. Many buildings are also equipped with cooling systems for the summer. Conventional heating systems use oil or natural gas as fuels, and air conditioners typically use electricity. In some cases, electric heaters are used for heating. Scientists and engineers are also developing more affordable energy-efficient alternatives that Canadians will be able to start using for their heating and cooling needs.

Conventional Heating Systems

Heating systems contain a source of thermal energy, a means of distributing the energy, and a device that controls or regulates the production and distribution of energy. Conventional heating systems use either electricity or fossil fuels as a source of thermal energy. **Electrical heating systems** generate thermal energy by allowing an electric current to pass through metal wires that have a high resistance to the flow of the current. Similar wires are used in the elements of an electric stove and an incandescent light bulb. The thermal energy is transferred throughout the room by convection. Fossil fuel systems generate thermal energy by combusting (burning) fossil fuels such as oil, coal, and natural gas.

electrical heating system a system that uses electricity to produce thermal energy for heating

Some heating systems use the thermal energy that is generated to warm up air while others use the thermal energy to warm up water. A **forced-air heating system** uses warm air to heat a building. In these systems, the warm air passes through ducts that empty into vents located in the floor or ceiling. The warm air is transferred throughout the building by convection (**Figure 1**). As warm air enters a room through the vents, colder air is pushed through another set of ducts called the cold air return, providing more air for the furnace to heat. Fresh air is also brought into the system through an intake pipe that is also heated by the furnace. An exhaust system releases gases such as carbon dioxide from the home. **Hot water heating systems** use the thermal energy produced by electricity or the burning of fossil fuels to warm up water. The hot water is then pumped to radiators located in various rooms of the building.

forced-air heating system a system that uses hot air to heat a building

hot water heating system a system that uses hot water to heat a building

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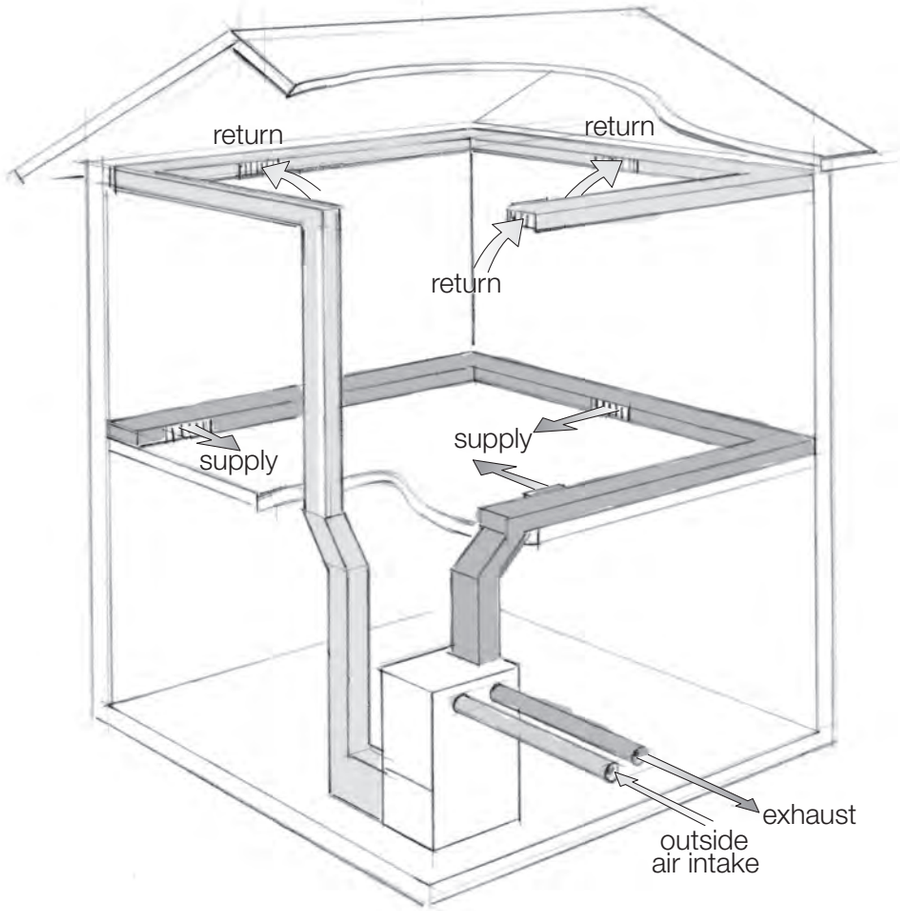

Figure 1 In a typical forced-air system, warm air from the furnace is supplied to each room through ductwork. A separate set of ducts returns cooler air to the furnace and brings in fresh air from outside to the furnace for heating.

Conventional Cooling Systems

The physics of conventional air conditioners, refrigerators, and freezers is very similar. All of these appliances use the evaporation of a liquid to absorb thermal energy from air. First, a compressor puts a special type of gas, called a refrigerant, under pressure. Whenever a gas is compressed, its temperature increases. Compressing a refrigerant causes it to warm up. The warm refrigerant gas runs through a coil of tubes, where it starts to release some of its thermal energy. As the refrigerant cools, it turns to a liquid. The liquid refrigerant then passes through an expansion valve, moving from a high-pressure area to a low-pressure area. At this point, the refrigerant absorbs thermal energy from the surrounding air and evaporates back into a gas. The surrounding air cools down as a result (**Figure 2**). The cool air is released into one room of the building or pumped to other rooms using the same ductwork that is used to heat the home. The compressor of an air conditioner gets very warm, so air conditioning units are installed outside the house, where the thermal energy can be released into the external environment.

In a refrigerator or freezer, the same type of compressor and coil system is used. The only difference is that the cooled air is released into the refrigerator or freezer and the warm air is released into the external environment.

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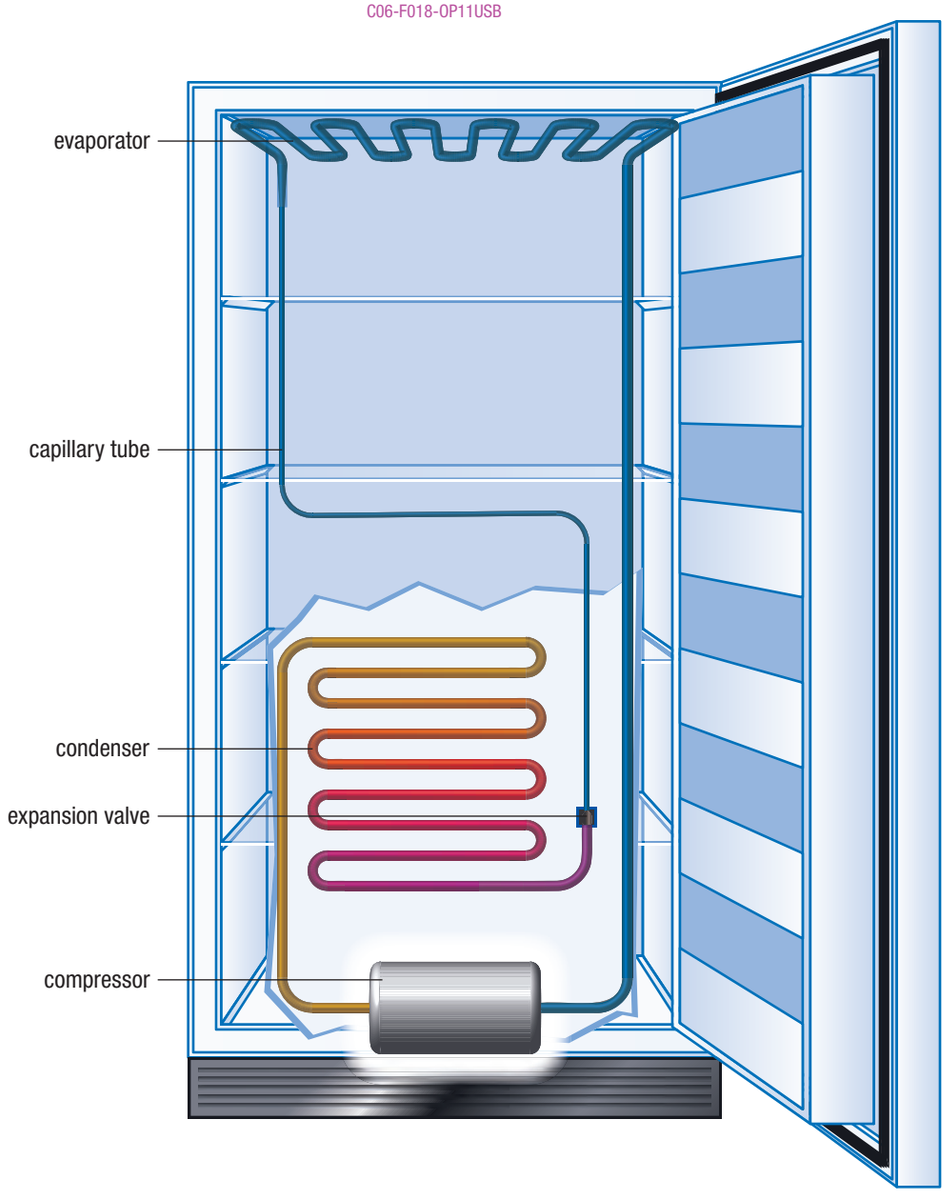

Figure 2 In a compressor, (a) a refrigerant in the form of a gas is put under pressure to change it to a liquid. When the refrigerant moves through the compression valve (b), the pressure decreases and the liquid evaporates, removing thermal energy from the air being pumped across the pipes (c).

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Figure 3 A bimetallic strip is curled into a coil so it winds up or unwinds as the temperature changes, resulting in the tilting of the mercury switch on the top.

Controlling Heating and Cooling Systems

Both heating and cooling systems contain a thermostat to determine the temperature of the environment and turn the furnace or air conditioner on or off accordingly. Conventional thermostats contain a coiled bimetallic strip and a mercury switch (**Figure 3**). A bimetallic strip consists of two types of metal bonded together back to back. Due to the different types of metals, the two sides of the strip expand and contract at different rates when heated or cooled. Expansion and contraction make the coil tighten and loosen as the temperature of the house fluctuates. On top of the bimetallic strip is the mercury switch. Mercury is a liquid metal that flows like water and also conducts electricity. When the bimetallic strip coil changes shape, the mercury switch tilts and the mercury moves inside. When the temperature in the building is above or below the temperature that an operator has set on the thermostat, the switch tilts in one direction and causes the mercury to touch two bare wires. This creates a closed circuit and turns the furnace or air conditioner on. As the environment warms up or cools down, the bimetallic coil changes shape. This causes the

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switch to tilt in the opposite direction, moving the mercury away from the circuit wires. This opens the circuit and turns the furnace or air conditioner off.

Geothermal Systems: An Alternative Method of Heating and Cooling

The most popular methods of heating involve the combustion (burning) of fossil fuels (oil, coal, and natural gas). This results in the release of greenhouse gases, such as carbon dioxide, into the atmosphere, contributing to global warming. The refrigerants used in cooling systems are also greenhouse gases and can also contribute to global warming if they leak into the environment. Some refrigerants have also been linked to damage to the ozone layer, a layer of ozone gas in the upper atmosphere that helps reduce the amount of ultraviolet radiation from the Sun that reaches Earth's surface. Damage to the ozone layer might be responsible for increases in skin cancer caused by ultraviolet radiation. To reduce production of greenhouse gases and protect the ozone layer, alternative forms of heating and cooling are being developed. Several alternatives were introduced in Chapter 5. One of the newest heating and cooling technologies makes use of the thermal energy contained within Earth. **Geothermal systems** use heat pumps to transfer Earth's natural thermal energy for heating and cooling.

geothermal system a system that transfers thermal energy from under Earth's surface into a building to heat it, and transfers thermal energy from the building into the ground to cool the building

Temperatures at a depth of 3 m below the ground remain fairly steady throughout the year. Depending on the latitude, the actual ground temperature can vary. In Ottawa, the temperature remains at about 9 °C, which might seem cold, but it can still be used to heat a building.

During the winter, the temperature below the ground is higher than the temperature above the ground. In a geothermal system, a liquid antifreeze-water mixture is pumped through a series of coils of plastic pipes, called a loop field, that is set a few metres underground. As the antifreeze-water mixture is pumped through the pipes of the loop field, the thermal energy from the ground transfers by conduction through the walls of the pipe and then by convection throughout the liquid. The liquid is then piped into a house or other building, where a heat pump removes the thermal energy (**Figure 4(a)**).

Inside the heat pump, a liquid refrigerant is pumped through a series of coils. Thermal energy moves from the antifreeze-water mixture into the refrigerant, turning the refrigerant into a gas. The gas moves into another set of coils where the pressure is increased. As the pressure of a gas increases, its temperature also increases. Air blows over the coils containing the hot refrigerant gas, and the hot air is sent through ducts to warm the building.

During the summer, the heat pump process is reversed. Hot air from the house is pumped over the refrigerant, causing it to warm up. The refrigerant then transfers its thermal energy to the antifreeze-water mixture so that the mixture warms up as well. Since it is cooler underground than above ground during the summer, the thermal energy moves from the liquid into the ground by conduction (**Figure 4(b)**).

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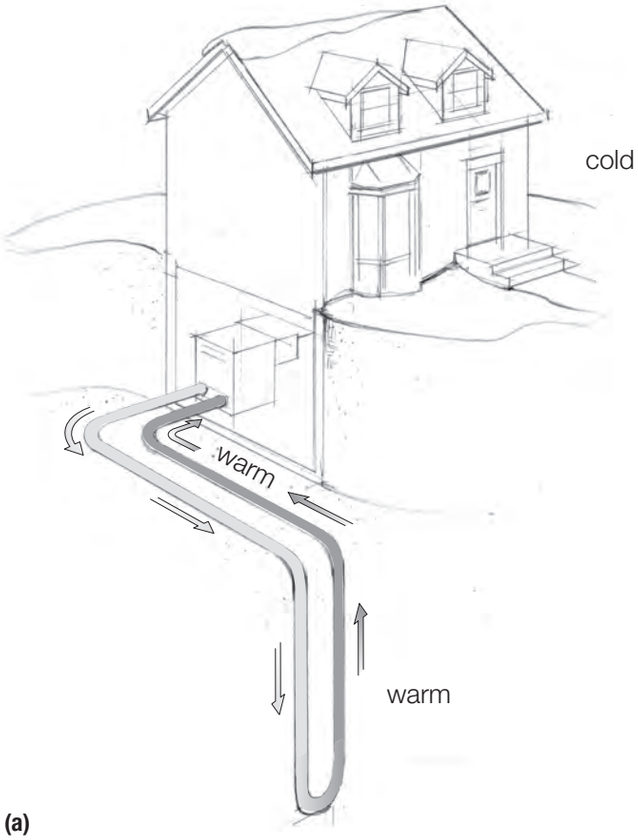

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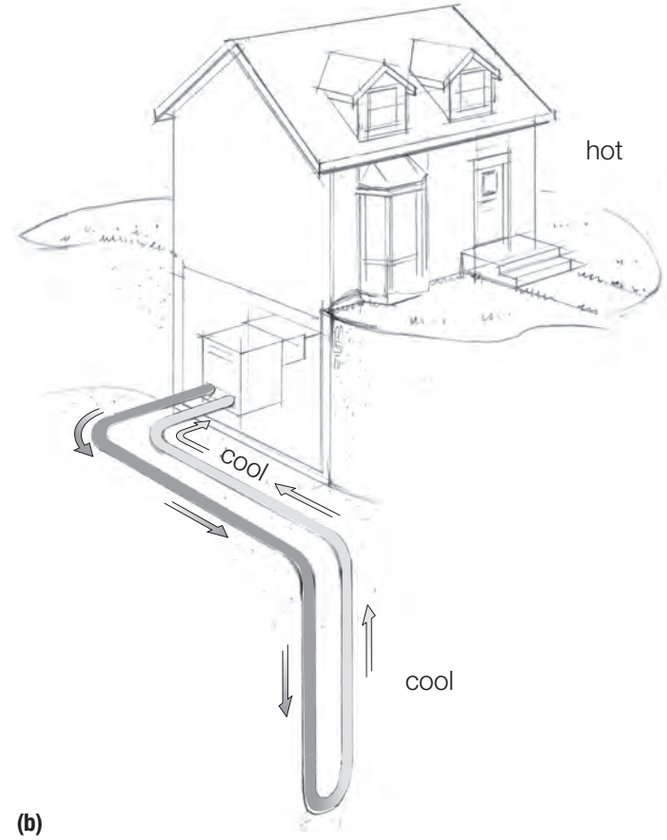

Figure 4 (a) In a geothermal system, thermal energy is transferred from below the ground to a heating system inside a building during the winter, heating the building. (b) During the summer, thermal energy is transferred from the building to the ground outside, cooling the building.

6.4 Summary

- Conventional heating systems use either electricity or fossil fuels as a source of thermal energy. In electric heating systems, an electric current is passed through high-resistance metal wires, generating thermal energy that is transferred throughout a building by convection. In fossil fuel systems, thermal energy is generated by the combustion of fossil fuels.
- Conventional cooling systems use the evaporation of pressurized refrigerants to remove thermal energy from the air, resulting in cool air that can then be blown through a duct system.
- A typical thermostat uses a bimetallic strip and a mercury switch to turn on or off the heating and cooling system as temperatures change.
- Conventional heating and cooling systems tend to create greenhouse gases such as carbon dioxide, so they are not considered environmentally friendly.
- Geothermal heating systems pipe an antifreeze-water mixture through pipes buried underground to collect Earth's natural thermal energy. The liquid is piped to a heat pump, which transfers the thermal energy to a refrigerant, changing it to a gas. The gas moves into a set of coils where its pressure is increased, thus increasing its temperature. Air blows over the coils of hot gas, and the hot air is sent through ducts to warm the building.
- Geothermal cooling systems transfer thermal energy from a building to a refrigerant and then to an antifreeze-water mixture, which then transfers the thermal energy into the ground via conduction as the antifreeze-water mixture moves through a system of pipes.

see OVERMATTER

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6.4 Questions

1. Forced-air heating systems are found in the majority of homes. Brainstorm reasons why they are so popular. K/U A
2. Refrigerants used in air conditioners and refrigerators can be a type of CFC, or chlorofluorocarbon. Research other uses for CFCs. A
3. Why can a geothermal system be used as both a heating system and a cooling system? K/U
4. Geothermal energy is the thermal energy radiating from the Earth. Does a geothermal heating and cooling system truly use geothermal energy? K/U

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6.5 Explore an Issue in Thermal Energy

SKILLS MENU

- Defining the Issue
- Researching
- Identifying Alternatives
- Analyzing the Issue
- Defending a Decision
- Communicating
- Evaluating

CAREER LINK

To learn about a careers in the geothermal heating/cooling industry,

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Geothermal Heat Pump: Friend or Foe?

Geothermal heating and cooling systems are slowly becoming popular alternatives to conventional heating and cooling systems. The purpose of installing a geothermal system is to heat and cool your home efficiently without causing damage to the environment. Although they are expensive to install, there is very little cost involved in running a geothermal heating system, so homeowners can also save money.

Geothermal systems are advertised to be safe and environmentally friendly because they do not use fossil fuels, so they do not release greenhouse gases. To run a geothermal system, water containing antifreeze must be pumped into the ground to be warmed by the Earth. This antifreeze-water mixture is then sent into a heat pump, which removes the thermal energy from the liquid, using it to heat your home. All heat pumps use a refrigerant during the exchange of thermal energy.

During the summer the process is reversed: the antifreeze-water mixture absorbs thermal energy from a building and releases it underground, cooling the building in the process.

It is not always possible to install a geothermal system in a building, since you need a suitable area to place the piping (**Figure 1**). Environmental issues might also be involved because of the use of refrigerants and the possible leakage of antifreeze into the ground.

Figure 1 Pipes are buried under the ground to allow for the exchange of thermal energy between an antifreeze-water mixture and Earth.

The Issue

Do the benefits of geothermal systems outweigh the risks and costs?

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Role

You will assume the role of a builder of custom houses. As a geothermal heating and cooling expert, you want to provide your customers with all of the information they need to make an informed choice.

Audience

Your clients have been asking you if they should install geothermal heat pumps instead of conventional heating systems. They are considering this change because they are concerned about the environment and want to do their part to help. Most of the pamphlets they have read about geothermal systems make it sound like an amazing solution to our environmental problems.

You will need to communicate your findings clearly to your clients so they can understand the pros and cons of including geothermal heating and cooling in the design of their new house. You will need to discuss the environmental and financial advantages and disadvantages of installing geothermal heating and cooling.

Goal

To advise your clients on the pros and cons of geothermal heating and cooling systems so that they can decide if they should include such a system in their new home design

Research

Research the pros and cons of geothermal heating and cooling systems at the library or on the Internet. Be sure to include the dangers associated with antifreeze and refrigerants in geothermal systems. Also include information on the cost of installing the system, as this is important information for your clients.

WEB LINK

To learn more about geothermal heating and cooling systems,

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Identify Solutions

You might want to consider the following in your analysis:

- environmental damage associated with producing the electricity to run the heat pump in a geothermal system
- problems with antifreeze
- environmental benefits of geothermal systems.
- environmentally friendly alternatives to geothermal systems

Make a Decision

What would you recommend to clients who are interested in installing geothermal heating and cooling systems? Make sure that you develop clear reasons for your viewpoint by creating a risk-benefit analysis.

Communicate

Create a clear outline of the pros and cons of a geothermal heating system. You can present the information in the form of a pamphlet, multimedia presentation, video presentation, or web page.

Plan for **Action**

Create a plan for how to distribute the information you collected to local homeowners. Consider the homeowners in your community (staff, parents, and neighbours). Use resources such as the school website, school newspaper, parent newsletters, and local newspapers. Make sure that you present an unbiased view of the issue so that community members can make their own decisions on the issue. To do this you will need to clearly outline both the pros and the cons of geothermal heating systems.

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6.6 Physics JOURNAL

ABSTRACT
James Prescott Joule did not start off his career as a scientist, but through hard work and perseverance became one of the most famous physicists of his day. His goal was to determine how work, mechanical energy, and thermal energy are related. Through years of experimentation, he gathered and analyzed extensive amounts of data until his theories were finally taken seriously. The result was a dramatic change in our understanding of thermal energy.

A Scientist Is Born

James Prescott Joule (**Figure 1**) was born into a family of English brewers. Due to poor health, he was not given a formal education. Instead, he studied at home with the help of tutors until the age of 15, when he went to work at the brewery. His interest in science was sparked when he and his brother went to study under the famous chemist John Dalton. His studies were aimed at learning more about the brewing process, but the result was a lifelong love of science. When Joule returned home, he set up his own laboratory and started experimenting. Science became Joule's hobby, one that he was passionate about. Unfortunately, this did not make his work acceptable to other scientists at the time.

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Figure 1 text to come

Early Experiments

Joule's scientific career began when he determined the amount of thermal energy produced by an electric current. He discovered that current and resistance were directly related to the amount of thermal energy generated, a concept now referred to as Joule's law. Joule's scientific report was presented to the Royal Society of London, which was made up of some of the day's most distinguished scientists. However, at the time the report was not met with much enthusiasm.

Undaunted, James Joule started investigating thermal energy from both electric and mechanical sources. He used electricity to warm up a volume of water so that it changed in temperature by 1 °F. He then used mechanical energy, by forcing water through a perforated cylinder, to produce friction and increase the temperature of the same amount of water by 1 °F. These investigations showed that a similar amount of energy was needed in both cases. These findings were presented to the British Association for the Advancement of Science, but again there was very little interest in his work. Joule was considered to be a wealthy brewer, not a scientist, so the scientists in the association did not take his results seriously.

Joule summarized his feelings when he said, "I shall lose no time in repeating and extending these experiments, being satisfied that the grand agents of nature are . . . indestructible; and that wherever mechanical force is expended, an exact equivalent of heat is always obtained." Joule firmly believed that energy (the "grand agents of nature") was "indestructible" and that it could be changed from one form into another.

At this time, scientists believed that a fluid-like material called caloric was responsible for making objects warm or cold. When objects absorbed caloric they would become warmer, and when they lost caloric they would become colder. According to this theory, an object could become warmer only if it came into contact with a warmer object so that caloric could flow from the warmer object into the cooler object. Joule did not share this view. He thought that objects could become warmer without coming into contact with warmer objects. Joule believed that all forms of energy are the same, and that one form can be changed into another. Thus, he believed that mechanical energy or electrical energy could be changed into thermal energy.

Finally, a Breakthrough

In a report published in a leading British physics journal in 1845, entitled "The Mechanical Equivalent of Heat," Joule described an investigation in which he used a falling mass to turn a paddlewheel placed inside an insulated barrel of water (**Figure 2**). As the paddlewheel turned, the water

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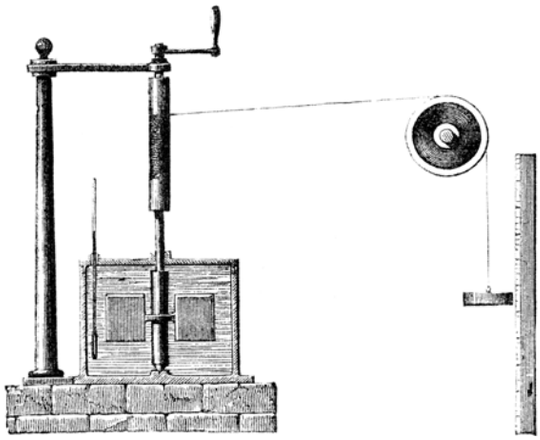

Figure 2 Joule's apparatus to measure the mechanical equivalent of heat. As the mass on the right falls, its energy is used to turn the paddlewheel inside the water in the barrel. The thermometer measures any changes in the temperature of the water.

inside the barrel warmed up and its temperature rose. This indicated that mechanical energy could be transformed into thermal energy. Joule precisely measured the amount of mechanical energy that was needed to raise the temperature of 1 lb (0.45 kg) of water by 1 °F. This result allowed Joule to determine the amount of mechanical energy needed to generate a unit of heat (thermal energy was called "heat" at that time). Joule called this value the "mechanical equivalent of heat" since it related mechanical energy to thermal energy.

Eventually, Joule became a highly respected scientist and was elected as a member of the Royal Society. Many of his theories led to the development of the first law of thermodynamics, otherwise known as the law of conservation of energy. The SI unit of energy is called the joule in his honour.

Further Reading

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Reynolds, Osbourne. *Memoir of James Prescott Joule.* Volume 36. Manchester, UK: Manchester Literary and Philosophical Society, 1892.

Steffens, Henry J. *James Prescott Joule & the Concept of Energy.* Dawson, UK: Folkstone, 1979.

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6.6 Questions

1. How did Joule's discoveries change our understanding of thermal energy? K/U
2. In science, we often repeat investigations or conduct a number of related investigations and compare the results. Why is this done? How is Joule's work a good example of this? K/U T/I
3. Why was Joule's early scientific work not taken seriously? Why was his work accepted by scientists later on? K/U
4. Consider the equipment Joule used in his investigations. How would it compare to equipment used today? T/I

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Investigation 6.2.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Researching
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Specific Heat Capacity of Brass

In Section 6.3, you learned that the quantity of heat can be found using the equation $Q = mc\Delta T$. Different substances absorb thermal energy differently due to their specific chemical properties. This can be seen in the differing specific heat capacities of various materials.

When a warmer object is in contact with a cooler object, thermal energy moves from the warmer object to the cooler object until their temperatures are equal. The quantity of heat lost by the warmer object is equal in magnitude to the quantity of heat gained by the cooler object, so $Q_{lost} + Q_{gained} = 0$.

Purpose

To observe the experimental quantities of heat lost, heat gained, and specific heat capacity in a laboratory situation

Equipment and Materials

- eye protection
- graduated cylinder
- thermometer
- stirring rod
- 250 mL beaker
- retort stand
- ring clamp
- hot plate
- 100 g brass mass
- tongs
- 2 Styrofoam cups

Procedure

Part A: Determining Heat Exchange

1. Put on your eye protection.
2. Use a graduated cylinder to measure 100 mL of cold tap water and place it in a Styrofoam cup. Measure and record the temperature of the cold water in a copy of **Table 1**.

Table 1 Determining heat exchange

Temperature of cold water (°C)	
Temperature of hot water (°C)	
Temperature of mixed water (°C)	

3. Measure 100 mL of hot tap water and place it in a separate Styrofoam cup. Measure and record the temperature of the hot water in Table 1.
4. Pour the cold water into the hot water. Put the thermometer in the cup and use the stirring rod to mix the water. Watch the temperature carefully and record the highest temperature reached in Table 1.
5. Use the equation $Q = mc\Delta T$ to calculate the quantity of heat (Q) lost by the hot water.
6. Use the equation $Q = mc\Delta T$ to calculate the quantity of heat (Q) gained by the cold water.
7. Use the percent difference equation to determine the error involved in the calculation:

Part B: Determining the Specific Heat Capacity of Brass

8. Place a retort stand with a ring clamp beside a hot plate. Turn the iron ring until it is over the hot plate. The iron ring needs to be large enough for a 250 mL beaker to sit inside it. The ring should be positioned so that the beaker rests on the hot plate.
9. Fill the 250 mL beaker one third full with water from the tap. Place it inside the ring over the hot plate.
10. Use an electronic balance to measure the mass of the 100 g brass mass and record the mass in a copy of **Table 2**.

Table 2 Data for specific heat capacity of brass

	Water	Brass
Mass (kg)		
Initial temperature (°C)		
Final temperature (°C)		

11. Place the brass mass in the beaker of water on the hot plate. Turn on the hot plate and let the water come to a boil.
12. While waiting, measure 100 mL of cold tap water using a graduated cylinder. Put the cold water into a Styrofoam cup and take its temperature. Record this value.

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13. Once the water on the hot plate boils, use the thermometer to measure its temperature. Assume that the temperature of the brass mass is equal to the temperature of the boiling water. This is the initial temperature of the brass. Turn off the hot plate.
14. Using a pair of tongs, remove the brass mass from the boiling water and put it in the Styrofoam cup containing the cold water.
15. Gently stir the water surrounding the brass mass with a stirring rod and take its temperature with a thermometer. Record the highest temperature reached.
16. Use the equations $Q = mc\Delta T$ and $Q_{lost} + Q_{gained} = 0$ to calculate the specific heat capacity of brass. This is the measured value for the specific heat capacity of brass.
17. The accepted value for the specific heat capacity of brass is 3.8×10^2 J/(kg · °C). Find the percent error for the calculation using the percent error equation:
18. Clean up and return all of the equipment. Remember that the hot plate will remain hot for a long time after it is turned off.

When unplugging the hot plate, pull the plug not the cord.

Analyze and Evaluate

(a) Discuss the amount of error found in Part A. What might have caused this error?

(b) Discuss the amount of error found in Part B. What might have made the amount of error in part B different from the amount of error in part A?

Apply and Extend

(c) Although simplistic, this investigation shows a method of determining the specific heat capacity of a substance. Scientists often find the specific heat capacity of unknown substances. Why would this be valuable to a scientist?

(d) Explain what a high specific heat capacity tells you about a substance. State some uses of substances with high specific heat capacities. What are some uses for substances with low specific heat capacities?

Investigation 6.3.1 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Heating Graph of Water

As you learned in Section 6.3, as a substance cools down or warms up, a specific pattern of temperature changes occurs. During a change of state, the temperature of a pure substance remains constant. While a substance is melting, the thermal energy that is added changes the potential energy of the particles, not their kinetic energy and temperature. As a substance cools and freezes, the thermal energy that is removed also changes the particles' potential energy, not their kinetic energy and temperature. In this investigation, you will observe the pattern of temperature changes for water as it warms up.

Purpose

To observe the temperature change as ice changes to liquid water and to create a heating graph of water

Equipment and Materials

- 500 mL beaker
- retort stand
- ring clamp
- hot plate
- thermometer
- thermometer clamp
- test tube
- test tube holder
- test tube rack
- stopwatch or timer
- crushed ice

Procedure

1. Read through this Procedure and create a table suitable for collecting the data in the investigation.
2. Place a retort stand with a ring clamp and a thermometer clamp beside a hot plate. Turn the iron ring until it is over the hot plate. The iron ring needs to be large enough for a 500 mL beaker to sit inside it.
3. Fill the beaker two thirds full with crushed ice. Place it inside the ring over the hot plate.
4. Place a thermometer in the thermometer clamp and immerse the thermometer in the crushed ice until the thermometer bulb is 1 cm to 2 cm above the bottom of the beaker.
5. Turn the hot plate on to the high setting.
6. Take the temperature of the ice-water mixture every 15 s, using a stirring rod to stir between measurements. Record these values in your data table.

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7. In your data table, note the temperature at which you first notice the ice melting into liquid water, the temperature at which the last crystal of ice melts into liquid water, and the temperature at which the liquid water begins to boil.
8. Stop taking measurements when the water has boiled for approximately 1 min.
9. Clean up all of the equipment and return it to where you found it. Be careful with the hot plate as it will maintain its temperature for a long time after it has been turned off.
10. Create a temperature-time graph for the data. In your graph, label the various regions of the graph (as in **Figure 4** on page 00) and the three points noted in Step 7.

Analyze and Evaluate

(a) What variables were measured in this investigation?

(b) Compare your heating graph of water with the heating graph in **Figure 4** on page XX. Describe any similarities and differences. Suggest reasons for any differences you noticed.

(c) Use the kinetic molecular theory to describe what is happening to the water molecules in the different regions of the graph.

(d) Use your graph to determine the melting point of water. Why might this measured value deviate from the accepted value of 0 °C?

(e) Use your graph to determine the boiling point of water. Why might this value deviate from the accepted value of 100 °C?

(f) Suggest sources of error for this investigation. How might these sources of error be avoided?

Apply and Extend

(g) [TO COME]

Investigation 6.3.2 OBSERVATIONAL STUDY

SKILLS MENU

- Questioning
- Hypothesizing
- Predicting
- Planning
- Controlling Variables
- Performing
- Observing
- Analyzing
- Evaluating
- Communicating

Specific Latent Heat of Fusion for Ice

The latent heat of fusion is the amount of thermal energy required for a substance to melt or freeze. The amount of thermal energy required is specific to a substance because of its individual chemical properties. In this investigation you will determine the latent heat of fusion for melting ice.

Purpose

To observe the specific latent heat of fusion for ice

Equipment and Materials

- electronic balance
- thermometer
- Styrofoam cup
- ice cubes

Procedure

1. Find the mass of the empty Styrofoam cup on an electronic balance. Record this value in a copy of **Table 1**.

Table 1 Data to determine the latent heat of fusion of ice

Mass of Styrofoam cup (kg)	
Mass of Styrofoam cup and hot water (kg)	
Mass of hot water (kg)	
Initial temperature of hot water (°C)	
Final temperature of water (°C)	
Final mass of Styrofoam cup and water (kg)	
Mass of ice (kg)	

2. Fill the Styrofoam cup half full with hot water from the tap. Measure and record the mass of the cup and hot water.
3. Calculate and record the mass of the hot water.
4. Use the thermometer to measure the initial temperature of the hot water. Record this value.
5. Immediately add four ice cubes to the water. Stir the mixture with a stirring rod until the ice completely melts.

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6. As soon as the last piece of ice melts, record the temperature of the water. This is the final temperature of the water.
7. Place the Styrofoam cup back on the balance and determine the final mass. Calculate and record the mass of the ice.
8. Calculate the thermal energy lost by the hot water using the equation $Q = mc\Delta T$.
9. The amount of thermal energy lost by the hot water (Q) is equal to the amount of thermal energy gained by the ice. Use the value calculated in Step 8 and the equation $Q = mL_f$ to calculate the specific latent heat of fusion for ice.
10. The known value for the specific latent heat of fusion of ice is 3.4×10^5 j/kg. Determine the percent error using the equation

$$\text{Percent error} = \frac{\text{accepted value} - \text{measured value}}{\text{accepted value}} \times 100\ \%$$

11. Suggest sources of error for this investigation. How might these sources of error be avoided?

Analyze and Evaluate

[TO COME]

(a)

(b)

(c)

(d)

Apply and Extend

(e) Cities like Toronto that are near large bodies of water that freeze in the winter experience cooler springs and warmer winters than cities that are not near large bodies of water. How does the latent heat of fusion of water help explain this cooling and warming effect?

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CHAPTER 6 SUMMARY

Summary Questions

1. Create a study guide based on the points in the margin on page XXX. For each point, create three or four subpoints that provide further information, relevant examples, explanatory diagrams, or general equations.
2. Look back at the Starting Points questions on page XXX. Answer these questions using what you have learned in this chapter. Compare your latest answers with those that you wrote at the beginning of the chapter. How has your understanding changed during the study of this chapter? Note how your answers have changed.

Vocabulary

kinetic molecular theory (p. XXX)
thermal energy (p. XXX)
temperature (p. XXX)
Celsius scale (p. XXX)
Fahrenheit scale (p. XXX)
Kelvin scale (p. XXX)
melting point (p. XXX)
freezing point (p. XXX)
boiling point (p. XXX)
condensation point (p. XXX)
heat (p. XXX)
thermal conduction (p. XXX)
convection (p. XXX)
convection current (p. XXX)
radiation (p. XXX)
thermal conductor (p. XXX)
thermal insulator (p. XXX)
specific heat capacity (c) (p. XXX)
quantity of heat (Q) (p. XXX)
principle of thermal energy exchange (p. XXX)
thermal expansion (p. XXX)
thermal contraction (p. XXX)
fusion (p. XXX)
heating graph (p. XXX)
cooling graph (p. XXX)
latent heat (Q) (p. XXX)
latent heat of fusion (p. XXX)
latent heat of vaporization (p. XXX)
specific latent heat (L) (p. XXX)
specific latent heat of fusion (L_f) (p. XXX)
specific latent heat of vaporization (L_v) (p. XXX)
electric heating system (p. XXX)
forced-air heating system (p. XXX)
hot water heating system (p. XXX)
geothermal system (p. XXX)

CAREER PATHWAYS

SKILLS HANDBOOK T/K

Grade 11 Physics can lead to a wide range of careers. Some require a college diploma or a B.Sc. degree. Others require specialized or post-graduate degrees. This graphic organizer shows a few pathways to careers mentioned in this chapter.

1. Select an interesting career that relates to Thermal Energy. Research the educational pathway you would need to follow to pursue this career.
2. What is involved in becoming a [XXXX]? Research at least two pathways that could lead to this career, and prepare a brief report of your findings.

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Reference still to come.

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To Come

To do an online self-quiz,

GO TO NELSON SCIENCE

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To Come

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