9.3 Heat Transfer

Thermal energy flows from a material at a higher temperature to a material at a lower temperature. This process is called heat transfer. How is heat transferred from material to material, or from place to place? It turns out there are three ways that heat flows. In this section, you will learn about heat conduction, convection, and thermal radiation.

Heat conduction

What is conduction? Heat conduction is the transfer of heat by the direct contact of particles of matter. If you have ever held a mug of hot cocoa, you have experienced conduction. Heat is transferred from the mug to your hand. Conduction only occurs between two materials at different temperatures when they are touching each other. In conduction, heat can also be transferred through materials. If you stir hot cocoa with a metal spoon, heat is transferred from the cocoa, through the spoon, and to your hand.

Conduction is the transfer of heat by the direct contact of particles of matter.

How does conduction work? Imagine placing a cold spoon in the mug of hot cocoa (Figure 9.18). The molecules in the cocoa have a higher average kinetic energy than those of the spoon. The molecules in the spoon exchange energy with the molecules in the cocoa through collisions. The molecules in the spoon spread the energy up the spoon through the intermolecular forces between them. Conduction works through both collisions and also through the intermolecular forces between molecules.

 Thermal equilibrium As collisions continue, the molecules of the hotter material (the cocoa) lose energy and the molecules of the cooler material (the spoon) gain energy. The kinetic energy of the hotter material is transferred to the cooler material, as the molecular collisions occur. Eventually, both materials are at the same temperature. When this happens, they are in thermal equilibrium. Thermal equilibrium occurs when two bodies have the same temperature. No heat flows in thermal equilibrium because the temperatures are the same.
9.3 Heat Transfer

**Thermal conductors and insulators**

**Which state of matter conducts heat best?**

Conduction can happen in solids, liquids, and gases. Solids make the best conductors because their particles are packed closely together. Because the particles in a gas are so far apart, relatively few collisions occur; air, for instance, is a poor conductor of heat. This explains why many materials used to keep things warm, such as fiberglass insulation and down jackets, contain air pockets (Figure 9.19).

**Thermal conductors and insulators**

Materials that conduct heat easily are called **thermal conductors** and those that conduct heat poorly are called **thermal insulators**. For example, metal is a thermal conductor, and a foam cup is a thermal insulator. The words *conductor* and *insulator* are also used to describe a material’s ability to conduct electrical current. In general, good electrical conductors—like silver, copper, gold, and aluminum—are also good thermal conductors.

**Heat conduction cannot occur through a vacuum**

Conduction happens only if there are particles available to collide with one another. For this reason, heat transfer by conduction cannot occur in the vacuum of space. One way to create an excellent thermal insulator on Earth is to make a vacuum. A thermos bottle keeps liquids hot for hours using a vacuum. It is a container consisting of a bottle surrounded by a slightly larger bottle. Air molecules have been removed from the space between the bottles to create a vacuum. This prevents heat transfer by conduction. A small amount of heat is conducted through the cap and the glass where the two walls meet, so eventually the contents will cool, only much slower than they would otherwise (Figure 9.20).

*Figure 9.19: Because air is a poor conductor of heat, a down jacket keeps you warm in the cold of winter.*

*Figure 9.20: A thermos bottle uses a vacuum to prevent heat transfer by conduction and convection.*
Convection

What is convection? Have you ever watched water boil in a pot? Bubbles form on the bottom and rise to the top. Hot water near the bottom of the pan circulates up, forcing cooler water near the surface to sink. This circulation carries heat through the water (Figure 9.21). This heat transfer process is called convection. Convection is the transfer of heat through the motion of fluids, such as air and water.

Natural convection Fluids expand when they heat up. Since expansion increases the volume, but not the mass, a warm fluid has a lower mass-to-volume ratio (called density) than the surrounding cooler fluid. In a container, warmer fluid floats to the top and cooler fluid sinks to the bottom. This is called natural convection.

Forced convection In many houses, a boiler heats water and then pumps circulate the water to the rooms. Since the heat is being carried by a moving fluid, this is another example of convection. However, since the fluid is forced to flow by the pumps, this is called forced convection.

Natural and forced convection Both natural and forced convection often occur at the same time. Forced convection transfers heat to a hot radiator. The heat from the hot radiator then warms the room air by natural convection. The warmer air rises and cooler air from the far side of the room replaces it. Then the cooler air is warmed and rises. The circulation distributes heat throughout the room.

Figure 9.21: Convection currents in water. The hot water at the bottom of the pot rises to the top and replaces the cold water.
Thermal radiation

Definition of thermal radiation
If you stand in the Sun on a cold, calm day, you will feel warmth from the Sun. Heat from the Sun is transferred to Earth by thermal radiation. Thermal radiation is electromagnetic waves produced by objects because of their temperature. All objects with temperatures above absolute zero (−273 °C or −459°F) emit thermal radiation. To emit means to give off.

What is an electromagnetic wave?
An electromagnetic wave is the result of oscillating electric and magnetic fields. For example, visible light is an electromagnetic wave. You will learn more about electromagnetic waves in Chapter 23.

Thermal radiation comes from atoms
Thermal radiation comes from the thermal energy of atoms. The energy in thermal radiation increases with higher temperatures because the thermal energy of atoms increases with temperature (Figure 9.22). Because the Sun is extremely hot, its atoms emit lots of thermal radiation.

Objects emit and absorb radiation
Thermal radiation is also absorbed by objects. An object constantly receives thermal radiation from everything else in its environment. Otherwise, all objects would eventually cool down to absolute zero by radiating their energy away. The temperature of an object rises if more radiation is absorbed. The temperature falls if more radiation is given off. The temperature adjusts until there is a balance between radiation absorbed and radiation emitted.

Some surfaces absorb more energy than others
The amount of thermal radiation absorbed depends on the surface of a material. Black surfaces absorb almost all the thermal radiation that falls on them. For example, black asphalt pavement gets very hot in the summer sunlight because it effectively absorbs thermal radiation. A silver mirror surface reflects most thermal radiation; it absorbs very little (Figure 9.23). A mirrored screen reflects the Sun’s heat back out of your parked car, helping it stay cooler on a hot day.

Radiation can travel through space
Thermal radiation can travel through the vacuum of space. Conduction and convection cannot carry heat through space because both processes require matter to transfer heat. Thermal radiation is different because it is carried by electromagnetic waves that do not require matter to provide a path for heat flow. Thermal radiation also travels fast—at the speed of light in a vacuum.
The rate of heat transfer

The cause of heat transfer
In nature, heat transfer always occurs from hot to cold until thermal equilibrium is reached. The rate of heat transfer is proportional to the difference in temperature. If the temperature difference is large, heat flows faster than when the temperature difference is small.

Heat transfer in living things
Heat flow is necessary for life. Biological processes release energy. Your body regulates its temperature through the constant flow of heat. The inside of your body averages 98.6°F. Humans are most comfortable when the air temperature is about 75°F because the rate of heat flow out of the body matches the rate at which the body generates heat internally. If the air is 50°F, you get cold because heat flows too rapidly from your skin to the air. If the air is 100°F, you feel hot, partly because heat flows from the air to your body and partly because your body cannot get rid of its internal heat fast enough (Figure 9.24).

Heat transfer is everywhere
All three forms of heat transfer are usually working at the same time to transfer energy from warmer objects to cooler objects. Heat flow continues as long as there is a temperature difference. If you look around you, you can see heat transfer virtually everywhere—between air and objects, between objects, and even between you and the environment!

9.3 Section Review

1. Name one example of heat transfer through conduction.
2. What is the primary type of heat transfer that occurs between a hot and a cold fluid when they are mixed together?
3. Which object would you expect to emit more thermal radiation: a lamp that is turned on, or a rock at room temperature? Explain your answer.
4. In which direction will heat flow between an ice cube and the air in the room where it is located? Explain your answer.