Name Period Date

24. Heat of Fusion

Driving Questions

How much heat does it take to melt ice?

Background

On a microscopic level, thermal energy has to do with the energy of molecules. Substances that are perceived as hot have molecules with a large amount of kinetic energy. In addition to kinetic energy, potential energy exists between molecules in the form of inter-molecular bonds. The molecules in a solid or liquid are held together as a result of these inter-molecular attractions. In everyday life, we quantify thermal energy in terms of temperature. The standard unit of measure for temperature is Kelvin. To simplify our experiment, we use the more common, water centric scale, Celsius.

Heat is the energy that transfers from one substance to another as a result of a difference in their temperature. Heat, like all energy, is measured in joules *J*. An object's heat capacity is its ability to absorb heat; it is the ability of the molecules within the object to acquire kinetic energy. We express this as the specific heat of a substance c, or the joules of heat required to raise one kilogram of the substance by 1 °C. The heat lost or gained by a substance is defined as:

$$Q = mc\Delta T \qquad \textbf{Eq.1}$$

where Q is the amount of heat, m is the mass of the substance, c is the specific heat of the substance, and ΔT is the change in temperature of the substance.

In addition to changing the temperature of a substance, heat can also break inter-molecular bonds causing the substance to change phase. When this happens, no energy goes into changing the temperature of the substance; it is all being used to alter the inter-molecular bonds within the substance. The heat energy required for a substance to change phase between solid and liquid is represented by:

$$Q = mL_f \qquad \textbf{Eq.2}$$

where Q is the heat, m is the mass of the substance changing phase, and L_f is the latent heat of fusion of the substance. Like the specific heat of a substance, the latent heat of fusion of a substance is a property dependent on the type of substance and the substance's ability to absorb heat while it changes phase. Heat, like all energy, is conserved. This means that the heat that flows out of one object must equal the heat that flows into another object.

Materials and Equipment

For each student or group:

- ♦ Data collection system
- ♦ Temperature sensor
- ♦ Beaker, 600-mL
- ♦ Calorimetry cup
- ♦ Balance (1 per classroom)
- ♦ Hot plate
- ♦ Stirring rod
- ♦ Stir station (optional)
- ♦ Water, 300 mL
- ♦ Ice (3 or 4 cubes)
- ♦ Paper towel

Safety

Add these important safety precautions to your normal laboratory procedures:

- ♦ Keep water away from sensitive electronic equipment.
- ♦ Be careful using the hot plate. Always be aware that it is on, and be conscious of any loose clothing or papers that could accidently catch fire.

Sequencing Challenge

The steps below are part of the Procedure for this lab activity. They are not in the right order. Determine the proper order and write numbers in the circles that put the steps in the correct sequence.

◯	◯	◯	◯	◯
Calculate the amount of heat lost by the water.	Measure the initial temperature of the water.	Calculate the heat of fusion of ice.	Add ice to the water. After the ice has melted, measure the equilibrium temperature.	Connect the temperature sensor to your data collection system.

Procedure

After you complete a step (or answer a question), place a check mark in the box (☐) next to that step.

Note: When you see the symbol "�" with a superscripted number following a step, refer to the numbered Tech Tips listed in the Tech Tips appendix that corresponds to your PASCO data collection system. There you will find detailed technical instructions for performing that step. Your teacher will provide you with a copy of the instructions for these operations.

Set Up

1. ☐ Heat 300 mL of water to approximately 40 °C in the beaker on the hot plate.

2. ☐ Start a new experiment on the data collection system. �(1.2)

3. ☐ Connect the temperature sensor to the data collection system. �(2.1)

4. ☐ Display temperature in a digits display. �(7.3.1)

5. ☐ Monitor live temperature data without recording. �(6.1)

6. ☐ Carefully measure the mass of the calorimetry cup, and record this value in Table 1 in the Data Analysis section.

7. ☐ Fill the cup ¾ with heated water (approximately 40 °C).

8. ☐ Quickly (but accurately) measure the weight of the filled cup, and record your value in Table 1 in the Data Analysis section.

Collect Data

9. ☐ Insert the temperature sensor into your cup, and allow the temperature reading to stabilize. Record the initial temperature of the water to the nearest tenth of a degree in Table 1 in the Data Analysis section.

Note: If you choose to use a stir station, place the calorimetry cup on the stir station with the stir bar in the cup.

10. ☐ Dry off 3 or 4 ice cubes using a paper towel.

11. ☐ Place the ice cubes into the cup, slowly stirring until the ice completely melts. Continue stirring for 1 minute, ensuring that the temperature of the water has reached equilibrium. Record the final temperature of the water in the cup in Table 1 in the Data Analysis section.

12. ☐ Why did you dry the ice cubes before you placed them in the beaker?

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13. ☐ Remove the temperature sensor from the calorimetry cup.

14. ☐ Use the balance to measure the mass of the cup, initial water, and melted ice. Record your answer in Table 1 in the Data Analysis section.

15. ☐ Stop monitoring temperature data. �(6.1)

Data Analysis

Table 1: Temperature and mass data

Parameters	Value
Mass of calorimetry cup (kg)	
Mass of cup and initial water (kg)	
Mass of initial water (kg)	
Mass of cup, initial water and melted ice (kg)	
Mass of ice (kg)	
Initial temperature of water in the cup (°C)	
Final temperature of water in the cup (°C)	
Temperature melted ice (°C)	
Temperature change of water (°C)	
Temperature change of melted ice (°C)	

1. ☐ Calculate the initial mass of the water by subtracting the mass of the cup alone from the mass of the water and cup. Record the mass of the initial water in Table 1.

2. ☐ Calculate the mass of the ice that melted in the cup by subtracting the mass of the cup and initial water from the mass of the cup, initial water and melted ice. Record the mass of melted ice in Table 1.

3. ☐ Calculate the change in temperature of the water in the cup by subtracting the initial temperature from the final temperature. Record the temperature change in Table 1.

4. ☐ Calculate the change in temperature of the water that is melted from ice by subtracting the initial temperature from the final temperature. Record the temperature change in Table 1.

Analysis Questions

1. What was the source of heat that melted the ice?

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2. What is the sign of each temperature change that you calculated? And what do they mean?

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3. Given the specific heat capacity of water c is 4,186 J/(kg·°C), use the values from Table 1 to find the heat transferred from the water initially in the cup.

4. **Use the values in Table 1 to determine how much of the heat transferred out of the water in the cup went into warming the melted ice to the final temperature.**

5. **Conservation of energy means accounting for all of the energy leaving the water in the cup. If the heat needed to warm the melted ice does not account for all the heat transferred from the water, where does the additional heat go? Use your previous heat calculations to determine the amount of additional heat lost by the water that *did not* go into warming the melted ice.**

6. **We know the mass of the ice that was melted into water. If all of the remaining heat can be attributed to phase change, what is the latent heat of fusion L_f of water?**

7. **If the theoretical value for the latent heat of fusion is 3.340×10^5 J/kg, what is the percent difference between your value and the theoretical value?**

8. **What are you assuming about the ice, if you assume that you added 0 °C water to the cup after the ice melts?**

9. **How would you need to modify the heat transfer calculations to account for this extra heat absorbed by the ice?**

10. **Explain any assumptions that you had to make about heat transfer as you were conducting this experiment.**

11. **Keeping those assumptions in mind, what could you do to improve the accuracy of your results?**

12. **What procedural changes would you make to improve your results?**

Synthesis Questions

Use available resources to help you answer the following questions.

1. Can an object absorb heat without changing temperature? Explain.

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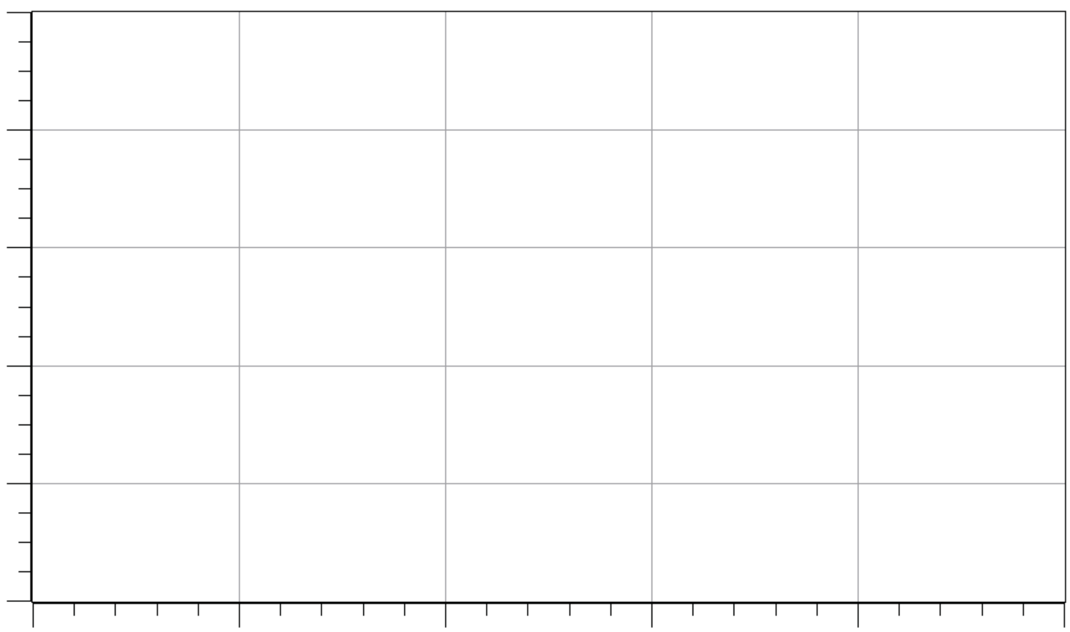
2. Sketch a graph of Heat Added versus Temperature for the collection of water molecules that were originally added in the form of ice. Start at the time when you added the ice to the cup and end at the time the water in the cup reached equilibrium. Don't worry about showing specific temperatures; just show a general trend. However, be sure to include key points on the graph, such as the melting temperature of ice, the heat of fusion, and the final temperature of the water molecules.



3. The volume of Lake Tahoe is 150 km^3. How much heat would be required to raise its temperature 3 °C? Assume the density of water is 1×10^{12} kg/km^3.

4. A student adds a measured amount of ice to a cup of hot water. The student records the initial temperature of the water before adding the ice and the final temperature after the ice melts. The student calculates the heat lost by the water and reasons that it equals the heat required to melt the known mass of ice. The student solves for the heat of fusion of the ice and gets a number significantly higher than the accepted value. Explain where the student made a mistake.

5. How much ice must you add to cool 500 mL of water from 50 °C to 25 °C. (Hint: Remember, heat will be lost by the water to melt the ice *and* raise the temperature of the additional 0 °C water).

Multiple Choice Questions

Select the best answer or completion to each of the questions or incomplete statements below.

1. Between the time you recorded the initial temperature of the water in the cup and the final temperature, heat energy caused the ice in the cup to undergo the following changes:

- **A.** Heat flowed from the ice, causing it to melt and the water to become warmer. Once the ice melted, heat flowed from the newly formed water into the existing water, causing the temperature to rise even more.
- **B.** Heat flowed from the water and was absorbed by the ice. The temperature of the ice rose as it underwent a phase change into water. By the time the ice melted, all of the water in the cup was at the final temperature.
- **C.** No heat flow occurred at all. The ice melted because liquid is the natural state into which water molecules arrange themselves.
- **D.** Heat flowed from the water and was absorbed by the ice. As the ice absorbed the heat, it remained at a constant temperature. The heat energy caused the phase change from solid to liquid. Once the ice melted, heat energy continued to flow from the liquid water into the newly formed liquid water because it was at a cooler temperature. Eventually, all of the liquid water in the cup became the same temperature.

2. The units of heat of fusion are

- **A.** J/(kg·°C)
- **B.** N/m^2
- **C.** Heat of fusion is unitless
- **D.** Ω/kN

3. On a microscopic level, the sensation of warmth is actually a result of?

- **A.** The average kinetic motion of the molecules that make up the substance
- **B.** The gravitational forces between the molecules of a substance
- **C.** The electrical conductivity of the molecules of a substance
- **D.** None of the above

Key Term Challenge

Fill in the blanks from the list of randomly ordered words in the Key Term Challenge Word Bank.

1. In this ____________ experiment, the amount of ____________ that was lost by the warm water in the cup was equal to the amount of heat that ____________ the ice placed into that cup, plus the amount of heat used to raise the ____________ of the water from the melted ice to the equilibrium temperature. This is another example of how ____________ is conserved.

2. To calculate the heat ____________ by the water, one needs to know the ____________ and initial temperatures, the mass of the water, and the ____________ heat of water. By assuming that the heat lost by the water is equal to the heat absorbed by the ____________, one can calculate the heat of ____________ of ice.

Key Term Challenge Word Bank

Paragraph 1	Paragraph 2
Calorimetry	Final
Energy	Fire
Force	Fusion
Freezes	Gained
Heat	Ice
Mass	Internal
Melted	Lost
Temperature	Specific