

# Thermal Energy Transfer

## Reflect

What kinds of things flow? Water flows in rivers, air flows as winds blow across the planet. What about heat?

Water and air are fluids, which means they are substances. It is easy to imagine how they flow. Heat is not a substance; it is a form of energy. However, heat does move from place to place. How do you think heat moves or “flows”? In this companion you will learn three different ways that heat “flows.”

### Heat is different than thermal energy.

Often people talk about heat and thermal energy as though they are identical. However, there is an important difference. Heat is thermal energy that is being transferred from one place to another. So what is thermal energy? All matter is made of tiny particles, much too small to be seen. These particles are always in motion, and motion is a form of energy. An object’s thermal energy equals the total energy of all its moving particles. Heat transfer happens when some of this energy moves from one object to another object.



Energy is never created and never destroyed; it simply changes form. This is the law of conservation of energy. Most forms of energy are eventually transformed into thermal energy, which then flows away into nature. This is what we mean when we say that a system loses energy as heat. In most cases, we cannot capture and reuse this energy. For example, a fire gives off heat as it burns. Eventually, the fire burns itself out. Its energy has not been destroyed, even though we can no longer use it. It has simply been transformed into heat.



## Look Out!

Temperature does not measure heat or thermal energy. Temperature measures the average energy of motion of an object’s particles. Thermal energy is a measure of the total energy of motion of an object’s particles.

Suppose a glass of water and a lake of water have the same temperature. The average water particle in the lake and the average water particle in the glass have the same energy of motion. However, the lake has much greater thermal energy because it contains many more particles.



A thermometer measures the average energy of particle motion in an object.

# Thermal Energy Transfer

## Look Out!

**Thermal energy is transferred by three main processes.**

How does thermal energy move as heat from one object to another? Think of the different ways you experience heat. You feel heat as the sun shines on you and as you sit by a fire. You can use a microwave oven to heat cold food. If you place a pot of water on a hot stove, you can see the water begin to boil. The stove can burn you if you touch it. Each of these processes involves the transfer of heat. How are they similar? How are they different?

**Thermal energy can transfer by conduction.**

Try to imagine the tiny, constantly moving particles that make up an object. In a solid object, these particles vibrate back and forth without changing position. Now imagine placing a solid metal frying pan on a hot burner on a stovetop. The burner transfers heat to the pan, and the pan gets hot. The bottom of the pan gets hot before the pan's handle. Why does this happen?



When the burner is turned on, the handle of the pan will get hot last.

Before the pan is placed on the burner, its particles are moving at the same average speed. The whole pan is at the same temperature. The hot burner is at a much higher temperature. In other words, the particles that make up the burner are moving at a greater average speed and therefore have greater thermal energy.

When the pan is placed on the stove, the burner's particles collide with the particles in the bottom of the pan. Some of the **energy** in the burner's particles moves to the pan's particles. As a result, the particles in the bottom of the pan begin to move faster. These particles collide with nearby particles in the pan, which collide with other particles. Each collision passes **energy** from particles moving quickly to particles moving slowly. In this way, the energy spreads throughout the pan and finally reaches the handle.

This process is called conduction. Conduction is the transfer of heat that happens when particles collide with each other. It can happen in solids, liquids, and gases.

**Thermal energy can transfer by radiation.**

You don't actually have to touch a hot frying pan to know it is hot. If you hold your hand a few inches from the pan, you can feel the heat. How is it possible to feel heat without touching a hot object? The answer is that hot objects emit radiation.

Radiation is energy that travels as electromagnetic waves. You do not need to touch an electromagnetic wave to feel it. Sunlight is another form of radiation. Light from a light bulb and heat from our bodies are also examples of radiation. Microwaves use radiation to heat food.

Like light, heat waves can travel through air—they can even move through empty space! Think about standing around a campfire or in front of a fire in a fireplace. Most of the heat you feel reaches you by radiation. If a large group of people are gathered around a campfire, only the people in the front will feel the heat. If someone is standing in front of you, they will block the radiant heat from reaching you.

# Thermal Energy Transfer

## Look Out!



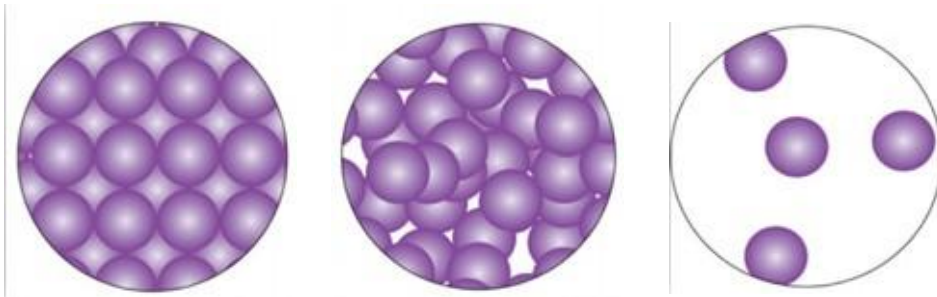
When radiation occurs, the waves move out in all directions from the producer of the energy.

### **Thermal energy can transfer by convection.**

Let's talk more about the frying pan. Many kitchen stoves have hoods several feet above the burners. The purpose of the hood is to carry smoke and other fumes away from the stovetop. But why is the hood above the stove? Why isn't it on the side? Similarly, why are chimneys above fireplaces? You never see a chimney next to or beneath a fireplace. The answer is that hot air rises.

The campfire warms people by transferring heat through radiation.

This brings us to the third type of heat transfer: convection. During conduction, heat energy moves between particles that touch. During convection, however, the particles themselves move. This happens only in liquids and gases because the particles in solids are stuck in place and cannot move. Particles that move more quickly are "hotter." As hot particles move into a new area, they increase the area's thermal energy. This makes the area hotter as well.



In solids (left), particles are stuck in place. In liquids (center) and gases (right), particles flow easily around each other. Note that a drop of liquid contains more particles than an equal amount of gas. Particles in gases have more energy and move greater distances.

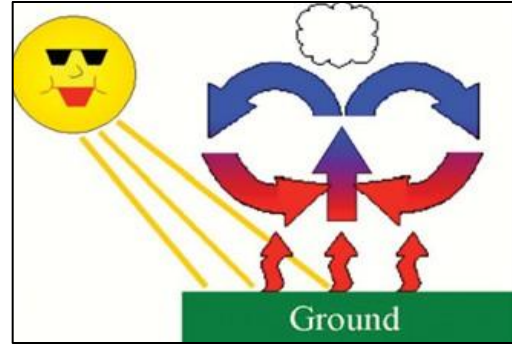
As particles increase their speed, they also move farther apart. As the particles in a group move apart, the whole group becomes lighter than the surrounding, "colder" particles. As a result, the "hotter" particles rise. As particles rise, they gradually lose energy, cool, and sink. This creates a **cycle** of rising and sinking particles. This circular motion is called a convection cycle.

# Thermal Energy Transfer

## Look Out!



Hot air balloons rise because of convection. A flame heats air particles inside the balloon. The heated air rises because it is lighter than the surrounding air outside the balloon. As the heated air rises, the balloon rises as well.



As sunlight heats the ground, air above the ground warms and rises. As the air rises it cools and sinks back to the ground, where it heats and rises again. This results in a convection cycle—and causes wind. Also, convection cycles in seawater power ocean currents.

### Heat flows in a predictable pattern.

Remember this important rule about heat flow: When objects of different temperatures are in contact, heat **always** moves from the warmer to the cooler object until their temperatures are equal.

If you accidentally touch a hot burner, the heat moves from the burner to your hand because your hand is cooler. What happens if you touch a piece of ice? Heat moves from your hand, which is warmer, to the ice, which is cooler. In other words, your body loses heat—that is why ice feels cold.

## What Do You Think?

A metal hammer has been lying in the sunlight on a hot day. When you pick up the hammer, it feels very warm in your hand. Can you explain the different ways that heat is moving in this situation?

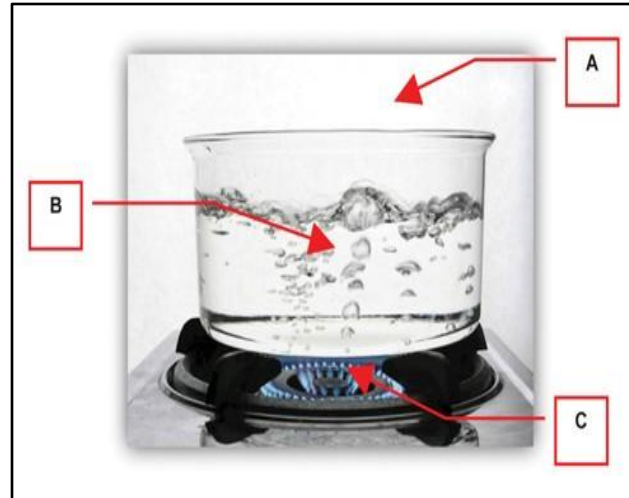
# Thermal Energy Transfer

## What Do You Think?

A pot is placed on a gas flame, and the water inside the pot begins to boil. Heat moves in three different ways, as shown in the image below. (Hint: "A" is labeling the steam.)

Which part of the image shows conduction? Which part shows convection? Which part shows radiation? Write your answers below.

- A. Heat is carried away from the pot in all directions. This shows \_\_\_\_\_.
- B. Warm water rises within the pot. This shows \_\_\_\_\_.
- C. Heat moves from the flame to the pot's bottom. This shows \_\_\_\_\_.



## Getting Technical: How a Refrigerator Works

A refrigerator relies on the properties of gases to stay cool. Inside a refrigerator is a part called a compressor and another part called an expansion valve. Metal coils connect these two parts. Inside these coils is a substance called tetrafluoroethane (HFC).



Depending on the amount of pressure put on it, HFC can be either a liquid or a gas. As the HFC flows through the compressor, it is squeezed into a gas. This causes the HFC to heat up. The heat is released into the air outside the refrigerator.

The HFC then flows through the expansion valve. There, the pressure is decreased and the HFC expands back into a liquid. When this happens, it gets very cold. The cold liquid flows through the refrigerator, cooling it. This process requires a lot of energy. Most refrigerators are powered by electric motors. Can you explain how this process demonstrates Thermal Energy Transfer?

This is the compressor of a kitchen refrigeration unit. It is in the back of the refrigerator.



# Thermal Energy Transfer

## What Do You Think?

Which way does heat travel? Think about what happens when you touch something like a hot hamburger. The thermal energy from the hamburger is shared with your hand. Your hand feels warmer than before it touched the hamburger. The hamburger loses some of its thermal energy so it becomes cooler. The energy from the hamburger is transferred to your hand.



Thermal energy is always shared between objects that touch each other, like your hand and a hamburger. The thermal energy always travels from the item with the most thermal energy to the item with the least. Find out how the heat moves with this activity:

**Purpose:** To determine whether heat travels from warm to cold or from cold to warm.

**Materials:** 2 thermometers; Hot water; Cold water; Large beaker; Small beaker.

### Procedure

1. Fill the large beaker  $\frac{1}{2}$  full of hot boiling water.
2. Fill the small beaker  $\frac{1}{2}$  full of cold refrigerated water.
3. Place a thermometer in each beaker.
4. Record the two temperatures.
5. Carefully set the small beaker WITH THE THERMOMETER STILL IN THE BEAKER inside the large beaker.
6. Check both water temperatures after 10 minutes.
7. Record final temperatures.

### Data

Water Temperature in °C		
	Start T °C	End T °C
Large beaker/ Hot Water		
Small beaker/ Cold Water		

### Conclusion

Which way does heat travel? Explain your answer.

## Connecting With Your Child

### Comparing Thermal Insulators and Conductors

For this experiment, you and your child will need eight identical plastic bottles filled with water. (You can complete the activity with fewer water bottles, but it will take longer.) Place a thermometer in one bottle, and then put all the bottles in the refrigerator. Wait about an hour for all the bottles to cool to the refrigerator's temperature; then, remove the bottles and record the temperature using the thermometer in the one bottle.

Next, your child should follow this procedure:

1. Wrap four bottles in these materials (one per bottle):
  - A wool sweater
  - A cotton T-shirt
  - Aluminum foil
  - Bubble wrap
2. Pour the water from one bottle into a metal container.
3. Pour the water from one bottle into an insulated container.
4. Place one bottle in a bowl of ice up to the shoulder of the bottle.
5. Leave one bottle sitting with nothing on it.

After 30 minutes, record the temperature of the water in each bottle and/or container. List the materials from lowest temperature to highest temperature. Which material prevented the most heat loss? (This material is a good *insulator* or a poor *conductor*.) Which material prevented the least heat loss? (This material is a good *conductor* or a poor *insulator*.)

Your child should have noted that aluminum foil was the best conductor. Explain that aluminum is a metal, and most metals are good conductors.

Here are some questions to discuss with your child after the experiment:

- If you want to stay warm on a cold day, should you wear a wool sweater or a cotton shirt? Why?
- What are some things made of insulating materials to prevent heat flow?
- What are some things made of conducting materials to encourage heat flow?
- If you place the bottles of water in the sunlight, the water will become warmer. Which process of heat transfer warms the water: conduction, convection, or radiation? Explain.
- If you pour the water into a metal pot and heat it on a stove, the water will become warmer. Which process of heat transfer warms the water? Explain.

