# Heat

6.2

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 releases 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 also includes the potential energy associated with the object's particles. How do the kinetic energy and the 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 material 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 that they have is different. 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 (**Figure 1(b)**). The more massive nail has more thermal energy than the less massive nail even though both nails have the same temperature.

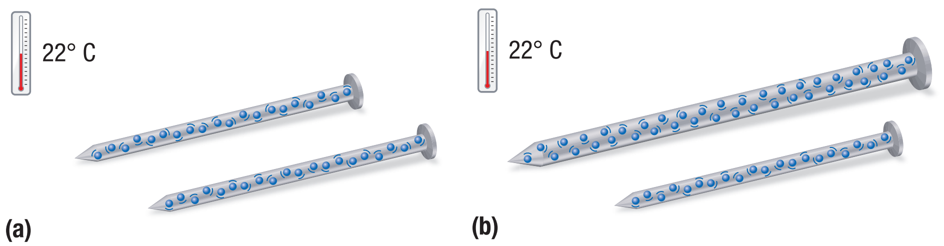


**Figure 1** (a) Two 1.0 g iron nails at the same temperature (22 °C) have the same amount of thermal energy. (b) A 1.0 g iron nail and a 2.0 g iron nail at the same temperature do not have the same amount of thermal energy. The 2.0 g iron nail has twice as many vibrating iron atoms as the 1.0 g iron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

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. So, 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 they will likely contain different amounts of thermal energy. 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 thermal energy includes both 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. The increase in kinetic energy, in turn, increases the temperature of the substance. Part of the absorbed energy also increases the potential energy of the particles. Note that an increase in potential energy does not increase the temperature of the substance. The proportion of the absorbed energy that goes toward increasing the potential energy of the particles is different in different substances.

## Distinguishing between Thermal Energy and Heat

**heat** the transfer of thermal energy from a substance with a higher temperature to a substance with a lower temperature

Thermal energy is the sum of the potential and kinetic energies possessed by the particles of an object. However, **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 a substance that makes objects become warmer. For example, in the phrase, "a glass of hot water has more heat in it than a glass of cold water," the word "heat" is being used in a non-scientific way. In science, thermal energy, not heat, is responsible for an object's warmth or coldness. It would be more correct to say, "a glass of hot water has more *thermal energy* in it than a glass 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 asking you to 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.

WEB **LINK**

To learn more about the methods of heat transfer,

GO TO NELSON SCIENCE

### Methods of Transferring Thermal Energy

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 can move 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 are in physical contact with colder objects

Thermal energy can move from a warmer object to a colder object by a process called **thermal conduction** if the two substances physically touch each other. 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**).

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 spoon, transferring thermal energy 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. This results in the thermal energy being transferred from the spoon's ladle to the spoon's handle until the thermal energy is evenly distributed throughout the spoon.

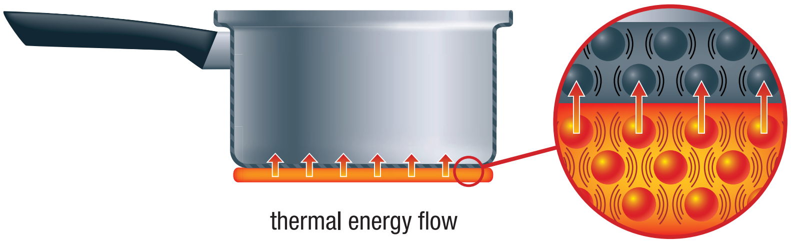


**Figure 2** The transfer of thermal energy from an electric stove element to a metal pot involves thermal conduction.

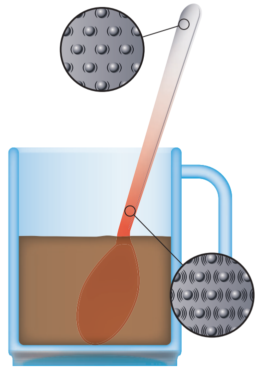

**Figure 3** Thermal energy slowly moves up the spoon by conduction as the spoon sits in a hot liquid.

## 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 warmer, less dense fluid. We can illustrate the process of convection by analyzing the changes that occur in a pot of water that is being heated on a stovetop (**Figure 4**). When the water particles 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 than the colder water above it. 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 farther 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.

**convection** the transfer of thermal energy through a fluid that occurs when colder, denser fluid falls and pushes up warmer, less dense fluid

**convection current** a current that occurs when a fluid is continuously heated; caused by warmer, less dense fluid being constantly pushed upward as colder, denser fluid falls downward

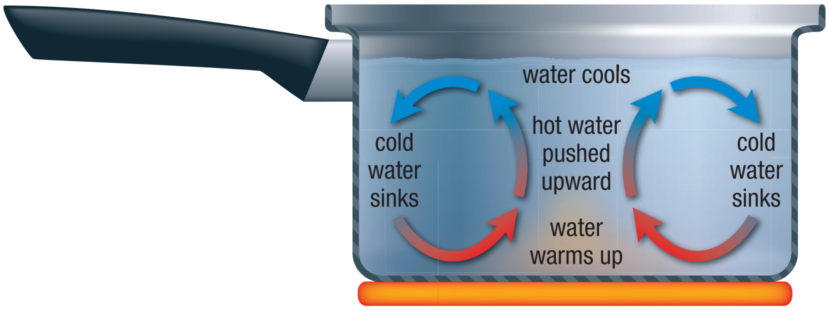


**Figure 4** Convection currents cause the liquid in the pot to move around, spreading the thermal energy evenly.

Convection currents 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.

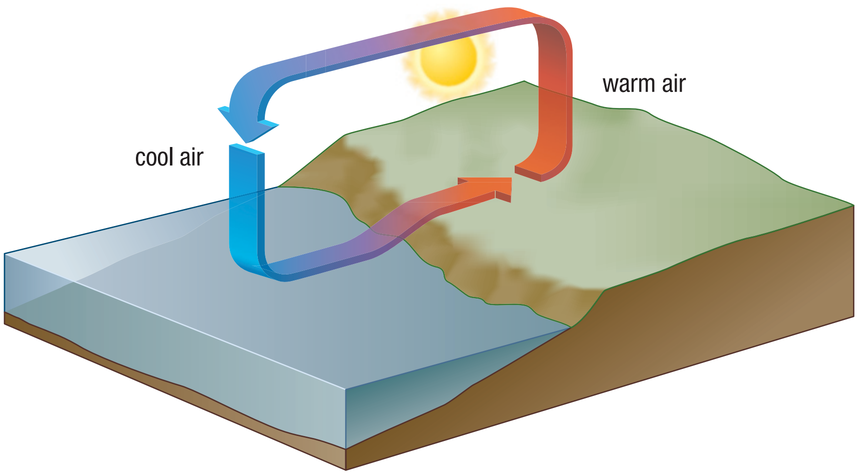


**Figure 5** During the day, ocean breezes are created when cool air above the water falls downward and onto the land, pushing the warmer air over the land upward.

## TRANSFER OF THERMAL ENERGY BY RADIATION

**radiation** the movement of thermal energy as electromagnetic waves

Thermal energy can also be transferred by radiation. **Radiation** is a thermal energy transfer that involves electromagnetic waves being emitted from sources such as lamps, flames, and the Sun. While the Sun is the largest source of radiant energy, all particles that have kinetic energy emit some radiant energy (**Figure 6**). These waves travel through materials such as air or glass or even through empty space.

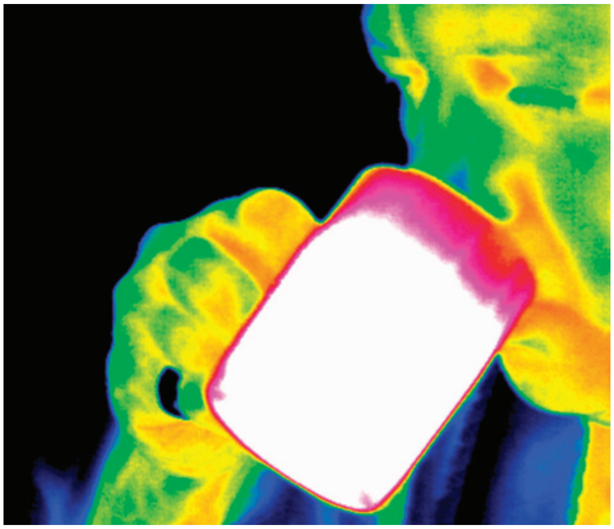

**Figure 6** A thermal imaging camera can detect infrared radiation and produce an image called a thermogram.

## Mini **Investigation**

### Observing Convection

**Skills:** Performing, Observing, Analyzing

SKILLS HANDBOOK A2.1

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

**Equipment and Materials:** 4 identical bottles; blue and 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 bottle.
3. Use an index card to cover the top of one blue, cold water bottle. Make sure there is a good seal between the card and the bottle, and then flip the bottle over. Place this bottle on top of one of the yellow, hot water bottles. Hold onto the top bottle and slide the index card out, making sure the mouths of both bottles stay overlapped (**Figure 7**). Water will move back and forth between the bottles but it should not spill out. Observe what happens.
5. Repeat the activity, only this time put the other yellow, hot water bottle on top of the other blue, cold water bottle. Observe what happens.

**Figure 7**

A. Use the concept of convection to explain what you observed in Step 3. K/U T/I

B. Explain why your observations were different in Step 4. T/I

## 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 in 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? 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. So, when your hand touches a metal sink, thermal energy moves easily and quickly from your hand to 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

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 molecules in gases such as air are farther apart than the particles in solids and liquids. So, 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

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 into the house or from inside the house to the outside. Understanding which materials reduce the transfer of thermal energy can help people develop better building materials. Programs such as R-2000 and LEED (Leadership in Energy and Environmental Design) are intended to promote the use of effective thermal insulation in energy-efficient homes in Canada.

**CAREER LINK**

Many products are designed to take advantage of the thermal insulating properties of materials. To learn more about a career researching and designing thermal insulating products,

GO TO NELSON SCIENCE

**WEB LINK**

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

GO TO NELSON SCIENCE

**Figure 8** Thermal insulators include (a) fur, (b) fibreglass, and (c) foam insulation. All of these materials trap air and help to prevent the transfer of thermal energy from an object to the surroundings.

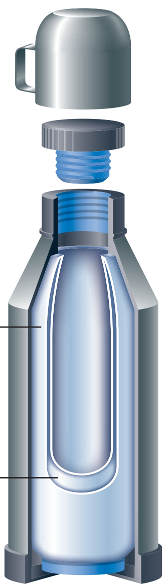


**Figure 9** The layers of a Thermos bottle minimize conduction, convection, and radiation of thermal energy, keeping the contents cool or hot.

The best thermal insulator of all is a vacuum. A vacuum contains no particles or very few particles. So, thermal energy cannot be transferred by conduction or convection. A Thermos bottle (**Figure 9**) is an example of a device used to keep hot foods hot and cold foods 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 may be transferred by radiation.

## 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 surroundings. 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 undesirable and a wasteful form of energy for the car since it does not contribute to the car's motion. As a result, 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 may want 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 large proportion of the input energy into thermal energy. Electric furnaces are essentially 100 % efficient, meaning that virtually all of the input electrical energy is transformed into thermal energy. The most efficient natural gas furnaces are approximately 96 % efficient while older, less efficient versions are about 60 % efficient.

UNIT TASK **BOOKMARK**

You can apply what you have learned about thermal energy transformation efficiency to the Unit Task on page 360.

## 6.2 Summary

- Thermal energy is the total amount of kinetic energy and potential energy of the particles in a 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: by thermal conduction, by convection, or by radiation.

## 6.2 Questions

1. How do thermal energy, temperature, and heat differ? K/U
2. Define thermal conduction, convection, and radiation. K/U
3. Why does a tile floor feel much colder to your bare feet than a thick carpet does? K/U
4. If the efficiency of an electric furnace is 96 %, then 96 % of the input electrical energy is transformed into thermal energy. What is the other 4 % of the electricity transformed into? A
5. Are the following materials used because they are a good thermal conductor or a good thermal insulator? Explain why. K/U
   (a) copper pot
   (b) wooden spoon
   (c) metal ice-cube tray
   (d) down-filled sleeping bag