Experiment 20

Changes of State

Pre-Lab Assignment

Before coming to lab:

- Read the lab thoroughly.
- Answer the pre-lab questions that appear at the end of this lab exercise.

Purpose

The heat of fusion and heat of vaporization of water will be determined using coffee-cup calorimetry and the results compared to the tabulated values of each constant.

Background

Adding or removing heat from a substance can either change the substance's temperature based on its mass and heat capacity or change the substance's phase of matter among solid, liquid, and gas, but not both. The characteristics of the latter, such as the temperature at which such phase changes occur and the quantity of heat involved, are unique to a particular substance and, if unknown, can be used to identify it.

The process of converting a solid to a liquid is called *melting,* while a liquid converting to a solid is called *freezing*. These processes occur at exactly the same temperature, called the melting/freezing point, and require exactly the same amount of energy, called the heat of fusion (ΔH_{fus}). The only difference is the direction. Melting is an endothermic process requiring heat to be absorbed. Freezing is an exothermic process requiring heat to be released. In both cases, the temperature of the substance remains constant at its set melting/freezing point until the entire sample fully undergoes the phase change.

The process of converting a liquid to a gas is called *vaporization* or *evaporation*, while a gas converting to a liquid is called *condensation*. The temperature at which these phase changes occur is called the boiling point and the heat required is known as the heat of vaporization (ΔH_{vap}). Vaporization is the endothermic process while condensation is the exothermic process. Like melting and freezing, the temperature of the substance remains constant throughout its phase change.

The quantity of heat required for any substance's temperature change is determined by $q = mC\Delta T$, but the quantity of heat involved with any phase change is controlled by the enthalpy value associated with that change times its amount, as seen in Eqn. 1.

$$q = \text{mols} \times \Delta H \text{ (kJ/mol)} \qquad \text{Eqn. 1}$$

Example Exercise: Using a Heating Curve

Calculate the amount of energy lost when 25.0 g of $H_2O(g)$ at 115.0°C cool to $H_2O(l)$ at 80.0°C.

Step 1: Calculate q when $H_2O(g)$ cools as steam

ΔT = 100°C (boiling point) – 115.0°C = - 15.0°C
q = (25.0 g)(1.89 J/g °C)(-15.0°C) = -70$\underline{8}$.7 J

Step 2: Calculate q when $H_2O(g)$ condenses to liquid

$$25.0 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.016 \text{ g } H_2O} \times \frac{-40.7 \text{ kJ}}{1 \text{ mol } H_2O} \times \frac{1000 \text{ J}}{1 \text{ kJ}} = -56477 \text{ J}$$

Step 3: Calculate q when $H_2O(l)$ cools as liquid

ΔT = 80.0°C - 100°C (boiling point) = - 15.0°C
q = (25.0 g)(4.184 J/g °C)(-15.0°C) = -1569 J

Step 4: Add each q together

-708.7 J + (-56477 J) + (-1569 J) = -58750 J

Since the heat of fusion and the heat of vaporization are both enthalpy values, they can be determined experimentally using coffee-cup calorimetry. To find the heat of fusion for pure water, solid H_2O in the form of ice cubes will be melted in warm liquid water until the temperature of the mixture reaches approximately 4°C. Since the ice cubes are melting, their initial temperature can be assumed to be 0°C (the tabulated melting point of H_2O) and the heat they absorb to melt (q_{melt}) coming from the warm liquid water (q_{liquid}). There must also be some quantity of heat absorbed from the warm water to heat the now-melted ice cubes to the final temperature (q_{heat}), as it will be higher than the initial, as seen in Eqn. 2. Some heat is also absorbed by the calorimeter, but this can be assumed to be small and negligible.

$$-q_{liquid} = q_{melt} + q_{warm} \qquad \text{Eqn. 2}$$

Example Problem: Determining ΔH_{fus}

100.5 g of liquid water initially at 60.0°C was cooled by melting ice cubes until the mixture reached a final temperature of 3.8°C. The final mass of the mixture was 105.2 g. Determine the heat of fusion of water, in kJ/mol.

Step 1: Find the heat lost by the liquid, q_{liquid}

$$q_{liquid} = (100.5 \text{ g})(4.184 \text{ J/g °C})(3.8°\text{C} - 60.0°\text{C}) = -2360 \text{ J}$$

Step 2: Find the heat gained by the ice after melting, q_{warm}

$$q_{warm} = (105.2 \text{ g} - 100.5 \text{ g})(4.184 \text{ J/g °C})(3.8°\text{C} - 0°\text{C}) = 74.7 \text{ J}$$

Note: the heat capacity of liquid water is used since the ice is fully melted

Step 3: Find the heat gained by the ice due to melting, q_{melt}

$$-(-2360 \text{ J}) = q_{melt} + 74.7 \text{ J}$$
$$q_{melt} = 2290 \text{ J}$$

Step 4: Find the mols of ice

$$105.2 \text{ g} - 100.5 \text{ g} = 4.7 \text{ g} \times \frac{1 \text{ mol } H_2O}{18.01 \text{ g } H_2O} = 0.261 \text{ mols}$$

Step 5: Find ΔH_{fus}

$$\frac{2290 \text{ J}}{0.261 \text{ mols}} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 8.77 \text{ kJ/mol}$$

To find the heat of vaporization for pure water, steam will be added to room temperature water and allowed to condense until the temperature of the mixture rises by approximately 30°C. The initial temperature of the steam will be assumed to be 100°C since it is undergoing a phase change and releasing heat, $q_{condense}$. Once it fully converts to liquid, it will also release heat to cool to the final temperature of the mixture, q_{cool}. Both quantities of heat will be absorbed by the room temperature water, q_{liquid}, as seen in Eqn. 3. Again, consider the heat absorbed by the calorimeter as negligible. Note that the heat of condensation is being measured, leading to a positive value. The heat of vaporization will be the same value but a negative instead, representing its exothermicity.

$$-(q_{condense} + q_{cool}) = q_{liquid} \qquad \text{Eqn. 3}$$

Example Problem: Determining ΔH_{vap}

100.0 g of liquid water initially at 25.0°C was warmed by allowing steam to condense until the mixture reached a final temperature of 62.3°C. The final mass of the mixture was 108.2 g. Determine the heat of fusion of water, in kJ/mol.

Step 1: Find the heat gained by the liquid, q_{liquid}

q_{liquid} = (100.0 g)(4.184 J/g °C)(62.3°C – 25.0°C) = 15600 J

Step 2: Find the heat lost by the steam after condensing, q_{cool}

q_{cool} = (108.2 g – 100.0 g)(4.184 J/g °C)(62.3°C – 100°C) = - 1290 J

Note: the heat capacity of liquid water is used since the steam is fully condensed

Step 3: Find the heat lost by the steam due to condensing, $q_{condense}$

- ($q_{condense}$ + -1290 J) = 15600 J

$q_{condense}$ = -15600 J + 1290 J = -14300 J

Step 4: Find the mols of steam

$$8.2 \text{ g } H_2O \times \frac{1 \text{ mol } H_2O}{18.01 \text{ g } H_2O} = 0.455 \text{ mols}$$

Step 5: Find $\Delta H_{condense}$

$$\frac{-14300 \text{ J}}{0.44 \text{ mols}} \times \frac{1 \text{ kJ}}{1000 \text{ J}} = 32.5 \text{ kJ/mol}$$

Step 6: Find ΔH_{vap}

-(32.5 kJ/mol) = -32.5 kJ/mol

Procedure

Part I: Determination of ΔH_{fus}

1. Collect a temperature sensor. Connect the probe to a lab computer or a LabQuest 2 interface and start the Graphical Analysis application if it does not do so automatically.

2. Set the sampling options to 10 per second. The graph should be shown as time (x) versus temperature (y). Set the time for collection to 30 minutes.

3. Collect two Styrofoam cups and nestle them together with a cover as a coffee-cup calorimeter. Dry them thoroughly and weigh the cups and cover. Record the weight in your data sheet.

4. Gather a split stopper, clamp, and 250 mL beaker. Assemble the apparatus seen in Fig. 1, keeping the temperature sensor **out** of the cups for now.

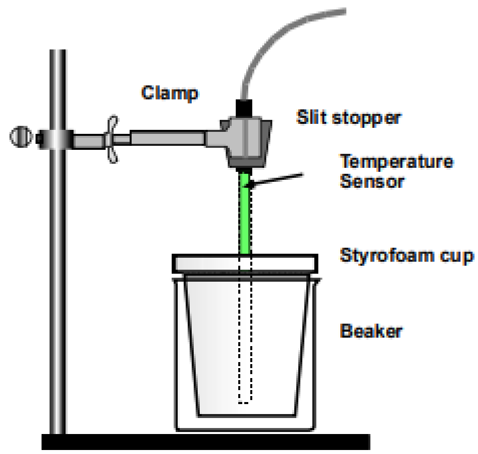


Figure 1: Coffee-cup calorimeter apparatus

5. Heat approximately 100 mL of water in a beaker to about 60.0°C, monitoring the temperature with a glass thermometer.

Note: prepare ahead of time to complete Steps 6-11 as quickly as possible.

6. Obtain ice cubes. Dry the ice cubes by shaking off excess water and patting with paper towels.

7. Add the warm water From Step 5 to your coffee-cup calorimeter, cover, and reweigh. Record this weight in your data sheet, then replace the coffee cups and cover to the glass beaker in the apparatus.

8. Lower the temperature sensor about 1 cm from the bottom of the cups and clamp in place.

9. Start recording temperature data by touching the green triangle button.

10. Wait until the temperature reaches a maximum. Record this maximum as the initial temperature of the warm water (T_i, liquid) in your data sheet.

11. Add enough dried ice cubes from Step 6 to fill the Styrofoam cups and then cover.

12. Gently stir the mixture with the temperature probe as the temperature approaches 4°C. If the ice fully melts before reaching 4°C, add more dried ice cubes.

13. When the temperature of the mixture reaches approximately 4°C, use tongs to remove any unmelted ice.

14. Continue stirring until the temperature reaches a minimum and begins to rise. Record this minimum as the final temperature of the mixture (T_f, all) in your data sheet.

15. Stop recording data by touching the red square button.

16. Weigh the Styrofoam cups, cover, and water. Record the weight in your data sheet.

17. Calculate the heat of fusion of water, ΔH_{fus}, in kJ/mol and compare to the tabulated value.

Part II: Determination of ΔH_{vap}

1. Repeat Steps 1-4 of Part I.

2. Add approximately 100 mL of room temperature water into the Styrofoam cups, cover, and reweigh. Record this weight in your data sheet.

3. Add approximately 200 mL of deionized water into a 500 mL Florence flask and seal with a one-holed stopper that has been fitted with rubber tubing with a glass end. Ensure that the rubber tubing is pointed downward into a sink and/or away from paper or people.

4. Place the Florence flask on wire gauze set up on an iron ring over a Bunsen burner. Make sure to clamp the neck of the flask securely to prevent tipping.

5. Begin heating the Florence flask.

6. When the water inside the Florence flask begins to boil, lower the temperature sensor about 1 cm from the bottom of the cups and clamp in place. Make sure that the cords are not anywhere near the open flame or heat.

Caution! Steam is very hot. Avoid burns by not touching or pointing at anyone.

7. Start recording temperature data by touching the green triangle button. Wait until the temperature stabilizes. Record this temperature as the initial temperature of the warming water (T_i, liquid) in your data sheet.

8. Using tongs, insert the glass end of the rubber tubing through the hole in the cups' cover and into the water inside. Ensure that the glass tube is close to the bottom of the calorimeter and fully submerged under the water.

9. Continue collecting data until the temperature has increased by 30°C *more* than in Step 6.

10. Carefully remove the rubber tubing from the Styrofoam cups, pointing it downward in the sink. Turn off the heat.

11. Wait until the temperature reaches a maximum. Record this maximum as the final temperature of the mixture (T_f, all) in your data sheet.

12. Stop recording data by touching the red square button.

13. Weigh the Styrofoam cups, cover, and water. Record the weight in your data sheet.

14. Calculate the heat of condensation of water in kJ/mol. Convert this value to the heat of vaporization of water, ΔH_{vap}, and compare to the tabulated value.

Experiment 20—Data Sheet

Name: ____

Part I: Determination of ΔH_{fus}

	Trial One	Trial Two
1. Mass of calorimeter and cover (g)	___________	___________
2. Mass of calorimeter, cover, and liquid water (g)	___________	___________
3. Initial temperature of liquid water, (T_i liquid, °C)	___________	___________
4. Final temperature of mixture (T_f all, °C)	___________	___________
5. Mass of calorimeter, cover, warm water, and melted ice (g)	___________	___________
6. Mass of liquid water (g)	___________	___________

show calculation:

7. Mass of melted ice (g)	___________	___________

show calculation:

8. Change in T of liquid water (ΔT liquid, °C)	___________	___________

show calculation:

9. Change in T of melted ice (ΔT ice, °C)	___________	___________

show calculation:

10. Heat released by liquid water (q_{liquid}, J)	___________	___________

show calculation:

	Trial One	Trial Two
11. Heat absorbed by warming melted ice (q_{warm}, J)	____________	____________

show calculation:

12. Heat absorbed by melting ice (q_{melt}, J)	____________	____________

show calculation:

13. Mols of melted ice (mols)	____________	____________

show calculation:

14. Heat of Fusion (ΔH_{fus}, kJ/mol)	____________	____________

show calculation:

15. Percent Error of ΔH_{fus} (%)	____________	____________

show calculation:

Part II: Determination of ΔH_{vap}

	Trial One	Trial Two
1. Mass of calorimeter and cover (g)	____________	____________
2. Mass of calorimeter, cover, and liquid water (g)	____________	____________
3. Initial temperature of liquid water, (T_i liquid, °C)	____________	____________
4. Final temperature of mixture (T_f all, °C)	____________	____________
5. Mass of calorimeter, cover, warm water, and condensed steam (g)	____________	____________
6. Mass of liquid water (g)	____________	____________

6. Mass of liquid water (g)
show calculation:

7. Mass of condensed steam (g) ____________ ____________
show calculation:

8. Change in T of liquid water (ΔT liquid, °C) ____________ ____________
show calculation:

9. Change in T of condensed steam (ΔT ice, °C) ____________ ____________
show calculation:

10. Heat absorbed by liquid water (q_{liquid}, J) ____________ ____________
show calculation:

	Trial One	Trial Two
11. Heat lost by cooling condensed steam (q_{cool}, J)	____________	____________

show calculation:

12. Heat lost by condensing steam ($q_{condense}$, J)	____________	____________

show calculation:

13. Mols of condensed steam (mols)	____________	____________

show calculation:

14. Heat of Condensation ($\Delta H_{condense}$, kJ/mol)	____________	____________

show calculation:

14. Heat of Vaporization (ΔH_{vap}, kJ/mol)	____________	____________

show calculation:

15. Percent Error of ΔH_{vap} (%)	____________	____________

show calculation:

Experiment 20—Post-Lab Assignment

Name: ______________________________________

1. Calculate the total heat, in kJ, released when 50.0 grams of water at 25.0°C is cooled to form ice at -8.0°C. (Hint: it will help to draw out the heating curve of water)

2. What was the percent error for your heat of fusion? Give three experimental errors that may account for this.

3. Assume that while determining ΔH_{fus}, a student places excess ice in the calorimeter and allows it to cool for an extended period of time past 4°C. Sketch this student's expected temperature versus time graph with specific values on the axes and explain these results.

4. What was the percent error for your heat of vaporization? Give three experimental errors that may account for this.

5. Assume that while determining ΔH_{vap}, a student allows steam to flow into the calorimeter for an extended period of time past the +30°C. Sketch this student's expected temperature versus time graph with specific values on the axes and explain these results.

Experiment 20—Pre-Lab Assignment

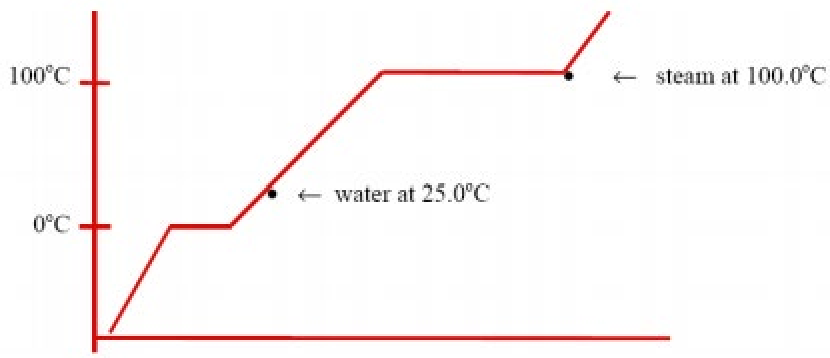
Name: ____

For all calculations, show all work and draw a box around the final answers.

1. Research the following constants:

Specific heat capacity of water:	___________	J/g °C
Specific heat capacity of ice:	___________	J/g °C
Specific heat capacity of steam:	___________	J/g °C
Heat of fusion for water:	___________	kJ/mol
` Heat of vaporization for water:	___________	kJ/mol

2. Calculate the total heat, in kJ, needed to change 3.50 kg of water at 25.0°C to steam at 100.0°C. A heating curve is provided for you below.



3. What will result in the greatest change in temperature of water initially at 50°C: adding 1 g of ice at 0°C or adding 1 g of steam at 100°C? Explain. (Hint: recall that $-q_{steam} = q_{liquid}$ and $q_{ice} = -q_{liquid}$).

4. Find the final temperature reached when 0.10 g steam condenses on 1 cm^2 of human skin to a depth of 1 cm. (Hint: assume that the density of skin is 1.0 g/cm^3. You will need to look up the heat capacity of human skin as well as the initial body temperature).