Section 2

The Transfer of Heat

Reading Preview

Key Concepts

- What are the three forms of heat transfer?
- In what direction does heat move?
- How are conductors and insulators different?

Key Terms

- conduction
- convection
- convection current
- radiation
- conductor
- insulator

Target Reading Skill

Identifying Main Ideas As you read the How Is Heat Transferred? section, write the main idea in a graphic organizer like the one below. Then write three supporting details that give examples of the main idea.

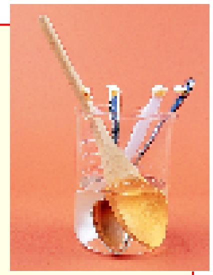
Main Idea

Heat can be transferred in three ways . . .

Detail | Detail | Detail

Lab zone Discover Activity

What Does It Mean to Heat Up?



1. Obtain several utensils made of different materials, such as silver, stainless steel, plastic, and wood.
2. Stand the utensils in a beaker so that they do not touch each other.
3. Press a small gob of frozen butter on the handle of each utensil. Make sure that when the utensils stand on end, the butter is at the same height on each one.
4. Pour hot water into the beaker until it is about 6 cm below the butter. Watch the butter on the utensils for several minutes. What happens?
5. Wash the utensils in soapy water when you finish.

Think It Over

Observing What happened to the butter? Did the same thing happen on every utensil? How can you account for your observations?

Blacksmithing is hot work. A piece of iron held in the fire of the forge becomes warmer and begins to glow. At the same time, the blacksmith feels hot air rising from the forge, and his face and arms begin to feel warmer. Each of these movements of energy is a transfer of heat.

A blacksmith at work ▶

Section 2

The Transfer of Heat

Objectives

After this lesson, students will be able to

M.6.2.1 Describe the three forms of heat transfer.

M.6.2.2 Identify the direction in which heat moves.

M.6.2.3 Describe the differences between conductors and insulators.

Target Reading Skill

Identifying Main Ideas Explain that identifying main ideas and details helps students sort the facts from the information into groups. Each group can have a main topic, subtopics, and details.

Answers

Sample graphic organizer:

Main Idea: Heat can be transferred in three ways.

Detail: Conduction—transfer of heat between particles without the movement of matter

Detail: Convection—transfer of heat by the movement of currents in a fluid

Detail: Radiation—transfer of energy by electromagnetic waves

All in One Teaching Resources

- Transparency M54

Preteach

Build Background Knowledge L2

Heat Transfer

Ask: **How would you safely remove a tray of hot cookies from the oven?** *(Sample answer: I would use an oven mitt.)* **What is the function of the oven mitt?** *(It keeps the cookies and tray from burning my hands.)* Tell students that in this section they will learn how the oven mitt protects their hands.

Lab zone Discover Activity

Skills Focus Observing L2

Materials frozen butter, glass beaker, hot water, utensils made of different materials

Time 15 minutes

Tips CAUTION: *Remind students to avoid touching the hot water and tasting the butter.* Have students record the order in which the butter melts on the utensils.

Expected Outcome The butter will melt more quickly on metal utensils than on the wood or plastic utensils.

Think It Over Sample answer: The butter melted. It melted faster on metal utensils than on wooden or plastic ones. Heat from the hot water moved along the utensils, but at a different rate for each material.

Instruct

How Is Heat Transferred?

Teach Key Concepts L2

Conduction, Convection, and Radiation

Focus Tell students that heat can be transferred in three ways—conduction, convection, and radiation.

Teach On the board write three headings: *conduction, convection,* and *radiation*. Ask for a volunteer to describe each type of heat transfer. Then, ask students to give examples of each kind of heat transfer. Write their answers on the board under the correct heading.

Apply Ask: **What type of heat transfer occurs when you burn your feet on hot sand at the beach?** *(Conduction)* **learning modality: verbal**

Go Online PHSchool.com
For: Links on heat transfer
Visit: www.SciLinks.org
Web Code: scn-1362

Students can research heat transfer online.

Help Students Read L1

Comparing and Contrasting Have students use the information in the text to create a table that compares and contrasts the three ways in which heat is transferred. Remind students that comparing and contrasting means looking for similarities and differences.

Independent Practice L2

All in One Teaching Resources

- Guided Reading and Study Worksheet: *The Transfer of Heat*

Student Edition on Audio CD

Go Online SCI LINKS NSTA
For: Links on heat transfer
Visit: www.SciLinks.org
Web Code: scn-1362

How Is Heat Transferred?

There are three ways that heat can move. **Heat is transferred by conduction, convection, and radiation.** The blacksmith experiences all three.

Conduction In the process of **conduction,** heat is transferred from one particle of matter to another without the movement of the matter. Think of a metal spoon in a pot of water on an electric stove. The fast-moving particles in the hot electric coil collide with the slow-moving particles in the cool pot. The transfer of heat causes the pot's particles to move faster. Then the pot's particles collide with the water's particles, which in turn collide with the particles in the spoon. As the particles move faster, the metal spoon becomes hotter.

If you were to touch the spoon, heat would be transferred to your fingers. Too much heat transferred this way can cause a burn!

In Figure 7, heat from the fire is transferred to the stone beneath it. Then it is transferred from the stone to the metal tools. This transfer of heat from the fire to the tools is due to conduction.

Convection If you watch a pot of hot water on a stove, you will see the water moving. This movement transfers heat within the water. In **convection,** heat is transferred by the movement of currents within a fluid.

When the water at the bottom of the pot is heated, its particles move faster, and they also move farther apart. As a result, the heated water becomes less dense. Recall from Chapter 3 that a less dense fluid will float on top of a denser one. So the heated water rises. The surrounding, cooler water flows into its place. This flow creates a circular motion known as a **convection current.**

Convection currents can transfer heated air. As the air above the fire in Figure 7 is heated, it becomes less dense and rises up the chimney. When the warm air rises, cool air flows into its place.

Radiation **Radiation** is the transfer of energy by electromagnetic waves. You can feel the radiation from a fire in a fireplace all the way across the room. Unlike conduction and convection, radiation does not require matter to transfer thermal energy. All of the sun's energy that reaches Earth travels through millions of kilometers of empty space.

Reading Checkpoint How does radiation transfer thermal energy?

Lab zone Try This Activity

Feel the Warmth

How is heat transferred from a light bulb?

1. Turn on a lamp without the shade. Wait about a minute.
2. Hold the palm of your hand about 10 cm from the side of the bulb for about 15 seconds. Remove it sooner if it gets too warm.
3. Now hold the palm of your hand about 10 cm above the top of the bulb for about 15 seconds.

Drawing Conclusions In which location did your hand feel warmer? Explain your observations in terms of heat transfer.

Lab zone Skills Activity

Skills Focus Inferring L1

Time 10 minutes

Answer Sample answer: The metal zipper feels much hotter because metal conducts thermal energy better than the material of the jeans.

Extend Have the students infer which would conduct thermal energy better—metal buttons or plastic buttons. *(metal buttons)* **learning modality: logical/mathematical**

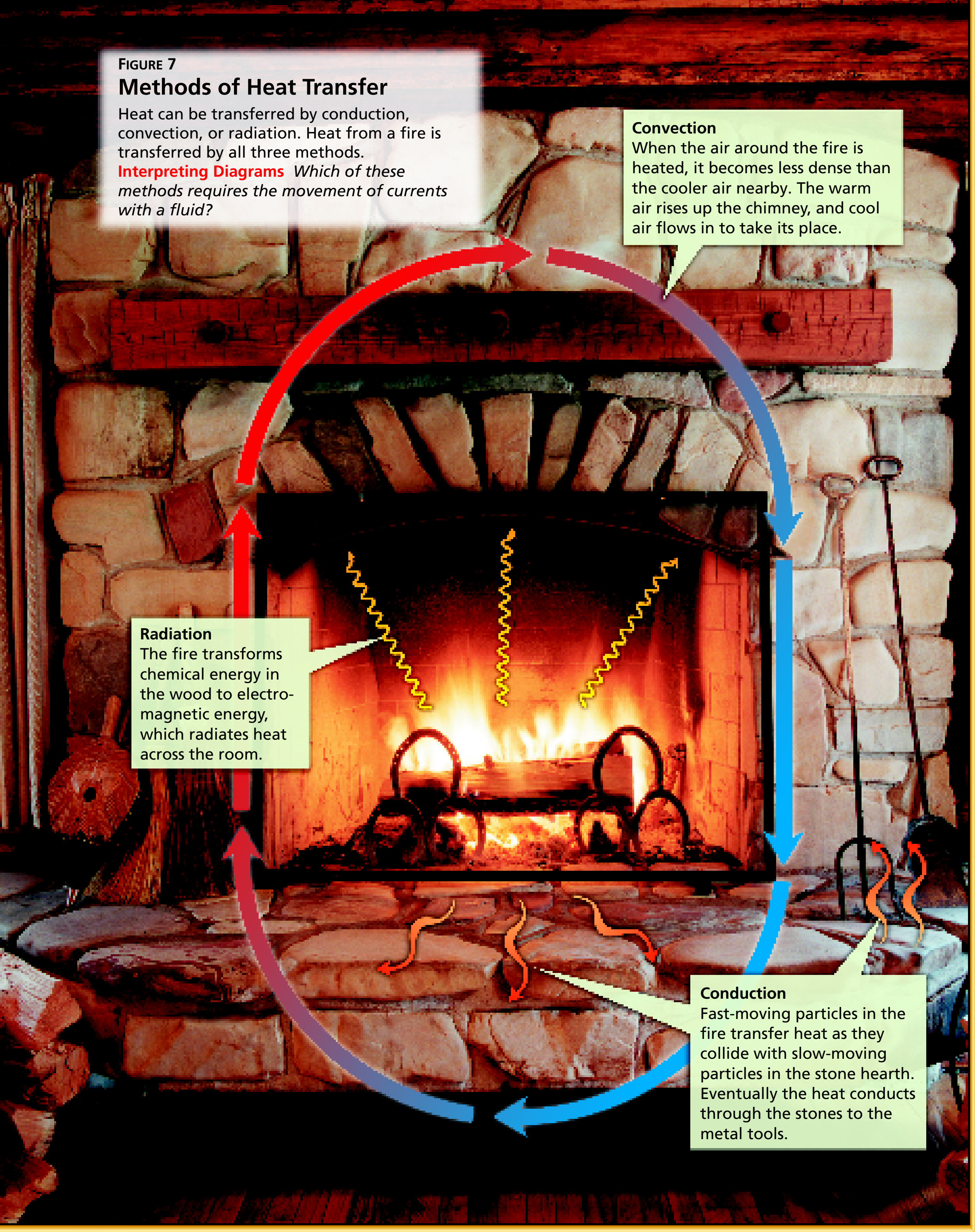


FIGURE 7
Methods of Heat Transfer
Heat can be transferred by conduction, convection, or radiation. Heat from a fire is transferred by all three methods.
Interpreting Diagrams *Which of these methods requires the movement of currents with a fluid?*

Differentiated Instruction

Special Needs L1

Observing Conduction Have students hold an ice cube for a brief period. Tell them to put down the ice if they become uncomfortable. Remind students that this is an example of heat transfer by conduction. Thermal energy from their hand is transferred to the ice cube, causing the ice cube to become warmer and their hand to become cooler. **learning modality: kinesthetic**

Gifted and Talented L3

Researching Weather Have students research El Niño and La Niña, weather patterns caused by convection currents. Students should write a short report describing their findings. **learning modality: verbal**

Lab zone **Build Inquiry** L2

Visualizing Convection Currents

Materials 2 test tubes, test tube holder, 2 beakers, red and blue food coloring, cold water, hot water, large dropper

Time 20 minutes

Focus Tell students they will use hot and cold water to visualize convection currents.

Teach Prepare hot water with red food coloring and cold water with blue food coloring. Have students place cold water in one test tube and hot water in the other. Then, demonstrate how to place one layer of water on top of the other by gently squeezing a full dropper against the side of the test tube. Students should add a layer of cold water to the tube containing hot water, and a layer of hot water to the tube containing cold water.

Apply Ask: **What happened when you placed cold water on top of hot water? Why?** *(The hot water floated on top of the cold water because it is less dense.)* **learning modality: visual**

Integrating Earth Science L2

Convection currents in Earth's oceans and atmosphere cause major weather patterns. Convection currents also occur in Earth's mantle, causing Earth's plates to slowly move. Ask: **In what type of material does convection occur? Why?** *(Fluids, because they can flow)* **learning modality: verbal**

Monitor Progress L2

Drawing Have students draw a kettle of water being heated on a burner and label the convection currents and the path of heat conduction.

Students can keep their drawings in their portfolios. Portfolio

Answers

Figure 7 Convection requires movement of currents within a fluid.

Reading Checkpoint Radiation transfers thermal energy by electromagnetic waves.

Heat Moves One Way

Teach Key Concepts L2

The Direction of Heat Flow

Focus Explain that heat can flow spontaneously in one direction only: from a warmer object to a colder object.

Teach Write on the board the following pairs of terms, leaving a space between the terms in each pair: ice, lemonade; cool air, warm bath water; hot clothes dryer, cold clothes. Tell students you will draw an arrow between the terms indicating the direction of heat flow. Ask for volunteers to indicate the direction each arrow should point. (Arrows should point to *ice, cool air,* and *cold clothes*.)

Apply Ask: **Your friend asks if you want some ice to transfer coldness to your lemonade. What is incorrect about your friend's question?** *(There is no such thing as coldness, therefore it can't be transferred. Instead, heat flows from the lemonade to the ice, cooling the lemonade.)* **learning modality: visual**

Conductors and Insulators

Teach Key Concepts L2

Uses of Conductors and Insulators

Focus Ask: **Have you ever packed a picnic lunch in a cooler?** *(Some students will say yes.)* **What was the function of the cooler?** *(Sample answer: It kept our food cool even though it was hot outside.)*

Teach Explain that insulators are materials that do not transfer thermal energy well; conductors are materials that do conduct thermal energy well. Tell students that materials are selected for certain applications based on how well they conduct thermal energy.

Apply Ask: **Based on what you know about insulators and conductors, which type of material is a picnic cooler made of? Why?** *(An insulator, to keep thermal energy from the hot surroundings from being transferred to the cold food inside)* **learning modality: logical/mathematical**

FIGURE 8
Heat Transfer From Food
The soup's heat is transferred to the bowl, the spoon, and the air.
Predicting *If the soup is not eaten, what will happen to its temperature?*

Heat Moves One Way

If two objects have different temperatures, heat will flow from the warmer object to the colder one. When heat flows into matter, the thermal energy of the matter increases. As the thermal energy increases, the temperature increases. At the same time, the temperature of the matter losing the heat decreases. Heat will flow from one object to the other until the two objects have the same temperature. You have probably seen this happen to your food. The bowl of hot soup shown in Figure 8, for example, cools to room temperature if you don't eat it quickly.

What happens when something becomes cold, such as when ice cream is made? The ingredients used to make it, such as milk and sugar, are not nearly as cold as the finished ice cream. In an ice cream maker, the ingredients are put into a metal can that is packed in ice. You might think that the ice transfers cold to the ingredients in the can. But this is not the case. There is no such thing as "coldness." Instead, the ingredients grow colder as thermal energy flows from them to the ice. Heat transfer occurs in only one direction.

Lab zone Skills Activity

Inferring

You pull some clothes out of the dryer as soon as they are dry. You grab your shirt without a problem, but when you pull out your jeans, you quickly drop them. The metal zipper is too hot to touch! What can you infer about which material in your jeans conducts thermal energy better? Explain.

Reading Checkpoint Can heat flow from one object to a warmer object? Why or why not?

Conductors and Insulators

Have you ever stepped from a rug to a tile floor on a cold morning? The tile floor feels colder than the rug. Yet if you measured their temperatures, they would be the same—room temperature. The difference between them has to do with how materials conduct heat. A material can be either a conductor or an insulator. **A conductor transfers thermal energy well. An insulator does not transfer thermal energy well.**

Conductors A material that conducts heat well is called a **conductor.** Metals such as silver and stainless steel are good conductors. A metal spoon conducts heat better than a wooden spoon. Some materials are good conductors because of the particles they contain and how those particles are arranged. A good conductor, such as a tile floor, feels cool to the touch because it easily transfers heat away from your skin.

Insulators A material that does not conduct heat well is called an **insulator.** Wood, wool, straw, and paper are good insulators. So are the gases in air. Clothes and blankets are insulators that slow the transfer of heat out of your body.

A well-insulated building is comfortable inside whether it is hot or cold outdoors. Insulation prevents heat from entering the building in hot weather and from escaping in cold weather. Much of the heat transfer in a building occurs through the windows. For this reason, insulating windows have two panes of glass with a thin space of air between them. The trapped air does not transfer heat well.

FIGURE 9
Insulating Windows
Air between the panes of this window acts as an insulator to slow the transfer of heat.

Reading Checkpoint **Is air better as an insulator or as a conductor?**

Section 2 Assessment

Target Reading Skill
Identifying Main Ideas Use your graphic organizer to help you answer Question 1 below.

Reviewing Key Concepts

1. a. **Describing** What are conduction, convection, and radiation?
   b. **Classifying** Identify each example of heat transfer as conduction, convection, or radiation: opening the windows in a hot room; a lizard basking in the sun; putting ice on a sprained ankle.
   c. **Inferring** How can heat be transferred across empty space?
2. a. **Reviewing** In what direction will heat flow between two objects with different temperatures?
   b. **Applying Concepts** How does a glass of lemonade become cold when you put ice in it?
3. a. **Identifying** What kind of substance conducts thermal energy well?
   b. **Making Judgments** Would a copper pipe work better as a conductor or an insulator? Why do you think so?
   c. **Interpreting Diagrams** Why are two panes of glass used in the window in Figure 9?

Writing in Science

Explanation Suppose you are camping on a mountain, and the air temperature is very cold. How would you keep warm? Would you build a fire or set up a tent? Write an explanation for each action you would take. Tell whether conduction, convection, or radiation is involved with each heat transfer.

Monitor Progress L2

Answers

Figure 8 The soup's temperature will decrease as it transfers heat to materials around it.

Reading Checkpoint No. Heat transfer occurs spontaneously in only one direction—from a warmer object or material to a colder one.

Reading Checkpoint Air is a better insulator than a conductor.

Assess

Reviewing Key Concepts

1. a. Conduction, convection, and radiation are three means by which heat may be transferred. **b.** Convection; radiation; conduction **c.** By electromagnetic waves, which do not require matter to transfer thermal energy
2. a. Heat flows spontaneously from the warmer object to the colder object.
b. Thermal energy flows from the lemonade to the ice.
3. a. A conductor transfers thermal energy well. **b.** A conductor because copper is a metal. **c.** Because air is a good insulator, the air trapped between the two panes slows the transfer of heat into and out of the building.

Reteach L1

Have students work in pairs to review the key terms from section.

Performance Assessment L2

Writing Ask students to make lists of situations in which materials that are good insulators of thermal energy are helpful and situations in which good conductors of thermal energy are helpful.

All in One Teaching Resources
- Section Summary: *The Transfer of Heat*
- Review and Reinforcement: *The Transfer of Heat*
- Enrich: *The Transfer of Heat*

Lab zone Chapter Project

Keep Students on Track Instruct students to review the steps for designing an experiment in the Skills Handbook. Have students prepare a short summary of their experimental plan that includes identifying variables and controls. After students have completed their plans and you have approved them, have them begin their tests.

Writing in Science

Writing Mode Exposition/ How-To
Scoring Rubric
4 Exceeds criteria
3 Meets criteria
2 Meets most, but not all criteria; explanation lacks details and/or includes some incorrect information
1 Meets few criteria; includes few details and/or incorrect statements

Lab zone Skills Lab

Just Add Water

L2

Prepare for Inquiry

Skills Objectives

After this lab, students will be able to

- observe the transfer of thermal energy from hot water to cold water
- calculate the heat transferred from hot water to cold water in a calorimeter
- interpret data about the conservation of thermal energy in a calorimeter

Prep Time 15 minutes
Class Time 40 minutes

Advance Planning

Before the lab, gather the materials students will need. Provide sponges or paper towels to mop up spills.

Alternative Materials

Any kind of disposable, insulated cup can be used instead of plastic foam cups.

Safety

Caution students to be careful using thermometers. Review the safety guidelines in Appendix A.

All in One Teaching Resources

- Lab Worksheet: *Just Add Water*

Guide Inquiry

Invitation

Ask: **What would you do if you got in a bath and found that the water was too hot?** *(Sample answer: Add cold water)* **When you add cold water, what happens to the heat?** *(Heat is transferred from the hot water to the cold water.)*

Introduce the Procedure

- Describe the lab to students. Explain that they will calculate the amount of heat transferred when hot water and cold water are mixed.
- Set up and display a calorimeter.
- Help students understand how to use the equation for calculating the change in thermal energy in the hot water and the cold water.

Lab zone Skills Lab

Just Add Water

Problem

Can you build a calorimeter—a device that measures changes in thermal energy—and use it to determine how much thermal energy is transferred from hot water to cold water?

Skills Focus

observing, calculating, interpreting data

Materials

- hot tap water
- balance
- scissors
- pencil
- 4 plastic foam cups
- 2 thermometers or temperature probes
- beaker of water kept in an ice bath

Procedure

1. Predict how the amount of thermal energy lost by hot water will be related to the amount of thermal energy gained by cold water.
2. Copy the data table into your notebook.
3. Follow the instructions in the box to make two calorimeters. Find the mass of each empty calorimeter (including the cover) on a balance and record each mass in your data table.
4. From a beaker of water that has been sitting in an ice bath, add water (no ice cubes) to the cold-water calorimeter. Fill it about one-third full. Put the cover on, find the total mass, and record the mass in your data table.
5. Add hot tap water to the hot-water calorimeter. **CAUTION:** *Hot tap water can cause burns.* Fill the calorimeter about one-third full. Put the cover on, find the total mass, and record the mass in your data table.
6. Calculate the mass of the water in each calorimeter. Record the results in your data table.
7. Put thermometers through the holes in the covers of both calorimeters. Wait a minute or two and then record the temperatures. If you are using temperature probes, see your teacher for instructions.

Making a Calorimeter

A Label a plastic foam cup with the letter *C*, which stands for cold water.

B Cut 2 to 3 cm from the top of a second plastic foam cup. Invert the second cup inside the first. Label the cover with a *C* also. The cup and cover are your cold-water calorimeter.

C Using a pencil, poke a hole in the cover large enough for a thermometer to fit into snugly.

D Repeat Steps A, B, and C with two other plastic foam cups. This time, label both cup and cover with an *H*. This is your hot-water calorimeter.

Data Table

Calorimeter	Mass of Empty Cup (g)	Mass of Cup and Water (g)	Mass of Water (g)	Starting Temp. (°C)	Final Temp. (°C)	Change in Temp. (°C)
Cold Water						
Hot Water						

Troubleshooting the Experiment

- In the cold-water calorimeter, students may need to pull the thermometer up a bit to read it.
- Students should read the thermometer to the nearest half degree.
- In Step 8, students should wait a minute or two before recording the final temperature. Do not allow students to use the thermometers to stir the water.
- Remind students to use the final temperature to calculate the temperature change for both the hot and cold water.

8. Remove both thermometers and covers. Pour the water from the cold-water calorimeter into the hot-water calorimeter. Put the cover back on the hot-water calorimeter, and insert a thermometer. Record the final temperature as the final temperature for both calorimeters.

Analyze and Conclude

1. **Observing** What is the temperature change of the cold water? Record your answer in the data table.
2. **Observing** What is the temperature change of the hot water? Record your answer in the data table.
3. **Calculating** Calculate the amount of thermal energy that enters the cold water by using the formula for the transfer of thermal energy. The specific heat of water is 4.18 J/(g·K).
   Thermal energy transferred =
   4.18 J/(g·K) × Mass of cold water × Temperature change of cold water
   Remember that a change of 1°C is equal to a change of 1 K.
4. **Calculating** Now use the same formula to calculate the amount of thermal energy leaving the hot water.
5. **Calculating** What unit should you use for your results for Questions 3 and 4?
6. **Interpreting Data** Was your prediction from Step 1 confirmed? How do you know?
7. **Communicating** What sources of error might have affected your results? Write a paragraph explaining how the lab could be redesigned in order to reduce the errors.

Design an Experiment

How would your results be affected if you started with much more hot water than cold? If you used more cold water than hot? Make a prediction. Then design a procedure to test your prediction. *Obtain your teacher's permission before carrying out your investigation.*

Expected Outcome

The final temperature will be greater than the initial temperature of the cold water and less than the initial temperature of the hot water. The amount of thermal energy transferred to the cold water should be approximately equal to the thermal energy transferred from the hot water. Some heat will be lost to the surroundings during transfer.

Analyze and Conclude

1. Sample data: The temperature of the cold water increased by 14.5°C.

2. Sample data: The temperature of the hot water decreased by 24°C.

3. Answer for sample data: Thermal energy gained = 6300 J.

4. Answer for sample data: Thermal energy lost = 6840 J.

5. The unit should be joules.

6. Students' answers will depend on their original predictions. Sample answer: I predicted that the thermal energy lost by the hot water would be neary equal to the thermal energy gained by the cold water. Considering reasonable experimental error, 6840 J and 6300 J are nearly equal. I believe my prediction was confirmed.

7. Sample answer: Thermal energy in the form of heat was lost or gained through the sides or tops of the cups. Thermometers or balances may have been misread. I could have used thicker cups or better insulating materials, nested two or more cups together, or repeated the procedure several times and averaged the results.

Extend Inquiry

Design an Experiment Sample answer: With more hot water, the mixture would end up hotter; with more cold water, it would end up colder. In either case, however, the thermal energy lost by the hot water should be approximately equal to the thermal energy gained by the cold water.