Lesson 3

Thermal Energy and Heat

ESSENTIAL QUESTION

What is the relationship between heat and temperature?

By the end of this lesson, you should be able to analyze the relationship between heat, temperature, and thermal energy.

6.PS3.1, 6.PS3.3, 6.PS3.4

The Afar Depression, in eastern Africa, is one of the hottest places on Earth. In the summer, temperatures average over 38 °C (100 °F)!
Engage Your Brain

1 Describe Fill in the blanks with the words that you think correctly complete the following sentences.

When you put your hands on a cold object, like a glass of ice water, your hands become ______________. The glass of water becomes ______________ if you leave your hands on it for a long time. If you leave the glass of ice water out in the sun, the ice will start to ______________.

2 Describe Write your own caption for this photo.

Active Reading

3 Apply Many scientific words, such as conductor, also have everyday meanings. Use context clues to write your own definition for each meaning of the word conductor.

Example sentence That school’s band is very good because its conductor is a great teacher.

conductor:

Example sentence That metal spoon is a good conductor, so it will get hot if you put it into boiling soup.

conductor:

Vocabulary Terms

- temperature
- thermal energy
- heat
- calorie
- conduction
- conductor
- insulator
- convection
- radiation

4 Apply As you learn the definition of each vocabulary term in this lesson, create your own definition or sketch to help you remember the meaning of the term.
**What is temperature?**

Temperature is a measure of the average kinetic energy of all the particles in a substance. In the Celsius and Fahrenheit scales, temperature is measured in units called degrees. Degrees (°) are equally spaced units between two points. The space between degrees can vary from scale to scale. In the Kelvin scale, no degree sign is used. Instead, the unit is just called a kelvin. Temperature is measured using an instrument called a thermometer.

**What is thermal energy?**

Thermal energy is the total kinetic energy of all particles in a substance. In the SI system, thermal energy is measured in joules (J). If you have two identical glasses of water and one is at a higher temperature than the other, the particles in the hotter water have a higher average kinetic energy. The water at a higher temperature will have a higher amount of thermal energy.

**What is the difference between thermal energy and temperature?**

Temperature and thermal energy are different from each other. Temperature is related to the average kinetic energy of particles, while thermal energy is the total kinetic energy of all the particles. A glass of water can have the same temperature as Lake Superior, but the lake has much more thermal energy because the lake contains many more water molecules.

After you put ice cubes into a pitcher of lemonade, energy is transferred from the warmer lemonade to the colder ice. The lemonade’s thermal energy decreases and the ice’s thermal energy increases. Because the particles in the lemonade have transferred some of their energy to the particles in the ice, the average kinetic energy of the particles in the lemonade decreases. Thus, the temperature of the lemonade decreases.

**Active Reading 5 Explain** What are two factors that determine the thermal energy of a substance?
Under Where?

There are fewer water molecules in this glass than in the lake.

6 Apply For each object pair in the table below, circle the object that has more thermal energy. Assume that both objects are at the same temperature.

<table>
<thead>
<tr>
<th>bowl of soup</th>
<th>small balloon</th>
<th>tiger</th>
</tr>
</thead>
<tbody>
<tr>
<td>pot of soup</td>
<td>large balloon</td>
<td>house cat</td>
</tr>
</tbody>
</table>
Heat It Up!

What is heat?

You might think of the word *heat* as having to do with things that feel hot. But heat also has to do with things that feel cold. Heat causes objects to feel hot or cold or to get hot or cold under the right conditions. You probably use the word *heat* every day to mean different things. However, in science, *heat* is the energy transferred from an object at a higher temperature to an object at a lower temperature.

When two objects at different temperatures come into contact, energy is always transferred from the object that has the higher temperature to the object that has the lower temperature. Energy in the form of heat always flows from hot to cold. For example, if you put an ice cube into a glass of water, energy is transferred from the warmer water to the colder ice cube.

7 Apply For each object pair in the table below, draw an arrow in the direction in which energy in the form of heat would flow.

<table>
<thead>
<tr>
<th>Object 1</th>
<th>Direction of heat flow</th>
<th>Object 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>metal rod</td>
<td>fire</td>
<td>snowman</td>
</tr>
<tr>
<td>hat</td>
<td>glass of warm water</td>
<td></td>
</tr>
<tr>
<td>ice cube</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
How is heat measured?

Heat is measured in two ways. One way is the calorie (cal). One calorie is equal to the amount of energy needed to raise the temperature of 1 g of water by 1 °C. Heat can also be measured in joules (J) because heat is a form of energy. One calorie is equal to 4.18 J.

You probably think of calories in terms of food. However, in nutrition, one Calorie—written with a capital C—is actually one kilocalorie, or 1,000 calories. This means that one Calorie (Cal) contains enough energy to raise the temperature of 1 kg of water by 1 °C. Each Calorie in food contains 1,000 cal of energy.

To find out how many Calories are in an apple, the apple is burned inside an instrument called a calorimeter. A thermometer measures the increase in temperature, which is used to calculate how much energy is released. This amount is the number of Calories.

How is heat related to thermal energy?

Adding or removing heat from a substance will affect its temperature and thermal energy. Heat, however, is not the same as thermal energy and temperature. These are properties of a substance. Heat is the energy involved when these properties change.

Think of what happens when two objects at different temperatures come into contact. Energy as heat flows from the object at the higher temperature to the object at the lower temperature. When both objects come to the same temperature, no more energy as heat flows. Just because the temperature of the two objects is the same does not mean they have the same thermal energy. One object may be larger than the other and thus have more particles in motion.

Active Reading 9 Relate What will happen if two objects at different temperatures come into contact?
How can heat affect the state of an object?

The matter that makes up a frozen juice bar is the same whether the juice bar is frozen or has melted. The matter is just in a different form, or state. Remember that the kinetic theory of matter states that the particles that make up matter move around at different speeds. The state of a substance depends on the speed of its particles. Adding energy in the form of heat to a substance may result in a change of state. The added energy may cause the bonds between particles to break. This is what allows the state to change. Adding energy in the form of heat to a chunk of glacier may cause the ice to melt into water. Removing energy in the form of heat from a substance may also result in a change of state.

Active Reading 11 Predict What are two ways to change the state of a substance?

Think Outside the Book Inquiry

10 Compare Have you ever needed to touch a very hot object? What did you use to touch it without burning yourself? Make a list. Have you ever needed to protect yourself from being cold? What sorts of things did you use? Make a list. Now, looking at the two lists, what do the things have in common?
Keep Your Cool

What is conduction?
There are three main ways to transfer energy as heat: conduction, convection, and radiation. **Conduction** is the transfer of energy as heat from one substance to another through direct contact. It occurs any time that objects at different temperatures come into contact with each other. The average kinetic energy of particles in the warmer object is greater than the average kinetic energy of the particles in the cooler object. As the particles collide, some of the kinetic energy of the particles in the warmer object is transferred to the cooler object. As long as the objects are in contact, conduction continues until the temperatures of the objects are equal.

Conduction can also occur within a single object. In this case, energy in the form of heat is transferred from the warmer part of the object to the cooler part of the object. Imagine you put a metal spoon into a cup of hot cocoa. Energy will be conducted from the warm end of the spoon to the cool end until the temperature of the entire spoon is the same.

Conductors
Some materials transfer the kinetic energy of particles better than others. A **conductor** is a material that transfers heat very well. Metals are typically good conductors. You know that when one end of a metal object gets hot, the other end quickly becomes hot as well. Consider pots or pans that have metal handles. A metal handle becomes too hot to touch soon after the pan is placed on a hot stove.

Insulators
An **insulator** is a poor conductor of heat. Some examples of insulators are wood, paper, and plastic foam. Plastic foam is a good insulator because it contains many small spaces that are filled with air. A plastic foam cup will not easily transfer energy in the form of heat by conduction. That is why plastic foam is often used to keep hot drinks hot. Think about the metal pan handle mentioned above. It can be dangerous to have handles get hot so quickly. Instead, pot handles are often made of an insulator, such as wood or plastic. Although a plastic handle will also get hot when the pot is on the stove, it takes a much longer time for it to get hot than it would for a metal handle.

12 Classify Decide whether each object below is a conductor or an insulator. Then check the correct box.

<table>
<thead>
<tr>
<th>Object</th>
<th>Conductor</th>
<th>Insulator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Flannel shirt</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Iron skillet</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Copper pipe</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Oven mitt</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
What is convection?

Energy in the form of heat can also be transferred through the movement of gases or liquids. **Convection** (kuhn•VEK•shuhn) is the transfer of energy as heat by the movement of a liquid or gas. In most substances, as temperature increases, the density of the liquid or gas decreases. Convection occurs when a cooler, denser mass of a gas or liquid replaces a warmer, less dense mass of a gas or liquid by pushing it upward.

When you boil water in a pot, the water moves in roughly circular patterns because of convection. The water at the bottom of the pot gets hot because there is a source of heat at the bottom. As the water heats, it becomes less dense. The warmer water rises through the denser, cooler water above it. At the surface, the warm water begins to cool. The particles move closer together, making the water denser. The cooler water then sinks back to the bottom, is heated again, and the cycle repeats. This cycle causes a circular motion of liquids or gases. The motion is due to density differences that result from temperature differences. The motion is called a **convection current**.

What is radiation?

Radiation is another way in which heat can be transferred. **Radiation** is the transfer of energy by electromagnetic waves. Some examples of electromagnetic waves include visible light, microwaves, and infrared light. The sun is the most significant source of radiation that you experience on a daily basis. However, all objects—even you—emit radiation and release energy.

When radiation is emitted from one object and then absorbed by another, the result is often a transfer of heat. Like conduction and convection, radiation can transfer heat from warmer to cooler objects. However, radiation differs from conduction and convection in a very significant way. Radiation can travel through empty space, as it does when it moves from the sun to Earth.

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**Active Reading**

13 **Identify** As you read, underline examples of heat transfer.

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**Example**

When you put some food in the microwave, it gets hot.

**Conduction, Convection, or Radiation**

Conduction

A heater on the first floor of the school makes the air on the second floor warm.
Visual Summary

To complete this summary, circle the correct word or phrase. Then use the key below to check your answers. You can use this page to review the main concepts of the lesson.

Thermal energy is the total kinetic energy of all particles in a substance.

18 If two objects are at the same temperature, the one with more / fewer / the same amount of particles will have a higher thermal energy.

19 Heat always flows from cold to hot / hot to cold / left to right.

Heat is the energy transferred from an object at a higher temperature to an object at a lower temperature.

Heat can change the state of a substance.

20 Adding heat to an object causes bonds between particles to form / break / combine. This is what allows the state change.

There are three main ways to transfer energy as heat: conduction, convection, and radiation.

21 Conduction is the transfer of energy from a warmer object to a cooler object through a gas / empty space / direct contact.

22 Energy from the sun travels to Earth through conduction / convection / radiation.

23 Conclude Suppose you are outside on a hot day and you move into the shade of a tree. Which form of energy transfer are you avoiding? Explain.
Lesson Review

Vocabulary
In your own words, define the following terms.

1 heat

2 thermal energy

3 conduction

4 convection

5 radiation

Key Concepts

6 Compare What is the difference between heat and temperature?

7 Predict If two objects at different temperatures are in contact with each other, what happens to their temperatures?

Use this photo to answer the following questions.

8 Classify Which type of energy transfer is occurring at each lettered area?
A
B
C

Critical Thinking

9 Synthesize Describe the relationships among temperature, heat, and thermal energy.

10 Synthesize Do you think that solids can undergo convection? Explain.

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