Heat Transfer

Throughout the guide, teaching tips are in red.

Activity Description & Estimated Class Time

In this 50-minute activity, students explore heat moving from a can of hot water into and through several materials, including metal, air, wood, plastic, and cardboard. They develop an understanding of the processes of convection, conduction, and radiation by using electronic temperature probes to track and compare the movement of heat through the different materials. Students are also challenged to use what they've learned to predict the warmest and coolest places in a system, and then gather the data needed to test their predictions.

Objectives

Students will develop an understanding of conduction, convection, and radiation of heat, and demonstrate understanding of these ideas by tracking and describing the means by which heat flows in a system they set up.

Correlations to NC Science Standards

6.P.3.1 *Illustrate the transfer of heat energy from warmer objects to cooler ones using examples of conduction, radiation and convection and the effects that may result.*

Brief Science Background

Heat is a restless form of energy, always moving from hotter places to cooler ones. Heat moves in three different ways. It can radiate through space the way heat from the sun crosses millions of miles of empty space to warm your skin. It can move directly through an object or material, such as a metal spoon in a cup of hot tea. It can also warm a region of gas or liquid, causing it to float upward and carry the heat with it, the way hot air rises over a stove. Heat can move in any one of these ways, or in any combination, including all three ways at once.

Part 1 — Restless Heat –50 minutes

Materials

Materials for the whole class

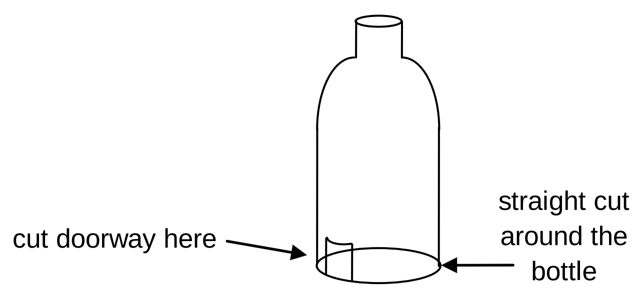
- 1 box cutter (to be used by the teacher)
- 1 hot pot
- 2 half-gallon thermos containers
- 1 funnel
- 2 pot holders
- 15 cone-top cans
- hot water (supplied by the teacher)
- 15 clean 2-liter bottles with labels removed (supplied by students)
- roll of aluminum foil

Materials for groups of 2 students

- 1 temperature probe and meter
- 1 steel cone-top can of hot water with lid on
- 1 two-liter soda bottle prepared by teacher (see Step 2 in the Preparation section)
- 1 piece of aluminum foil, prepared by the teacher (see Step 4 in the Preparation section)
- a small cardboard square
- a larger cardboard square
- Figure 5: Directions for Hot Can in a Bottle, one per team of two students

Preparation

1. A week or two before the activity, ask students to bring in enough clean 2-liter soda bottles to assemble 15 bottles. Bottles can be shared between classes.
2. Use the box cutter and scissors to remove the bottoms of the bottles. Cut straight around the bottles (see Appendix for tips on how to do this) so they sit on a flat surface without gaps between the bottom edge and the surface. Cut out a 1” x 1” square at the base of the bottle as shown below. It should look like a small doorway with no door.



Preparation cont.

3. Turn the temperature meter dials to the position shown on the right in Figure 1 (pointer to ˚C). If numbers do not appear on the screen, replace the batteries (included in the kit with a small screwdriver to remove the meter cover). When all meters work, insert the red and black probes in the jacks shown in Figure 1. *Note:* The temperature readings will not be the same on all the meters, but they should be within about 2˚ C of each other. (The temperature differences are a reflection of the accuracy, or lack thereof, of the probes. Other types of probes might measure more accurately, but they would be more expensive.) After checking all the meters, turn them off and remove the probes.

4. Tear off pieces of aluminum foil that are about one foot long. You will need one piece for each pair of students. Fold each one in half, and then fold again to make a strip that is about 3" wide. Use scissors to cut through all four layers of foil and make the circle-with-a-tongue shape shown below. Cut the circle about 3" in diameter with the tongue ½" wide, 2 ½" long.

5. Working around the shape's perimeter, pinch the foil layers together and fold them under the shape by about an eighth of an inch (this keeps the layers together). It should look like the picture below. **If you have enough scissors, students can make these shapes when they set up the system. It would be best to make one yourself ahead of time to serve as a model.**

6. About 20 minutes before the activity, heat the water in the hot pot to about 46˚C (115˚ F). It will feel hot but will not scald. Just before the activity, use the funnel and pot holders to transfer hot water to the thermos. Pour the hot water into the cone-top cans only when students are ready for them and not before.

Procedure

Ask students to work in pairs. Give each team a meter and a probe. Project an image of the meter (see Black Line Master Figure 1: Temperature Probe Meter) to show students how to plug in the probe and set the meter.

1. Ask students to find the air temperature and record it in their notebooks. Ask students to call out readings. Write the readings for all to see. Ask students to tell you the range they see. It might be several degrees. Ask them to speculate some reasons for this range. **Reasons might include someone touching the probe tip with their finger, reading while numbers are still changing, non-uniformity of the probes, different temperatures at different places in the room, etc.**

2. Ask students to touch the probe to their skin and the surface of the desk and record both of these temperatures. Ask them to call out readings for both. Write the readings for all to see.

3. Ask students what they notice about reading the probe. **Students might notice that the reading keeps changing or that it takes some time before the reading stays the same.** Ask how readings might be made more accurately. **Ideas might include waiting for readings to stop changing, or reading the meter after the probe has been at a spot for a specified time.** Incorporate the improved technique, try again, and record readings to check for a smaller range. **The class might not be able to reduce the range, but the exercise is useful anyway because it focuses the class on being more accurate. The probes are not perfectly calibrated to actual temperature, so two probes measuring the same thing at the same time could vary.**

4. Before distributing cans, project the image of a can (Black Line Master Figure 2). Ask students to draw it in their notebooks large enough to fill a page. After they have drawn it, distribute the hot cans. Project the following instructions (Black Line Master Figure 3):

   A. Leave the can where it was put down (don't move it).

   B. Pick five different spots on and around the can. On your drawing of the can, mark five large dots to show the spots you chose. Number them one through five.

   C. Starting with your first spot, measure the temperature. Record it and the time on your drawing next to the place you marked dot number one. Do the same thing for the rest of the spots on your can and on your drawing.

   D. Predict what you think the temperature will be at each spot 15 minutes from now. On your drawing, write a p near each dot. To the right of the p's, write your predicted temperatures. Underneath each p, write a letter a where you will record actual temperatures in 15 minutes.

5. After all the groups have made their predictions, assign two students to keep track of time and announce when 15 minutes are up.

6. When the 15 minutes are up, have students measure the can temperatures at their five spots and record them under their predicted temperatures on their drawings. Ask students to call out results, and record these for all to see.

Part 1 cont.

7. Ask: “Where did the heat go?” Accept all answers and discuss students’ ideas. When the discussion is complete, ask students to move the can aside and quickly use the probe to take the temperature of the desk’s surface that had been under the can. Compare this reading to the reading of the surface of the desk they took in Step 2 above. Ask for ideas about how the change occurred, specifically: did the table get hot from heat that was in the can? If so, has it left the can and how did the heat move? **Students might say that the heat sank down into the table, leaked into the table, or got into the table from touching the hot can. Some might think that the heat is still in the can. Some might know the term “conduction.” Some might say “I thought heat rises, so how could the table be warm?”**

8. Project Black Line Master Figure 4: Hot Can in a Bottle. Give each team Black Line Master Figure 5: Directions for Hot Can in a Bottle, and ask the teams to follow the setup directions..

9. Ask students to follow the directions on Black Line Master Figure 5 “Directions for Hot Can in a Bottle” and record their measurements directly on the diagram. In step 1, be sure they take temperatures at A, in the mouth of the bottle; B, on the foil where it touches the bottle; and C, 5 mm away from the can (not touching the probe to the can). If needed, show Black Line Master Figure 6: “Probe Close to Can.” Students also pick five additional spots and predict temperatures at those spots, recording their predictions on the diagram. They should indicate which spot they think is warmest and which spot they think is coolest. After recording all predictions, let students make their temperature measurements and record results below the corresponding predictions. Be sure they turn off the meters when finished. Students will need about 15 minutes.

10. Ask students to fill out Black Line Master Figure 7 “How Heat Moved.” Ask them to speculate how the heat might have moved from the can to each of the three spots.

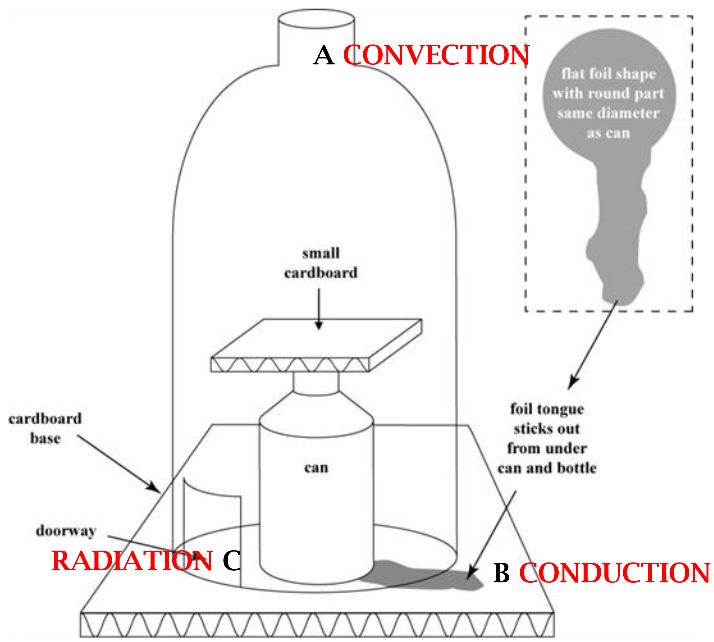
11. Discuss student’s ideas. As each type of heat transfer comes up, connect it to the word (conduction, convection, radiation) to tie students’ speculations to the three ways heat can move. As you summarize, ask students to fill in the column titled “Science Term for This Type of Heat Movement.” You might summarize by projecting Black Line Master Figure 8 “Ways Heat Can Move,” but avoid projecting it until students have made all the connections they can.

- Heat moves between and through objects that are touching each other. This is how a metal spoon handle gets hot in a cup of hot chocolate, even though the handle is not down in the drink. This is called CONDUCTION.
- Heat moves when one portion of a gas or liquid is warmer than the rest of the gas or liquid around it. When that happens, the warm area floats upward, moving its heat through the cooler parts to rise above them. This is why hot air balloons can fly, and why smoke from a fire rises through the air. You may have heard that “hot air rises.” When it does, it carries heat

Part 1 cont.

with it. This is called CONVECTION.Heat can move the same way light moves, by traveling through space as waves. You can't see it the way you can see light, but you can feel the way heat from the sun or a hot fire radiates out to a cooler surface like your skin. This is called RADIATION.

12. On the illustration, at the locations marked A, B, and C, have students label the type of heat transfer (Conduction, Convection, or Radiation) they think occurred there, along with reasons supporting their responses. After the activity is completed, discuss the results as a class.



Answer Key

A. Convection happens at A. The can heats the air inside the bottle, and that warm air rises up and out through the bottle's top. The probe is not touching anything that touches the hot can, so it is not conduction. It could be radiation, but the piece of cardboard blocks most of the radiation from the hot can.

B. Conduction happens at B. The metal is touching the hot can and heat is conducted between things in direct contact, especially metal. No air heated by the can could affect the probe because the probe is outside the bottle, so it is not convection. The temperature next to the foil (not touching it) is not the same as that of the foil, so it is not radiation.

C. Radiation happens at C. The probe does not touch the can, so conduction does not transfer the heat. The probe is low in the bottle, so it would not catch rising air there. The heat must be radiating from the can to the probe.

Part 1 cont.

Discuss what students noticed about the temperatures in the other locations they picked. What kind of heat transfer occurred in these spots? Where were the warmest and coolest spots? What might be some reasons that these places were the warmest or coolest? **It's likely that a spot near the top of the can (touching the can) will be hottest because convection concentrates heat in the water inside the can near the top of the can. Spot A will probably be the warmest place not touching the can. Convection brings warm air upward and the bottle's shape concentrates the warm air in the neck. The coolest spot will likely be in the doorway because convection is drawing cool air in there.**

Wrap-Up

1. Project Figure 9: Concept Cartoon A. Ask students to identify the type of heat transfer that each person is describing and give reasons for each one. Discuss with the whole class the type of heat transfer that each person in the cartoon is describing.

   Answer Key

   - The boy with no hat is describing conduction. The heat is moving from the part of the spoon that is touching the hot tea and through the handle of the spoon. Conduction occurs by direct contact.
   - The girl is describing convection. The heat is warming the air above the cup, which causes the air to rise up and carry heat with it.
   - The boy with the hat is describing radiation. Without touching the cup, and without feeling warm air rising above the cup, the boy with the hat can feel heat radiating from the cup.

2. Project Figure 10: Concept Cartoon B. Ask students to explain which person they agree with and what is wrong with each of the other students' ideas about heat transfer.

   Answer Key

   - The boy in the T-shirt is correct: people feel heat radiating from the fire
   - Hot air rises over the fire (notice the smoke rising), but because no one is leaning over the fire, rising hot air does not cause the people to feel heat.
   - It doesn't make sense that the wind is blowing the heat toward them because all of them feel heat. Wind doesn't blow in all directions at once.
   - Air can conduct some heat, but not to the people around the fire. Any air that is conducting heat from the flames rises up, so very little of it would touch the people around the fire.

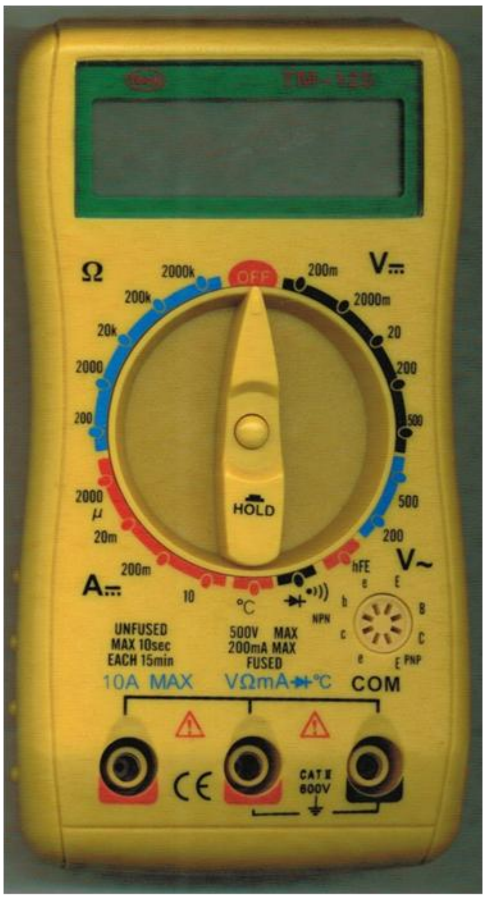
3. Ask:

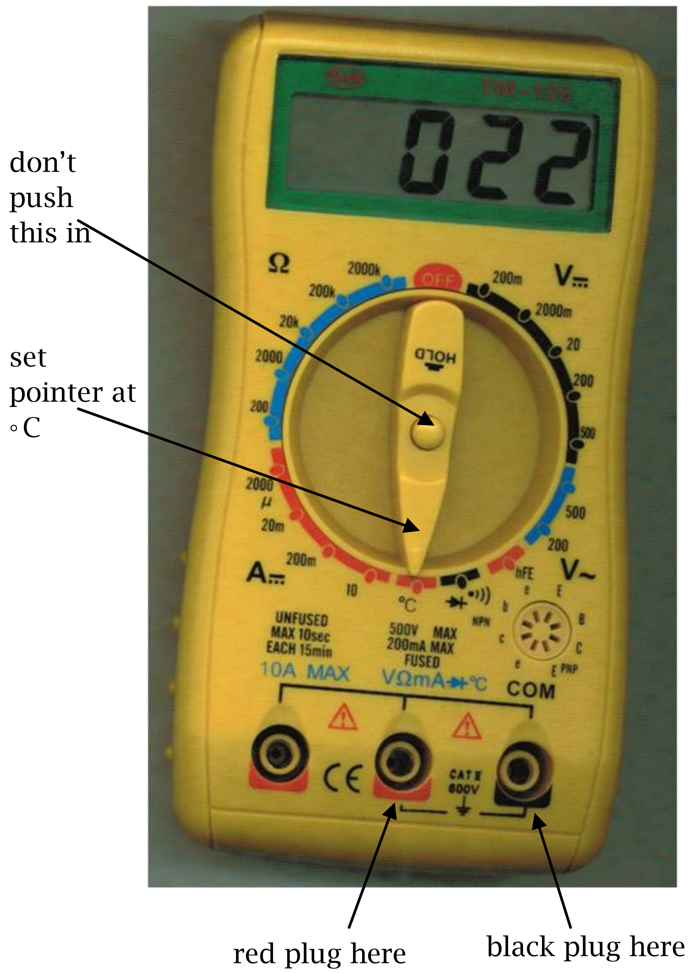
   - What process of heat transfer moved heat to the tabletop under the can? **conduction**
   - What process of heat transfer moved heat to the neck of the bottle? **convection**
   - What process of heat transfer moves heat from the sun to the earth? **radiation**

BLM 1 Temperature Probe Meter

The meter comes out of the box with the pointer in the OFF position. **RETURN TO THE OFF POSITION WHEN FINISHED.**

To use the meter as a temperature probe, put the red and black plugs in the holes shown, and set the pointer as shown (°C). Avoid the hold button.





BLM 2 Hot Can

BLM 3 Instructions for Hot Cans

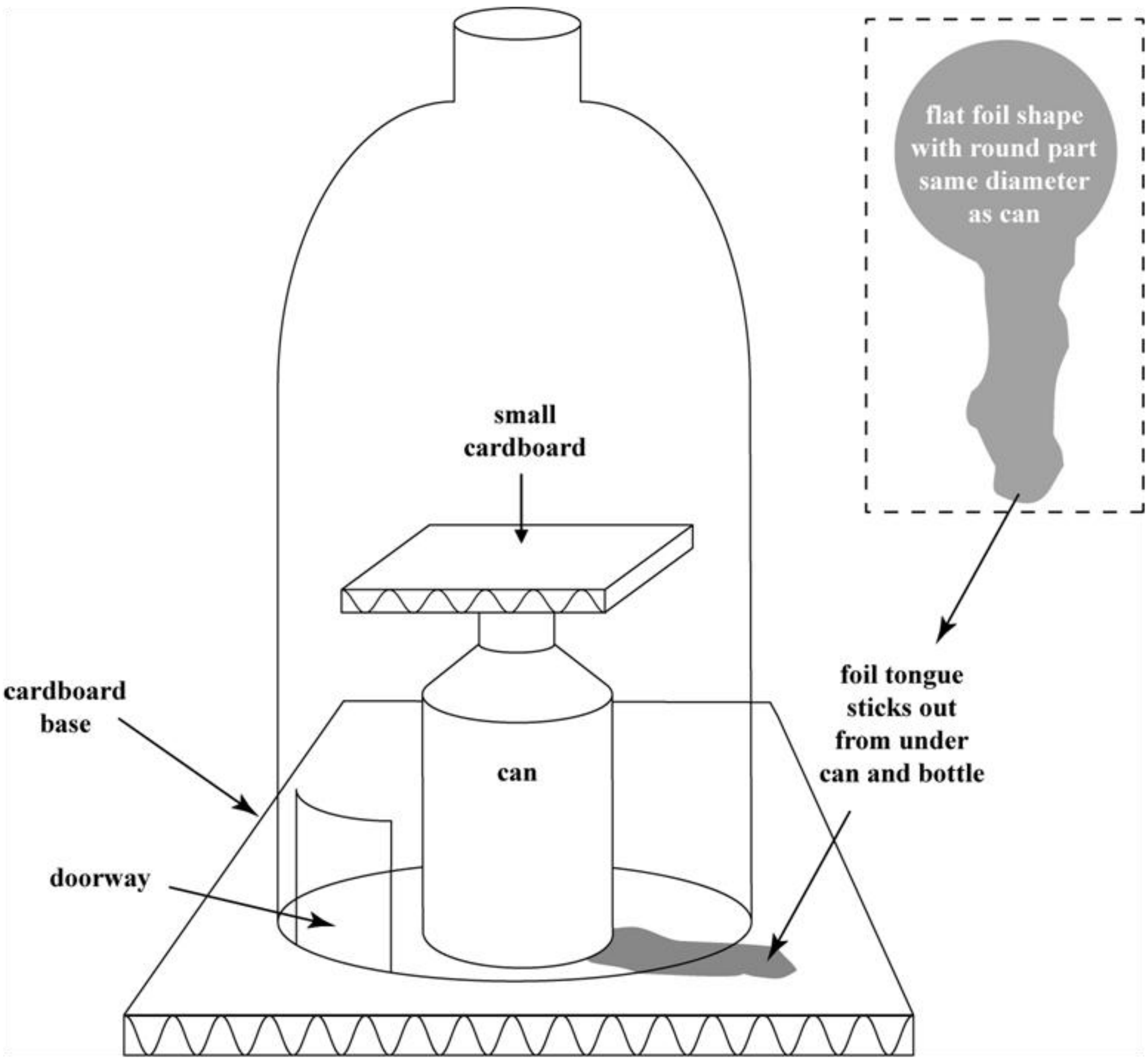
a. Leave the can where it was put down (don't move it).

b. Pick five different spots on and around the can. On your drawing of the can, mark five large dots to show where the spots you chose are. Number them one through five.

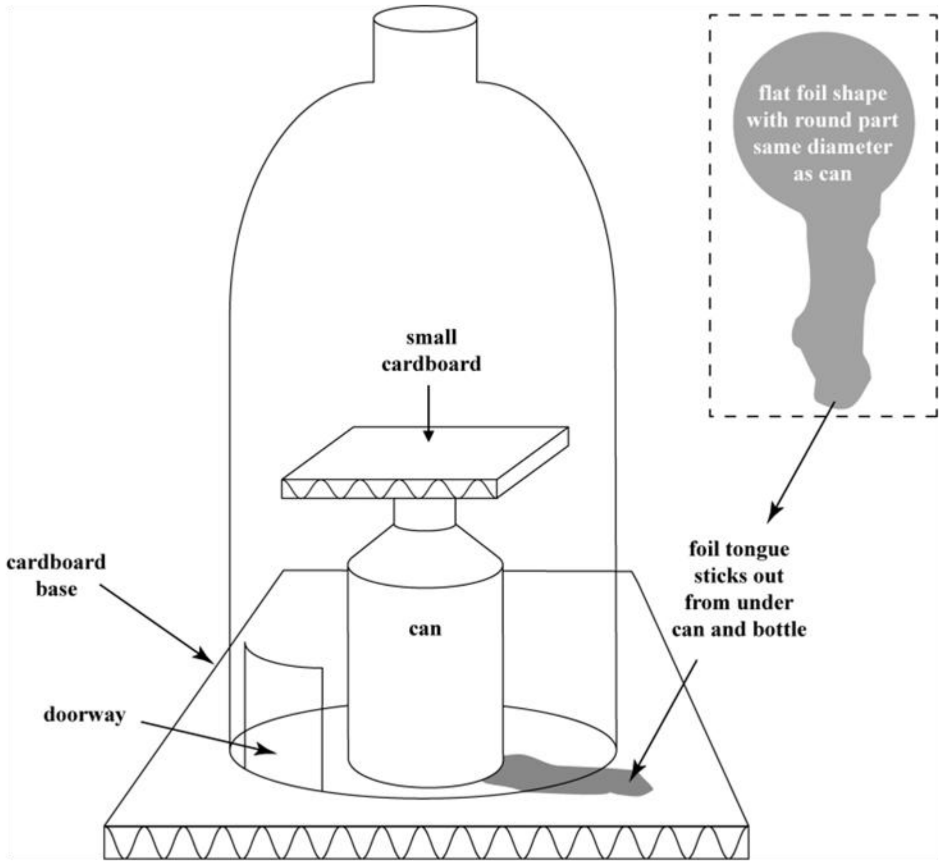
c. Starting with your first spot, measure the temperature. Record it and the time on your drawing next to the place you marked dot number one. Then do the same thing for the rest of the spots on your can and on your drawing.

d. Predict what you think the temperature will be at each spot 15 minutes from now. On your drawing, write a p near each dot. To the right of the p's, write your predicted temperatures. Underneath each p, write the letter a. This is where you will record the actual temperature in 15 minutes.

BLM 4 Hot Can in a Bottle



BLM 5 Directions for Hot Can in a Bottle



Setup

- Place the round part of the foil in the middle of the large square of cardboard. Put the can on top of the foil shape so that the tongue will extend out from the bottle when the bottle is put in place.
- Balance the small cardboard on top of the can. Put the plastic bottle over the setup with the can in the center. Take care not to knock off the small piece of cardboard. Make the foil extend under the bottle on or near the opposite side of the bottle from the doorway.

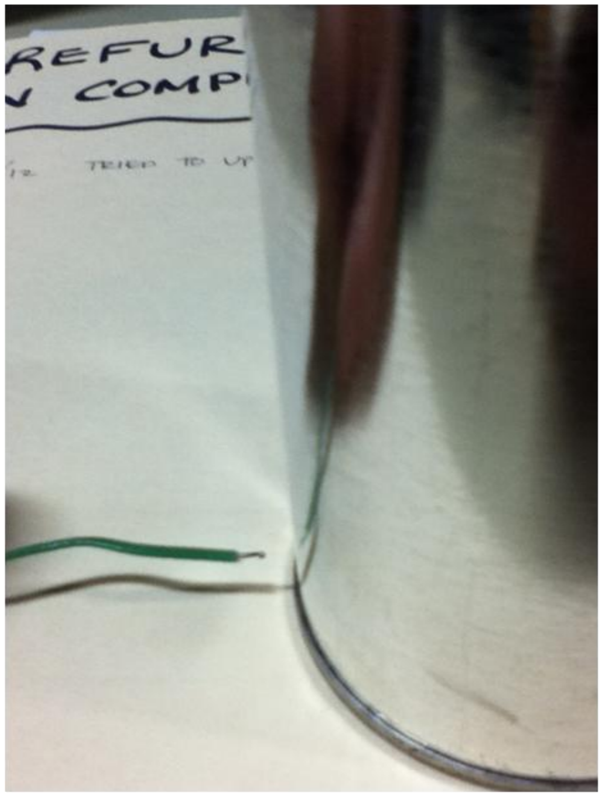
Where Does the Heat Go?

1. Measure the temperatures at each of the three locations marked A, B, and C on the diagram: **A** is in the mouth of the bottle, **B** is on the foil where it touches the bottle, and **C** is a few millimeters from the can (about the thickness of a nickel away) but not touching the can. Record the temperatures on the diagram next to the letters marking their locations. Turn off the meter when you are done.

2. With the meter off, predict temperatures at five places around the setup other than A, B, or C. Write your five predictions on the illustration, and put a "p" by these predictions. Include the spots that you think are warmest and coolest and mark these "warmest" and "coolest."

3. Turn the probe meter on. Measure temperatures at your five prediction spots. Record the actual temperatures beside your predictions. Label the actual temperatures "a." When you are finished, turn off your meter.

BLM 6 Probe Close to Can But Not Touching



probe a few millimeters from the can (about the thickness of a nickel)

BLM 7 How Heat Moved

Spot on the can	Your explanation for how the heat moved from the hot can to this spot:	Science term for this type of heat movement.
A		
B		
C		

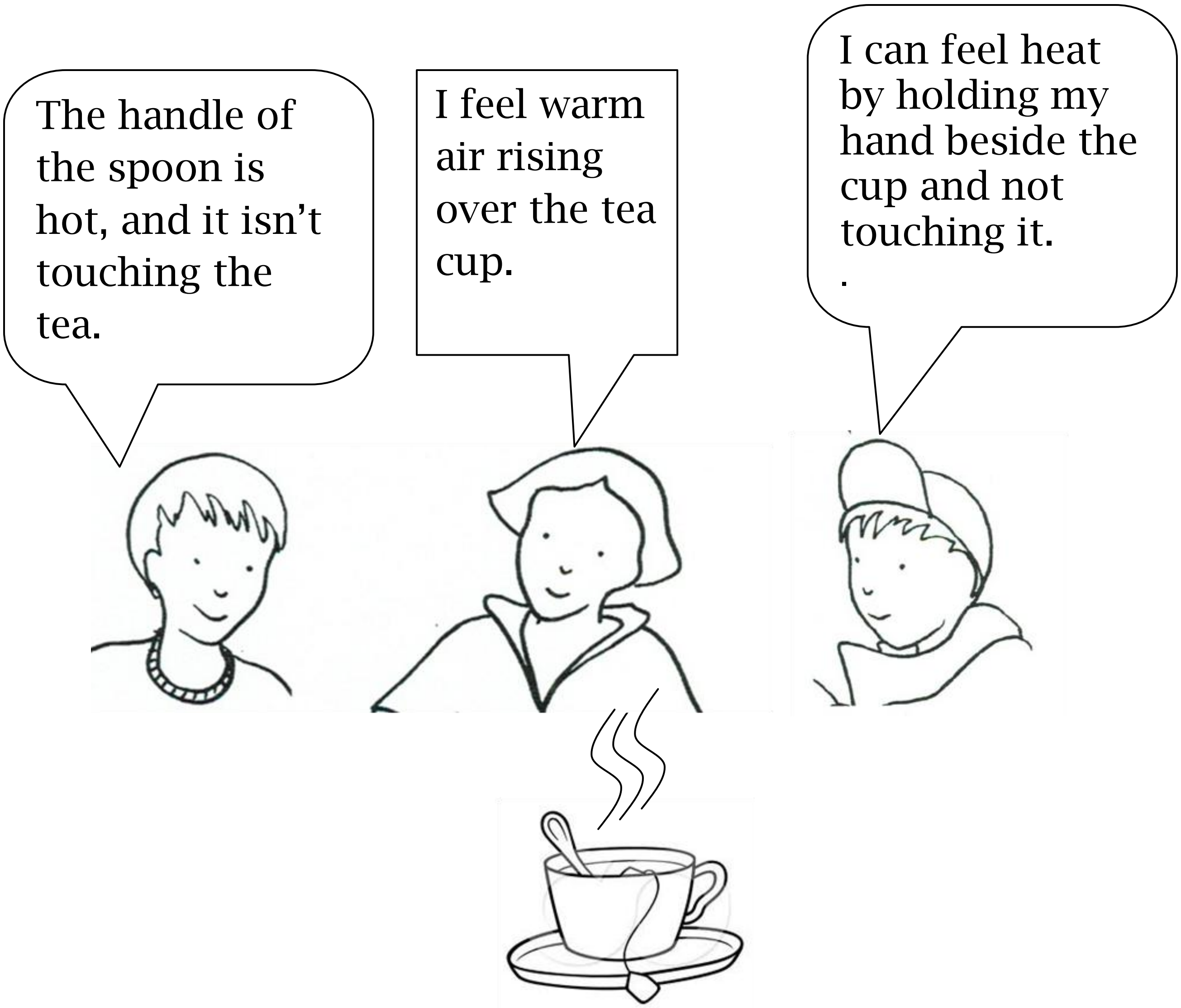
BLM 8 Ways Heat Can Move

- Heat moves between and through objects that are touching each other. This is how a metal spoon's handle gets hot in a cup of hot chocolate, even though the handle is not down in the hot drink. This is called **CONDUCTION.**

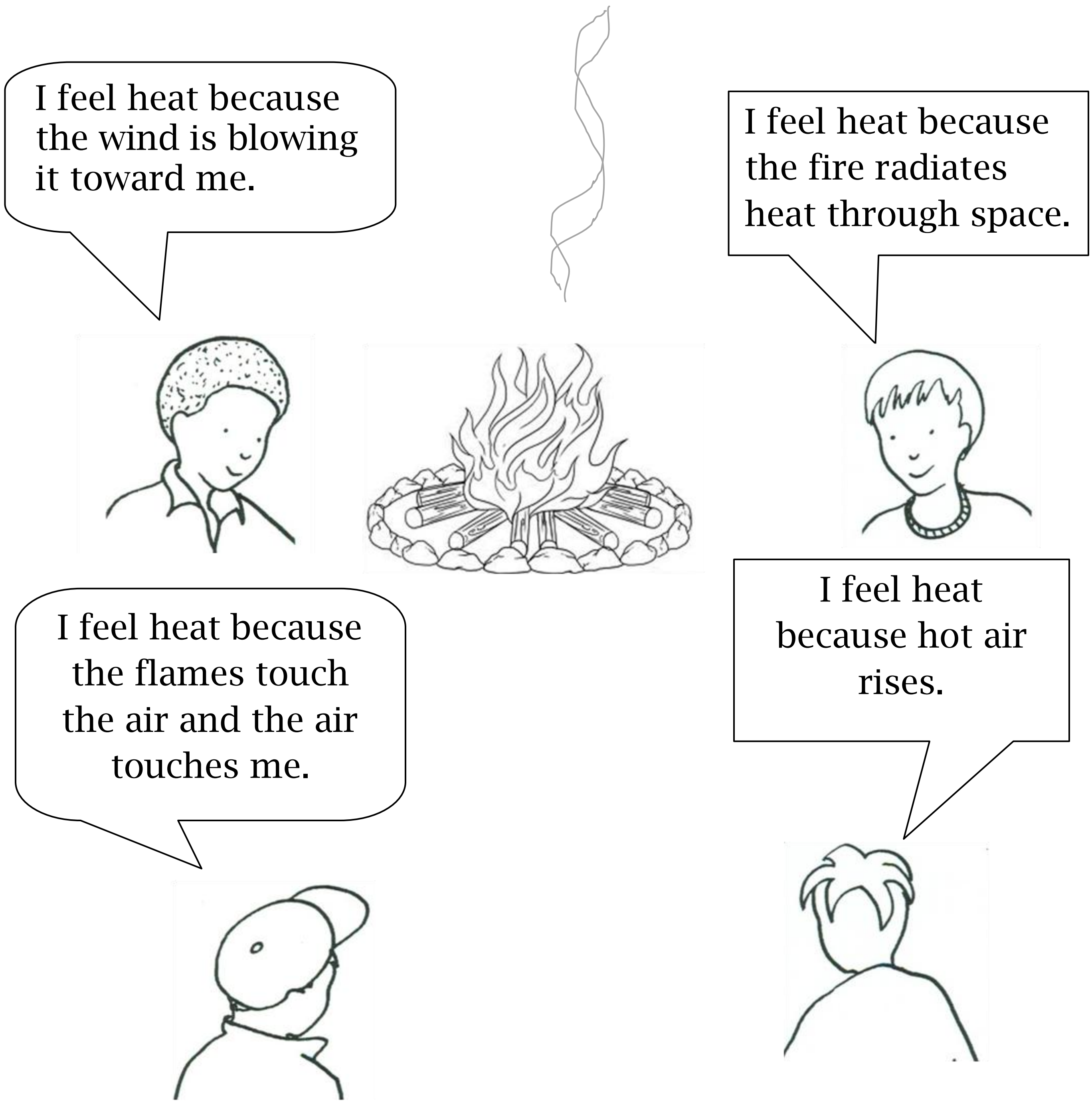
- Heat can move when one portion of a gas or liquid is warmer than the rest of the gas or liquid around it. When that happens, the warm area floats upward, moving its heat through the cooler parts to rise above them. This is why hot air balloons can fly, and why smoke from a fire rises through the air. You may have heard that "hot air rises." When it does, it carries heat with it. This is called **CONVECTION.**

- Heat can move the same way light moves, by traveling through space as waves. You can't see it the way you can see light, but you can feel the way heat from the sun or a hot fire radiates out to a cooler surface like your skin. **RADIATION**

BLM 9 Concept Cartoon A



BLM 10 Concept Cartoon B



Appendix

Common Student Preconceptions About This Topic

Children ages 11-16 tend to view heat as a kind of material. For example, when a long piece of metal is heated at one end and the other end eventually warms, students often think that excess heat in one spot "overflows" to another place, like a liquid. Alternatively, they might say that hot molecules move along the metal until they cool down and stop moving. Similarly, they think of the sensations of hotness or coldness as something entering or leaving the body. Feeling dense objects as cooler than insulators, many children say the dense objects "let heat in easier" or transfer coldness to their skin. Few see cold as absence of heat and heat as moving from warmer places to cooler ones. They may also say that metal parts of a bicycle feel colder than plastic parts because the metal attracts coldness. In general, few students, even beyond grade 8, understand heat transfer in terms of behavior of atoms and molecules.

Detailed Background Information

Conduction occurs because molecules are in motion, and as heat is added, the molecules move more. Conduction can occur in any material. For example, when a metal cooking pot sits on a hot stove, the metal molecules touching the stove begin vibrating more than their unheated neighbors. The energetic vibrations of these heated molecules cause them to bump repeatedly against their unheated neighbors, causing them to vibrate more quickly, too. These, in turn, bump their neighbors, who bump their neighbors, and so on, until the heat from the stove is distributed throughout the pot by the process of conduction. The pot's now rapidly vibrating metal molecules also bump against water molecules inside the pot. The bumps give the water molecules an extra push, so they bounce more vigorously against other molecules that aren't touching the pot. Those molecules in turn bounce more energetically off their neighbors, etc. In this way, heat from the pot transfers to the water by the process of conduction. Conduction can occur *within* a material, and *between* different materials.

Some materials conduct heat better than others, and metals do this especially well. Glass and ceramics, such as those used in baking also conduct heat well. Wood, plastic, and rubber are conduct heat poorly. This is why wooden spoons are good for stirring hot soup and most frying pans have plastic handles. Pot holders are such poor heat conductors that we call them *insulators*.

Less conduction occurs in gases because conduction requires molecules to contact one another. Molecules in gases are far apart and don't touch as often. In gases, heat is more commonly transferred by convection. Heating a gas causes the molecules to bounce vigorously off each other, spreading them out and producing lots of empty space between molecules. As a result, a heated gas such as warm air is less dense than cool air. In a mixture of warm and cool air, the less dense (warmer) portion floats upward because it is buoyant in the denser (cooler) portion. Convection is the phenomenon behind the well known phrase, "Hot air rises".

Common examples of convection are steam rising out of a tea kettle and the smoke rising from a fire. If you have a step ladder or can safely stand on a table, you can feel and measure a result of convection in your classroom. Turn off any ceiling fans for a few minutes, and measuring the temperature of the air near the ceiling and the air just above the floor. It is often several degrees warmer near the ceiling.

Convection occurs in liquids in the same manner as in gases, due to the motion of molecules and their distances apart. If students have swum in a lake during the summer, they might have noticed that the surface is warm, but a few feet below the surface, it is cooler. The surface water has been warmed a little by conduction from warm air and much more by radiation from the sun. The warm water is buoyant in the cooler water, and the cooler water sinks down because it is denser than the warm water.

When water is heated in a pot, the water at the bottom gets warm first, but it quickly rises to the surface by convection. Cooler water sinks to the bottom to replace it, and that water in turn is heated, and so on, until all the heat is distributed throughout the pot.

The third type of heat transfer, radiation, does not involve the motion of molecules. Radiation is the transfer of heat energy through space by means of infrared light waves and visible light waves. We are all familiar with it because radiation is the way energy from the sun warms the earth. We feel the heat given off by a light bulb or the flame of a candle, and we feel it without touching the bulb or the flame. Unlike conduction, direct contact is not necessary to transfer heat by radiation. Radiation moves outward in all directions, so we feel the heat of an overhead light while standing under it and the heat of a fire when sitting next to it.

Heat transfer by radiation is the result of light waves. It can be blocked, just like light, when a solid material is placed between the heat source and an object that would otherwise be warmed. On a hot day, the shade of trees provides such an obstacle, and makes it feel cooler. Dark surfaces absorb more radiated heat than pale-colored surfaces. Pale colors reflect more heat similar to the way a mirror reflects light. Sheets of black and white construction paper placed in a sunny window feel noticeably different a few minutes later. It is fairly easy to measure the temperature differences between the two colors.

Regardless of whether heat transfer occurs by conduction, convection, or radiation, heat is only transferred in one direction: from warmer to cooler. It might seem like something cold, such as an ice cube, makes as a glass of warm water cooler by transferring its coldness to the water. In fact, heat moves from the warm water into the ice cube by conduction, which makes the ice melt. Before long, the water in the glass is at a temperature that is warmer than the ice cube but cooler than the water was. Now the two materials, the formerly frozen water in the ice cube and the water already in the glass, are at a new equilibrium temperature. This is the end result of all heat transfers: heat flows from warmer things to cooler things until equilibrium is reached between them.

Appendix cont.

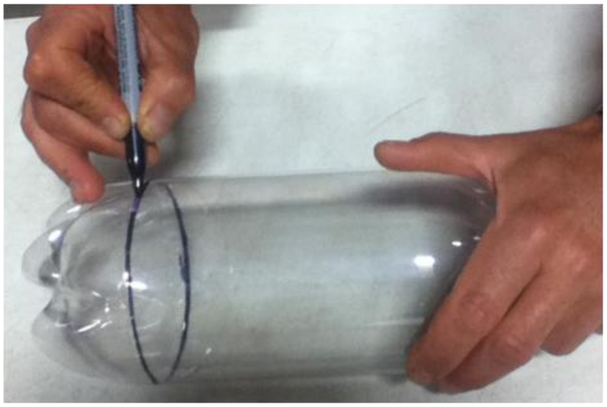
Tips for Cutting Plastic Bottles

To mark and cut the bottles you will need the following materials provided with the kit:

- 1 fine point permanent marker
- 1 box cutter (provided in kit materials)

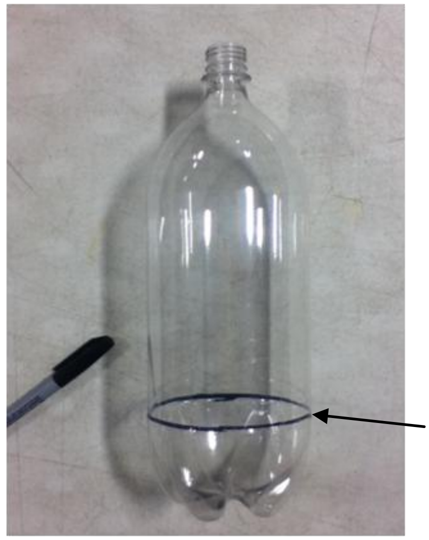
You will also need a pair of scissors that is not provided in the kit.

1. Put the point of the marker in the groove at the top of the thick plastic at the base of the bottle. Hold the marker steady and rotate the bottle to draw a line around the bottle at the top of the base.



Appendix cont.

2. Use a box cutter to cut about an inch along the line you just drew. Use scissors to finish the cut around the bottle's circumference.



Cut around this line