You're All Mixed-Up... Let Off Some Heat

Student Instruction Sheet

Challenge

Determine how much heat energy is required to melt a given amount of ice, and determine how much heat energy is needed to vaporize the same amount of water.

Equipment and Materials

• computer with USB port	• graduated cylinder, 100-mL
• PASORT USB interface	• beaker, 250-mL
• PASPORT Temperature Sensor	• Small Tripod Base & Rod
• DataStudio software	• hot-vessel gripping device
• Balance	• tongs
• Buret Clamp	• Erlenmeyer flask, 250-mL
• calorimeter (foam cup)	• rubber stopper, one-hole
• water, 300.0 mL	• glass and flexible tubing*
• ice, cubes, 5 (approx. 10 grams)	• protective gear
• stirring rod	• *Student Instruction Sheet*
• hot plate	• *Student Response Sheet*

*With the flexible tubing used in the steam generator, it may be helpful to insert a short length of glass tubing at the collection end to act as a weight and a "delivery tube" for the condensing steam.

Safety Precautions

Use caution any time you are heating something using a hot plate or burner. Be particularly careful in part B, where hot steam will be coming out of the glass tubing; steam can cause serious burns!

Keep water away from electrical outlets, the computer, the keyboard, and the PASPORT equipment!

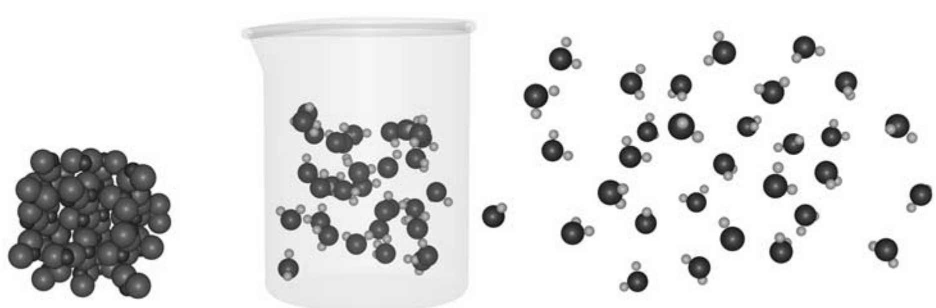
Remember, follow the directions for using the equipment.

Wear safety glasses and follow standard laboratory safety procedures.

Background

When you want a cool drink, you reach for your favorite beverage and add ice. How do the ice cubes cool your drink? Why do the ice cubes eventually melt? Ice cubes, like other solids, absorb heat energy from their surroundings (in this case, your drink) as they undergo a change of state by melting. According to the Law of Conservation of Energy, the amount of heat energy lost by the surroundings must be equal to the amount of heat energy gained by the ice cubes.

What if you continued adding energy to the system? If you add more heat energy to the melted ice cubes (water), what will the liquid water eventually turn into? What will happen to the temperature of the water as it undergoes its next change of state?



Different substances require different amounts of heat energy to undergo changes of state such as melting or boiling. A substance's molar heat of fusion is the amount of heat energy absorbed by one mole of the substance as it changes from a solid to a liquid. The substance's molar heat of vaporization is the amount of heat energy absorbed when one mole of the substance changes phase from liquid to gas.

The general equation to calculate heat is:

$$Q = mC\Delta T$$

heat energy = mass of H_2O x specific heat of H_2O x change in temperature

Where:

Q = heat energy (in joules or calories)

m = mass of the substance (in grams)

C = specific heat of the substance (in units of J/g °C or cal/g °C), and

ΔT = difference between starting and ending temperatures (in °C).

A substance's specific heat is one of its unique properties. It describes how much energy is required to raise the temperature of 1 gram of the substance 1 degree Celsius or 1 kelvin. For water, this value is 4.18 J/g °C, which is relatively high compared to other substances. Practically speaking, it takes a great deal of energy to raise or to lower the temperature of water. What practical consequences does this have on Earth?

Predict

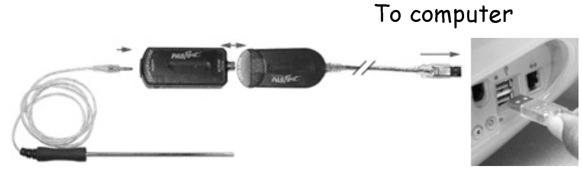
Before beginning the eLab, complete the prediction portion and define the vocabulary words on the *Student Response Sheet*.

Explore

Hint: If you will be completing Part B later in the same day or same class period, start the water needed for Part B boiling before beginning Part A.

Computer Setup

1. Plug the USB interface into the computer's USB port.
2. Plug the Temperature Sensor into the USB interface. This will automatically launch the PASPORTAL window.



3. Choose the appropriate DataStudio configuration file entitled

02 Heat of Fusion-Vapor CF.ds

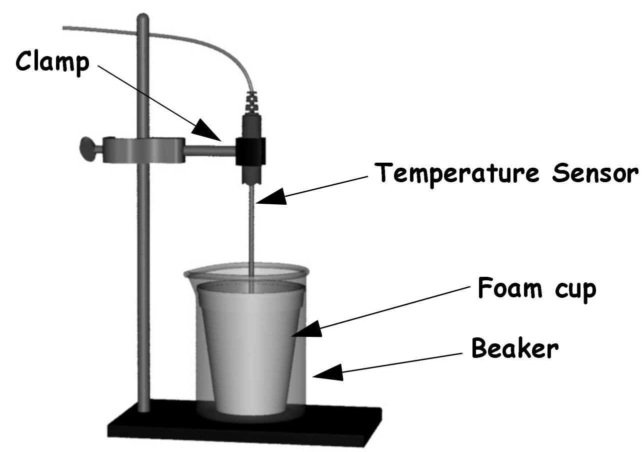
and proceed with the following instructions.

> **Note**: Configuration files automatically launch the appropriate display(s), sampling rate(s), etc.

Part A: Heat of Fusion

Equipment Setup

1. Fill the foam cup about 3/4 full with tap water and record the mass of the water and cup as m_w in Table 1 on the *Student Response Sheet*. You can ignore the mass of the cup (calorimeter) as it is insignificant compared to the mass of the water.
2. Set up the foam cup, beaker, and the Temperature Sensor as shown.
3. Lower the Temperature Sensor into the water (to about 1.0 cm from the bottom).



Record Data

1. Click the **Start** (▶ Start) button to begin recording the temperature.
2. Watch the Digits Display for the temperature to reach an equilibrium. This temperature will be the initial temperature, T_1, of the water.
3. Shake excess water from several (5 or 6) small ice cubes or dry them with a paper towel, then add them to the water.

> **Note:** You want approximately 10 grams of ice cubes for the best results. Use the balance for more exact measurement.

4. Stir with the stirring rod and monitor the temperature.

> **Note:** Do not use the Temperature Sensor to stir the water; it could add extra heat to the water. Use the stirring rod.

5. When the ice is completely melted, stir the mixture one more time and note this temperature as the final temperature, T_2.

6. Click the **Stop** (Stop) button to end data collection.

7. Use the balance to obtain the mass of the cup + water + melted ice. Record this mass as m_{w+i} in Table 1 on the *Student Response Sheet*.

Analyze

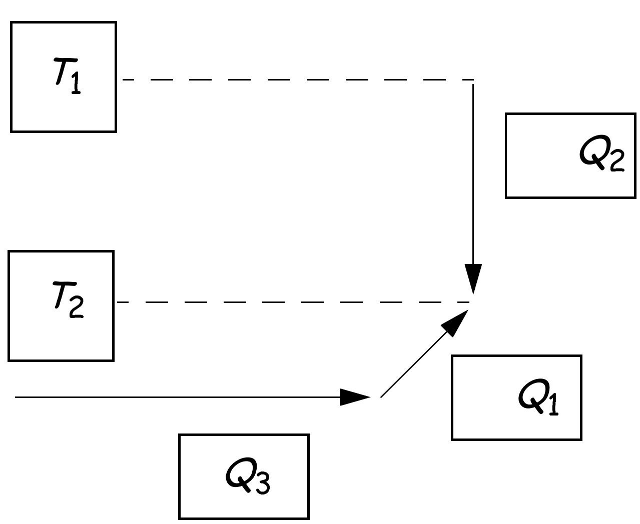
Record calculations in Table 1 on the *Student Response Sheet* as you complete your analysis.

1. Click the **Smart Tool** ( ) button. Drag the **Smart Tool** ( ) cursor to determine the initial temperature (T_1) and the final temperature (T_2), and then record these values in Table 1.

2. Subtract $T_1 - T_2$ to determine ΔT, the change in water temperature. Record this value in Table 1.

3. Subtract the mass of the cup + water (m_w), from the cup + water + melted ice (m_{w+i}) to obtain the mass of the ice. Record this value in Table 1 as (m_i).

4. The total amount of heat energy lost by the water (Q_2) is equal to the amount of heat energy absorbed by the ice as it melted (Q_3), plus an additional amount of energy required to bring the temperature to equilibrium (Q_1). In other words, Q_1 represents the energy needed to raise the temperature of the melted ice water to the final temperature.



The graph shows the heat (Q) involved in the fusion experiment. T_1 is the initial temperature and T_2 is the final equilibrium temperature. $Q_2 = Q_1 + Q_3$

5. To determine how much energy was required to melt the ice in your experiment, you will need to use the general equation for calculating heat that was discussed in the *Background* section. Follow the steps below to calculate the heat of fusion (in joules/g) for the ice you melted and record your values in Table 1 on the *Student Response Sheet*:

    a. Calculate the amount of heat (in joules) absorbed by the melted ice water as the temperature came to equilibrium, and record this as Q_1.

$$Q_1 = (m_i) \times (4.18\ \text{J/g °C}) \times T_1$$

    b. Calculate the total amount of heat energy lost by the water (used to melt the ice as well as to warm the water). Record this as Q_2.

$$Q_2 = m_w \times (4.18\ \text{J/g °C}) \times \Delta T$$

    c. Calculate the amount of heat absorbed by the ice as it melted by finding the difference between these values. Q_3 is equal to the heat of fusion for the amount of ice you used in this experiment:

$$Q_3 = (Q_2 - Q_1)$$

6. Calculate the heat of fusion for water in this experiment by dividing the heat absorbed by your ice (Q_3) by the mass of the ice (m_i).

7. Determine how much energy would have been needed if you had melted exactly 1 mole of ice. Using your experimental value for the heat of fusion for ice, calculate the MOLAR heat of fusion for water.

    Hint: Use the gram molecular mass of water to convert mass (grams) to amount (moles).

Part B: Heat of Vaporization

Note: Due to the potential hazard of working with steam, use extreme caution and carefully follow all standards of safe laboratory practice.

Equipment Setup

1. Set up the steam generator as shown.
2. Fill the cup (calorimeter) about 3/4 full with water and obtain the mass of the water and cup. Record this as m_1 in Table 2 on the *Student Response Sheet*. You can ignore the mass of the cup as it is insignificant compared to the mass of the water.
3. Lower the Temperature Sensor into the water in the cup (to about 1 cm from the bottom).

Record Data

1. Click the **Start** (▶ Start) button to begin recording the temperature.
2. Watch the Digits Display for the temperature to reach an equilibrium. This temperature will be the initial temperature, T_1, of the water.
3. Turn on the hot plate/burner to begin boiling the water in the steam generator apparatus. Position the glass tubing so that steam will be added to the cup when the water boils. Be careful to avoid escaping steam!
4. Monitor the temperature and continue stirring until the temperature climbs above 75°C. Turn off the hot plate and stir the water in the cup. Remove the tubing when it is cool enough to safely remove it from the cup (use gloves or tongs if necessary). Watch the temperature to see that it has reached its highest value. This temperature is the final temperature, T_2, of the water.
5. Click the **Stop** (■ Stop) button to end data collection.
6. Allow the steam generator and all equipment to cool before disassembling.

7. When sufficiently cool to handle, find the mass of the cup containing the water plus the condensed steam. Record this value as m_2 in Table 2 on the *Student Response Sheet*.

Analyze

Just as you did for part A, record calculations in Table 2 on the *Student Response Sheet* as you complete a similar analysis for vaporization.

1. Use the **Smart Tool** ( ) in DataStudio to determine the minimum and maximum temperature values (T_1 and T_2).
2. Subtract T_2 - T_1 to determine D T, the change in water temperature. Record this value in Table 2.
3. Calculate the mass of the steam (m_2 - m_1). Record this in Table 2 as m_3.

Recall that in order to calculate the heat of vaporization, you must know the substance's mass AND the amount of heat energy absorbed. For simplification, assume no heat loss to the surroundings. What happened to the heat energy of the steam? Heat was lost when the steam condensed from its gaseous form to its liquid form. More heat was lost when this amount of condensed steam, now water, cooled to the final temperature (T_2). What happens to this heat? The water already in the cup gains all of this heat. So the heat energy lost in condensing the steam and cooling it to the final temperature must equal the heat energy gained by the water.

Keep this in mind as you calculate the amount of heat, in joules, absorbed by the water in the cup.

$$\textit{Heat gained by water}\ (Q_1) = m_1 \times (4.18\ \mathrm{J/g\ °C}) \times \Delta T$$

4. Calculate the amount of heat lost by the condensed steam as it cools from 100°C to the final temperature.

$$\textit{Heat lost by condensed steam}\ (Q_2) = m_3 \times (4.18\ \mathrm{J/g\ °C}) \times (100\ °C - T_2)$$

5. Calculate the amount of heat lost by steam when changing its phase to water.

$$Q_3 = Q_1 - Q_2$$

6. The energy you just calculated was the amount of energy that the steam imparted to the water. Use this value to calculate the amount of energy per

gram for the water gained in the cup (Q_3 / m_3). We will call this the experimental value for the heat of vaporization.

7. Determine how much energy would have been needed if you had caused exactly 1 mole of water to turn into steam. Using your experimental value for the heat of vaporization for water, calculate the MOLAR heat of vaporization for water.

   Hint: Use the gram molecular mass of water to convert mass (grams) to amount (moles).

8. Save your DataStudio file (on the **File** menu, click **Save Activity As...**) to the location specified by your teacher.

9. Answer all the questions on the *Student Response Sheet*.

10. Follow your teacher's instructions regarding cleaning up your work space.

Student Response Sheet

Name: ______________________________

Date: ______________________________

You're All Mixed-up...Let Off Some Heat

Vocabulary

Use available resources to find the definitions of the following terms:

calorimeter: ______________________________

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condense: ______________________________

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heat: ______________________________

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hydrogen bond: ______________________________

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molar heat of fusion: ______________________________

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molar heat of vaporization: ______________________________

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phase change (change of state): ______________________________

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specific heat: ______________________________

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temperature: ______________________________________

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thermal energy: ____________________________________

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vaporization: ______________________________________

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vaporize: ____

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Predict

Do you think it will take more heat energy to melt the solid ice into liquid water, or more heat energy to vaporize the water into steam, or will it take exactly the same amount of heat energy for each change of state? Explain your prediction.

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Data

Table 1: Heat of Fusion (Part A)

Initial temperature (T_1)	
Final temperature (T_2)	
Change in temperature (ΔT)	
Mass of cup + water + melted ice (m_{w+i})	
Mass of cup + water (m_w)	
Mass of ice (m_i)	
Heat absorbed by ice water as tempeature equilibrium established (Q_1)	
Total heat energy lost by water (Q_2)	
Heat absorbed by ice as it melted (Q_3)	
Heat of fusion for water in this experiment	
Molar heat of fusion for water	

Table 2: Heat of Vaporization (Part B)

Initial temperature (T_1)	
Final temperature (T_2)	
Change in Temperature (ΔT)	
Mass of water (m_1)	
Mass of water + condensed steam (m_2)	
Mass of condensed steam (m_3)	
Heat gained by water (Q_1)	
Heat lost by condensed steam (Q_2)	
Heat lost by steam changing to water (Q_3)	
Heat of vaporization for water in this experiment	
Molar heat of vaporization for water	

Note: Do not forget units.

Analyze

1. Did it take more heat, less heat, or the same amount of heat energy for the first change of state (melting) or for the second (vaporization)? Explain.

2. Is it possible to add energy to a substance without changing its temperature? Why or why not?

Synthesize

Which could cause a more severe burn: scalding hot water at a temperature of 100°C, or steam at 100°C?

Hint: Think about water's heat of vaporization in order to explain your answer.