Thermal Conduction and Surface Area

Background Information

The quantity of energy transferred by heat from a body depends on a number of physical properties of the body and its surroundings. For a given substance, the rate at which thermal energy is transferred by conduction depends on temperature difference, cross-sectional area, and a thermal conductivity constant that is unique to the substance. By choosing one of these properties as a manipulated variable and making the other properties controlled variables, the effect of the manipulated variable on thermal conduction can be determined experimentally.

In this investigation, you will study the rates of cooling of three containers of water of equal volume but different surface area.

Problem

How does heat loss depend on surface area?

Pre-Lab Discussion

Read the entire investigation. Then, work with a partner to answer the following questions.

1. **Formulating Hypotheses** How would you expect the rate of thermal energy transfer from the water to depend on the water's surface area? What is your reason for this expectation?

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2. **Controlling Variables** Identify the manipulated, responding, and controlled variables in this investigation.

   a. Manipulated variable

   _____

   _____

   b. Responding variable

   _____

   _____

   c. Controlled variables

   _____

   _____

3. **Designing Experiments** Why should plastic containers be used for holding the hot water during the experiment? Why should the containers and the graduated cylinder be warmed first with hot water?

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4. **Using Tables and Graphs** How can you tell which graph indicates the greatest rate of thermal energy transfer?

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Materials *(per group)*

3 cylindrical plastic containers with different surface diameters
metric ruler
hot tap water
3 Celsius thermometers
100-mL graduated cylinder
grease pencil
clock or watch
graph paper
3 colored pencils
1000-mL beaker (optional)
hot plate (optional)

Safety

Put on safety goggles and a lab apron. Be careful to avoid breakage when working with glassware. Use extreme care when working with heated equipment or materials to avoid burns. Observe proper laboratory procedures when using electrical equipment. Note all safety alert symbols next to the steps in the Procedure and review the meaning of each symbol by referring to the Safety Symbols on page xiii.

Procedure

1. Label the plastic containers *A, B,* and *C,* using the grease pencil. Label the container with the smallest diameter *A* and the one with the largest diameter *C.*

2. Use the ruler to measure the diameter of each container and record this information in Data Table 1. Calculate the cross-sectional surface area, using the formula $Area = (Diameter/2)^2\pi$. Record these values in Data Table 1.

3. Run hot tap water until the water temperature reaches a constant value, about 50°C. Test the water temperature by holding a thermometer bulb in the stream of water. If you do not have a source of hot water, heat 600 mL of water in a beaker on a hot plate. Let the water reach a temperature of 50°C. **CAUTION:** *Use heat-resistant gloves. Be careful not to burn yourself or to break the thermometer or beaker. If using a hot plate, be careful to avoid burns and electrical shock.* Wipe up any spilled water immediately.

4. Warm the labeled containers by filling each of them with about 50 mL of hot water. Also fill the graduated cylinder to warm it. After a few minutes, pour out the water in the containers and the graduated cylinder. Refill the warm graduated cylinder with 100 mL of hot water. Quickly pour the water into container A. Repeat this process, pouring 100 mL of hot water into each of the other two containers.

5. Use the three thermometers to immediately measure the temperature of the water in the containers. Record the maximum temperature values in the second, third, and fourth columns of Data Table 2. The three beginning temperatures should be very similar. Look at a clock or watch and make a note of the time. Record the time in the "Time" column of Data Table 2. **CAUTION:** *Take care not to hit the thermometers against the sides of the containers.*

6. After 1 minute, record the time and the water temperature in each container. Continue to record the temperatures every minute for 15 minutes. Do not stir the water.

7. On a sheet of graph paper, make a graph of the information in Data Table 2. Plot the number of minutes from the start of the experiment on the horizontal axis (x-axis) and water temperature on the vertical axis (y-axis). Use a different-colored pencil for the data for each container. Draw curved lines to connect the data points for each container.

Name _____ Class _____ Date _____

Observations

DATA TABLE 1

	Diameter (cm)	Surface area (cm^2)
Container A		
Container B		
Container C		

DATA TABLE 2

Time (min)	Temperature of Water in Container A (°C)	Temperature of Water in Container B (°C)	Temperature of Water in Container C (°C)
0			
1			
2			
3			
4			
5			
6			
7			
8			
9			
10			
11			
12			
13			
14			
15			

Name _____ Class _____ Date _____

Analysis and Conclusions

1. **Observing** In general, what happened to the temperature of the water in the containers? Describe the three curves on your graph.

2. **Observing** From which container of water was thermal energy transferred the fastest? On what evidence do you base your answer?

3. **Applying Concepts** What happened to the thermal energy that was in the water? Where did it go?

4. **Predicting** What would have happened, in terms of thermal energy transfer, if the water temperature had originally been 10.0°C? Explain your reasoning.

5. **Drawing Conclusions** Based on your findings in this investigation, make a general statement relating thermal energy transfer to surface area. How does this statement compare to the hypothesis you made before the investigation?

6. **Making Generalizations** Two lakes have exactly the same amount of water in them. The surrounding environment is at the same temperature. You can presume the ground beneath each lake is a thermal insulator. Which lake would lose thermal energy at a faster rate—one that was large and shallow or one that was small and deep? Explain your answer.

Go Further

Plan an investigation to determine how containers made of different materials affect heat loss. Indicate how the containers would differ from the containers used in the current experiment. Show your plan to your teacher. When your teacher approves your plan, carry out your experiment and report your results.