PHYSICS 1030L LAB: Heat of Fusion

OBJECTIVE

In the Heat of Fusion Lab topics relating to the study of thermodynamics will be explored. The flow of heat will be examined in this experiment.
1) Ice cubes will be placed into a certain amount of water in a Styrofoam coffee cup that will be used as the inner cup of a calorimeter. The final temperature of the water after the ice has melted will be predicted and then measured experimentally.

Equipment List

Calorimetry

Styrofoam inner Calorimeter cup, Beaker used as outer Calorimeter cup, Vernier LabPro interface, Vernier LoggerPro software, Vernier Stainless Steel Temperature Probe, Ice Cubes, Triple Beam Balance, Water and paper towels, glass stirring rod.

Theoretical Background

Calorimetry

In this section, the theory behind heat flow will be discussed. The study of heat flow to and from objects is known as ***Calorimetry***. The basic principle behind Calorimetry is energy conservation: The heat energy that flows out of a collection of objects, ΔQ_{out}, is balanced by the heat energy flowing into another set of objects, ΔQ_{in}, so that the sum of the heat flowing into and out of the objects is zero

$$\textit{Heat Flow into objects + Heat Flow out of objects = zero}$$
$$\Delta Q_{in} + \Delta Q_{out} = 0 \qquad (1)$$

Heat flow into objects can change the object's properties in one of two ways. First, the heat flow can cause the object's temperature to change. The relationship between the heat flow and the temperature change of the object is given by

$$\Delta Q = mc(T_f - T_i) = mc\Delta T \qquad (2)$$

In this equation, ΔQ is the amount of heat energy flowing into or out of the object. This is typically measured in either the standard units of energy, Joules, or in *calories*. (Note: The calories listed on food labels are actually kilocalories, i.e. 1000 standard calories.) The m in Equation 2 is the mass of the object the heat is flowing into or out of, and c is an intrinsic constant of the material known as the specific heat. The initial and final temperature of the object is represented by T_i and T_f, respectively, in Equation 2.

In addition to changing the temperature of an object, heat flow can change an object from one state of matter into another. There are four basic states of matter: solid, liquid, gas, and plasma. If enough heat is added to an object, the object will change from one of these states to the other. While changing state, the temperature of the object will remain more or less constant. The amount of heat necessary to change the object can be represented mathematically by

$$\Delta Q = mL. \qquad (3)$$

In this equation, ΔQ is the amount of heat flow, as before, m is the mass of the object, and L is an intrinsic constant of the material. If the material is melting (i.e. changing from a solid to a liquid), then L is known as the ***Latent Heat of Fusion*** and is written as L_f. If the object is being vaporized (i.e. changing from a liquid to a gas), then L is known as the ***Latent Heat of Vaporization*** and is written an Lv. It should be noted that an object must first reach a critical temperature before it will begin melting or vaporizing (i.e. the melting point or the boiling point).

In this lab exercise, ice will be added to an amount of water. The initial temperature of the water, as well as the mass of the ice, water, and container will be measured. After the ice is placed into the water, heat will flow from the water and container into the ice, thus the ice begins to melt. Once the ice has melted, heat will continue to flow into the ice until an equilibrium temperature between the melted ice and the water/container has been reached. The heat flow into the ice can be represented mathematically as

$$\Delta Q_{in} = \textit{Ice melting + heating melted ice}$$
$$= m_I L_f + m_I c_w (T_f - T_{i,ice})$$
$$= m_I L_f + m_I c_w T_f, \qquad (T_{i,ice} = 0\,^\circ C) \quad (4)$$

In this equation, m_I is the mass of the ice; L_f is the Latent heat of fusion for water which is $3.33 \times 10^5\ J/kg$, c_w is the specific heat of water which is $4186\ J/(kg\cdot\,^\circ C)$, T_f is the final temperature of the system, and $T_{i,ice}$ is the initial temperature of the ice after it has melted, which can be assumed to be $0\,^\circ C$. The heat that melts the ice and raises the temperature of the melted ice comes from the water and calorimeter. As the ice melts, and as the melted ice warms, the water and the calorimeter cool. The heat lost by the water and calorimeter is expressed mathematically as:

$$\Delta Q_{out} = \textit{water cooling + calorimeter cooling}$$
$$= m_w c_w (T_f - T_i) + m_c c_c (T_f - T_i). \qquad (5)$$

In this equation, m_w is the mass of the water in the calorimeter, m_c is the mass of the calorimeter, c_c is the Heat Capacity of the calorimeter, and the T_i is the initial temperature of the water and calorimeter. Putting these two expressions together using Equation 1 yields:

$$\Delta Q_{in} + \Delta Q_{out} = 0$$
$$m_I L_f + m_I c_w T_f + m_w c_w (T_f - T_i) + m_c c_c (T_f - T_i) = 0 \quad (6)$$

Solving this equation for the final temperature of the system, T_f yields

$$T_f = \frac{m_w c_w T_i + m_c c_c T_i - m_I L_f}{m_I c_w + m_w c_w + m_c c_c} \qquad (7)$$

This equation will be tested experimentally by using it to calculate the final temperature of the melted ice and water and then measuring it.

Figure 1 Vernier LabPro Interface and Stainless Steel Temperature Probe

Heat of Fusion.

<u>Calorimetry:</u> **In this section, the final temperature of an ice/water combination will be predicted and then measured experimentally.**
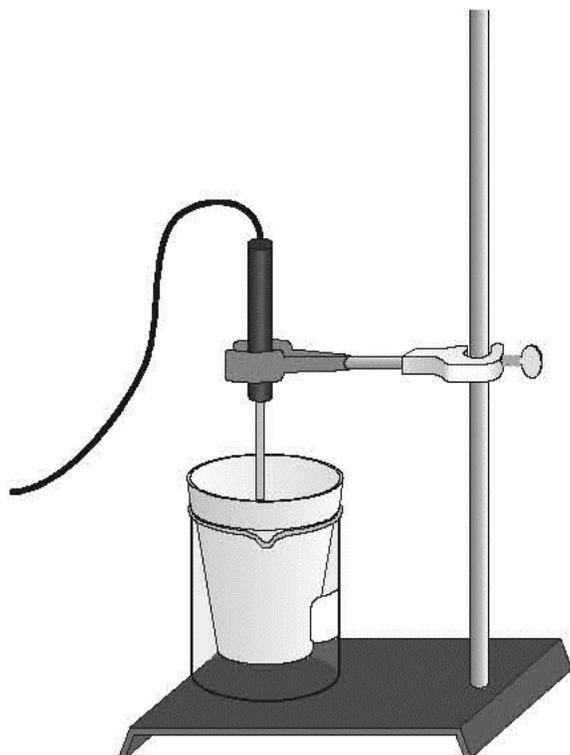
Figure 2 Triple Beam Balance

Figure 3 Styrofoam Calorimeter and Beaker

Procedure

1) **Run LoggerPro 8.*.***
2) **From the files menu open the Heat of Fusion experiment.(Chemistry With Vernier Experiment 04)**
3) **Under the Experiment menu choose the Extend Collection sub menu and click on it until the collection time is at least 1800 seconds**
4) **Remove the Styrofoam Calorimeter cup from the beaker.**
5) **(We will be using a Styrofoam cup as the inner Calorimeter cup in this experiment)**
6) **Use the triple beam balance to measure the mass of the inner Styrofoam cup and record this mass as m_c on your data table.**
7) **Fill the inner cup of the calorimeter with at least 200g of water (This is about 200 cm^3 of water using a graduated cylinder).**
8) **Measure the mass of the calorimeter cup with water record this mass as m_{c+w} on your data table.**

9) Subtract the mass of the calorimeter m_c from the cup with water combination m_{c+w} to obtain the mass of the water in the cup. Record the mass of the water in the cup as m_w on your data table.

10) Place the inner cup back into the beaker. Make sure to adjust it and not tip over the cup or spill any water.

11) Plug the Stainless Steel Temperature Probe into Channel 1 on the LabPro interface.

12) Clamp the Stainless Steel Temperature Probe into the clamp as shown in Figure 3. (DO NOT POKE A HOLE THROUGH THE BOTTOM OF THE STYROFOAM CUP)

13) Make sure the bottom third or more of the temperature probe is under the surface of the water at all times.

14) Wait for a few minutes (1 to 5 minutes) until the temperature displayed on the Logger   Pro Software stabilizes.

15) Record the temperature after the Stainless Steel Temperature Probe stabilizes on your data sheet as T_i.

16) Quickly remove 3 or 4 ice-cubes from the cooler at the side of the lab room.

17) Dry off the ice cubes using the paper towels provided before placing them in the Styrofoam calorimeter cup

18) Gently place the ice-cubes into the water of the calorimeter. DO NOT SPLASH THE WATER WHEN DOING THIS!!

19) Carefully watch the temperature of the ice/water as you gently stir the water/ice mixture with the glass stirring rod. STIRRING: It is important to stir the water and ice mixture to ensure that the temperature throughout the water is uniform. Not stirring the ice and water mixture causes the final temperature to be too warm and gives an experimental value of the Latent Heat of Fusion that is too low. (DO NOT POKE A HOLE THROUGH THE BOTTOM OF THE STYROFOAM CUP)

20) After about one minute has elapsed, gently stir the water/ice mixture again by moving the temperature probe gently side to side a few times. Continue watching the temperature of the ice/water and gently stir every minute or so until the temperature stabilizes. When the temperature has stabilized, record this temperature as $T_{f,exp}$ on your data sheet.

21) Carefully remove the inner Styrofoam Calorimeter cup and contents and find the TOTAL MASS on the Triple Beam Balance and record this value as "TOTAL MASS" in your data table.

22) After you have found the mass of the ice, calculate the final temperature $T_{f,theory}$ of the water using:

$$T_{f,\,theory} = \frac{m_w c_w T_i + m_c c_c T_i - m_I L_f}{m_I c_w + m_w c_w + m_c c_c}$$

(8)

$$c_w = 4186 \; J/(kg \cdot {}^{\circ}C) \;, \; L_f = 3.33 \times 10^{5} \; J/kg. \; c_c = 1311.486 \; J/(kg \cdot {}^{\circ}C)$$

23) Calculate the percent difference between the theoretical and experimental values of the final temperature of the water.

$$\% \; difference = \frac{Theoretical \; Value - Experimental \; Value}{Theoretical \; Value} \; X \; 100$$ **(9)**

22) Estimate and record the uncertainty in the mass and the temperature measurements.
The smallest mass that can be measured using the Triple Beam Balance is 0.0001 Kg
The error in the temperature measurements is $\pm$ 0.2 $^{\circ}$C at 0°C.
Using these estimated uncertainties, and the smallest measured value for the mass and the temperature, calculate the percent uncertainty in each experimental quantity.
Record the largest percent uncertainty in the space provided in your data table.

Other possible sources of error:
1. THERMOMETER: The Stainless Steel Temperature Probe should not come into contact with the Styrofoam calorimeter. This contact causes the final temperature to be too warm and gives an experimental value of the Latent Heat of Fusion that is too low.
2. DRYING THE ICE: If the ice is not dried there will be water at 0°C on the ice. The added water will contribute to the final mass of liquid but it will not gain the amount of heat that an equivalent amount of ice would gain. The initial temperature of the water in the calorimeter will not have to drop as far. Hence the final temperature will be too high. The result will be an experimental value of the Latent Heat of Fusion that is too low.
3. Do not splash any water from the Styrofoam cup when placing the ice cubes into the cup.

Discussion Questions:

Heat of Fusion
    1. A Thought Experiment:
        In the heat balance equation, if heat flow from the temperature probe and from the glass stirring rod were ignored. How would it affect your prediction of the water's final temperature if heat flow from these two objects has to be

considered?(i.e. would it be higher, lower, or not change)? Is this effect consistent with your data?

2. If we used the metal inner Calorimeter cup instead of the Styrofoam cup and the inner cup of the calorimeter got cold enough so that moisture from the air began to condense on the outer surface, how would this affect the final temperature?

3. Knowing the uncertainties in all your measurements, which variable will cause the largest difference between the Theoretical value of the Latent Heat of Fusion and your experimental value?

4. In our experiment we took into account the specific heat and mass of the Styrofoam cup. If we ignored these, how would the predicted value of the Final Temperature be different? Show the Calculation. (See Equation 8) Note: This is the assumption that the Styrofoam cup is a"Perfect Insulator" Is this true? Can the Heat lost to the environment from the Styrofoam cup be successfully ignored in our experiment?

 Lab Report Format:

Your lab report for this experiment should contain:

1. **Pre-lab (objective, theory, and procedure).**
2. **Neatly written copy of your experimental data sheet.**
3. **Sample calculations: Heat of fusion: m_w, ΔQ_{in}, ΔQ_{out}, $T_{f, theory}$, T_f, T_f with the affects of the Styrofoam cup ignored and the % difference**
4. **Results: State your results (in complete sentences) . Give the predicted value for the Heat of Fusion as well as the experimental value. Give values for $T_{f, theory}$, T_f and, T_f with the affects of the Styrofoam cup ignored. Make sure all values are properly rounded and have the correct number of significant digits. Report the % difference from the accepted values. Are these values large or small (within 10% error)?**

 Conclusions: Answer the discussion questions above.