CHAPTER 5

Thermal Energy

1 Temperature and Heat

TEKS 4(A), 5(A)

What You'll Learn

- what temperature is
- how thermal energy depends on temperature
- how thermal energy and heat are related
- calculate the change in thermal energy

Before You Read

You wake up in the morning and get out of bed. Does the floor feel cold or warm on your bare feet? On the lines below, write a sentence that compares how it feels to step on a bare floor and on a rug on a cold morning.

Focus →

Make an outline of the information you learn about in this section. Use the headings in the reading as a starting point. Include the boldface vocabulary terms in your outline.

Read to Learn

Temperature

The words *hot* and *cold* describe temperature. When you heat water on a stove, the temperature of the water increases. You've often heard the word *temperature*, but what is it?

What does motion have to do with matter?

All matter is made of tiny particles—atoms and molecules. The particles in all matter are constantly moving. The movement of the particles is random. This means that the particles move in all directions at different speeds. Because the particles are moving, they have kinetic energy. The faster they move, the more kinetic energy they have. When an object is hot, the particles move faster. As it cools, the particles move more slowly. Particles move faster in hot objects than in cooler objects.

What is temperature?

Temperature and kinetic energy are related. Temperature is a measure of the average value of the kinetic energy of the particles in an object. As the temperature of something increases, the average speed of its particles increases. The temperature of hot tea is higher than the temperature of iced tea because the particles in the hot tea are moving faster. Recall that in SI units, temperature is measured in kelvins (K). The Celsius scale is used more commonly than the Kelvin scale. One kelvin is the same size as one Celsius degree.

Think it Over

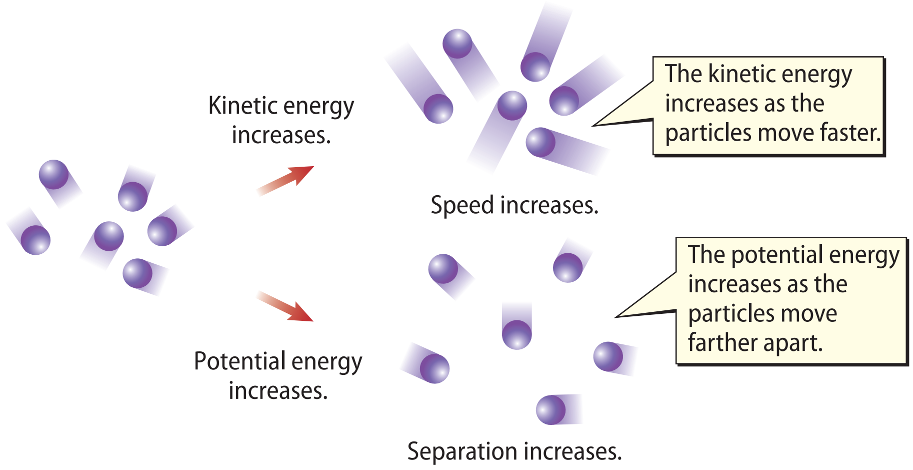
1. **Explain** Why is the temperature of hot tea higher than the temperature of iced tea?

Thermal Energy

When you take butter out of the refrigerator, it is cold and hard. If you let it sit at room temperature for a while, it gets warmer and softer. The air in the room is at a higher temperature than the butter. So, particles in the air have more kinetic energy than the butter particles. Air particles and butter particles bump into each other. The collisions transfer kinetic energy from the air to the butter. The butter particles begin moving faster and the temperature of the butter increases.

Potential Energy to Kinetic Energy Particles also have potential energy that can be changed into kinetic energy. How can particles have potential energy? Think about a ball. Earth exerts an attractive gravitational force on the ball. When you hold the ball above your head, the ball and Earth are separated. This gives the ball potential energy. The particles in a substance also exert attractive forces on each other. They have potential energy when they are separated.

As particles move farther apart, their potential energy increases. As they move faster, their kinetic energy increases. **Thermal energy** is the sum of the kinetic and potential energy of all the particles in an object. The figure shows that if either potential or kinetic energy increases, thermal energy increases.

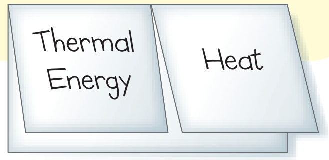


How are thermal energy and temperature related?

When the temperature of an object increases, the average kinetic energy of its particles increases. When the average kinetic energy of its particles increases, the object's thermal energy increases. Therefore, the thermal energy of an object increases as its temperature increases.

FOLDABLES® Study Organizer

Classify Make a two-tab book. Label it as shown. Use it to organize your notes on thermal energy and heat.



Think it Over

2. **Identify** What gives particles in a material potential energy?

Take a Look

3. **Use Scientific Illustrations** In the space below, sketch the particles in the figure if separation increased even more.

How are thermal energy and mass related?

Suppose you have a glass of water and a beaker of water. They are at the same temperature. The beaker contains twice as much water as the glass. The average kinetic energy of the water molecules is the same in both containers, since they are the same temperature. But there are twice as many water molecules in the beaker as there are in the glass. So the total kinetic energy of the water molecules in the beaker is twice as large as that of the water molecules in the glass. The water in the beaker has twice as much thermal energy as the water in the glass has. If the temperature doesn't change but the mass of the object increases, the thermal energy in the object increases.

Think it Over

4. Communicate Write in your own words the difference between temperature and heat.

Heat

Have you ever noticed that your chair felt warm when you sat down? You could tell that someone had been sitting in it recently. The chair felt warm because thermal energy from the person's body flowed to the chair and increased its temperature.

Heat is thermal energy that flows from something at a higher temperature to something at a lower temperature. Recall that joules are the units that energy is measured in. Heat is a form of energy, so it is measured in joules.

When you put ice in water, the ice seems to be cooling the water. Actually, the water is heating the ice. The water is transferring its thermal energy to the ice. This transfer of thermal energy does both, cool the water, and warm the ice. Even after the ice melts, heat continues to flow from the warmer water to the cooler water until all the water is the same temperature. Heat always flows from warmer materials to cooler materials.

Take a Look

5. Infer Read the **Before You Read** exercise on the first page of this section again. Use what you learned about specific heat. Why does a carpeted floor feel different to your bare feet than a bare floor feels on a cold morning?

Specific Heat

When you are at the beach in the summertime, the ocean probably feels much cooler than the air or the sand. Energy from the Sun is warming the air, sand, and water at the same rate. But the temperature of the water has changed less than the temperature of the air or sand has changed.

As a substance or material absorbs heat, how much its temperature changes depends on how much heat is added. But it also depends what the material is made of. For example, think about 1 kg of sand and 1 kg of water. It takes six times as much heat to raise the temperature of water 1°C than it takes to raise the temperature of sand 1°C. The ocean water at the beach would have to absorb six times as much heat as the sand to be at the same temperature.

The **specific heat** of a substance is the amount of heat needed to raise the temperature of 1 kg of that substance by 1°C. Specific heat is measured in joules per kilogram degree Celsius [J/(kg • °C)]. The table shows the specific heat of some familiar materials.

Specific Heat of Some Common Materials

Substance	Specific Heat [J/(kg • °C)]
Water	4,184
Wood	1,760
Carbon (graphite)	710
Glass	664
Iron	450

GET IT?

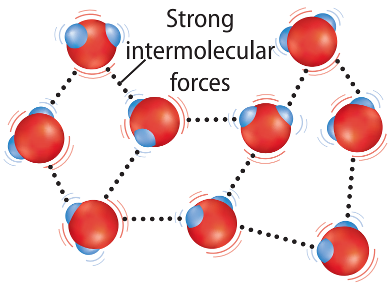
6. Define *specific heat.*

How does water cool things?

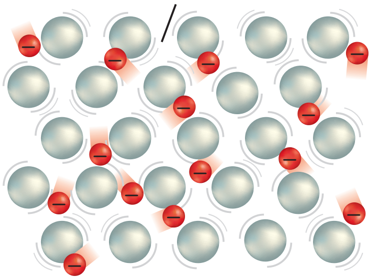
Look at the table of specific heat above. Compared with the other common materials, water has the highest specific heat. The figure below shows why this is. Water molecules form strong bonds with each other. When heat is added, the strong bonds make it hard for the molecules to move. Some of the added heat has to break these bonds before the molecules can start moving faster. In metals, electrons can move freely. When heat is added, no strong bonds have to be broken before the electrons can start moving faster.

Apply Math

7. Use a Table How much heat is needed to raise the temperature of 1 kg of iron from 25°C to 30°C? Show your work.



When heat is added to water, some of the added heat has to break some of these bonds before the molecules can start moving faster.



In metals, electrons can move freely. When heat is added, no strong bonds have to be broken before the electrons can start moving faster.

Take a Look

8. Interpret Scientific Illustrations Explain how strong bonds give water a high specific heat.

A coolant is a substance that is used to absorb heat. Water can absorb heat without a large change in temperature, so it is useful as a coolant. Water is used in the cooling systems of automobile engines. As long as the water temperature is lower than the engine temperature, heat will flow from the engine to the water. Compared to other materials that could be used in an engine, the temperature of water will increase less.

How does thermal energy change?

The thermal energy of an object changes when heat flows into or out of the object. You can use the following equation to calculate the change in thermal energy.

change in thermal energy (J) =

mass (kg) × **change in temperature** (°C) × **specific heat** $\left(\frac{J}{kg \cdot °C}\right)$

$$Q = m(T_f - T_i)C$$

In the equation, Q stands for the change in thermal energy. C stands for the object's specific heat. T_f is the final temperature and T_i is the initial temperature.

Suppose a wooden chair with a mass of 20 kg is sitting in sunlight. As it sits, it warms from 15°C to 25°C. The specific heat of wood is 1,700 J/(kg • °C). What is the change in the thermal energy of the chair?

The mass of the chair is 20 kg, so $m = 20$ kg. The temperature warms from 15°C to 25°C. So $T_i = 15°C$ and $T_f = 25°C$. The specific heat of wood is 1,700 J/(kg • °C), so $C = 1{,}700$ J/(kg • °C). These values can be put into the equation:

$$\begin{aligned} Q &= m(T_f - T_i)C \\ &= (20\ \text{kg})(25°\text{C} - 15°\text{C})(1{,}700\ \text{J/kg} \cdot °\text{C}) \\ &= (20\ \text{kg})(10°\text{C})(1{,}700\ \text{J/kg} \cdot °\text{C}) \\ &= 340{,}000\ \text{kg °C J/kg} \cdot °\text{C} \\ &= 340{,}000\ \text{J} \end{aligned}$$

The change in thermal energy of the chair is 340,000 J.

Apply Math

9. Calculate The specific heat of copper is 385 J/kg • °C. Find the change in thermal energy for a copper pipe with a mass of 8 kg when it is heated from 12°C to 21°C. Show your work.

Measuring Specific Heat

A calorimeter is a device that can be used to find the specific heat of a material. The specific heat of a material can be determined if the mass of the material, its change in temperature, and the amount of thermal energy absorbed or released are known. In a calorimeter, an object that has been heated transfers heat to a known mass of water. The transfer of heat continues until the object and the water are the same temperature. The energy absorbed by the water can be calculated by measuring the water's temperature change. The thermal energy released by the object equals the thermal energy absorbed by the water.

Think it Over

10. Explain What does a calorimeter measure?

After You Read

Mini Glossary

heat: thermal energy that flows from something at a higher temperature to something at a lower temperature

specific heat: the amount of heat needed to raise the temperature of 1 kg of a substance by 1°C

temperature: the average value of the kinetic energy of the particles in an object

thermal energy: the sum of the kinetic and potential energy of all the molecules in an object

Review

1. Review the terms and their definitions in the Mini Glossary. What is the difference between temperature and thermal energy?

2. Complete the chart below to organize information from this section about temperature.

Molecules in a substance

speed up when the substance is

so they have

(more or less) kinetic energy

slow down when the substance is

so they have

(more or less) kinetic energy

3. You made an outline as you read this section. How did that strategy help you learn the material?