

## HEAT MEASUREMENTS AND SPECIFIC HEAT OF FUSION

### OBJECTIVE

To investigate the flow of energy and specific heat of fusion for water.

### APPARATUS:

Styrofoam cup (**used as Calorimeter**), water, ice cubes, Triple Beam Balance, Vernier Stainless Steel Temperature Probe, Vernier LabPro interface, Vernier LoggerPro software.

### THEORETICAL BACKGROUND

The study of the flow of thermal energy (heat) is known as Calorimetry. The basic principle behind Calorimetry is energy conservation. When heat flows into a substance, the substance can change properties in one of two ways:

First, the energy flow can cause the substance's temperature to change. The relationship between the heat and the temperature change of an object is given by

$$Q = mc(T_f - T_i) = mc\Delta T, \quad (1)$$

where  $Q$  is the amount of heat flowing into the substance (Joules);  $m$  is the mass of the substance (kg), and  $c$  is an intrinsic property of the material known as the specific heat capacity (the amount of heat needed to raise the temperature of 1 kg of the substance by 1 °C). The initial and final temperatures of the object are  $T_i$  and  $T_f$ , respectively.

In addition to changing the temperature of a substance, heat can change it from one state of matter into another. There are four states of matter: solid, liquid, gas, and plasma. If enough heat is added to the substance, it will change its state. While changing state, the temperature of the substance will remain constant. The amount of heat necessary to change the state of matter is given by

$$Q = mL, \quad (2)$$

where  $L$  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 ( $L_f$ )**. 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 ( $L_v$ )**. 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).

If we place ice in a container with 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 flowing into the ice and used to melt the ice and heat it afterwards, can be written as

$$Q_{in} = m_i L_f + m_i c_w (T_f - T_0), \quad (3)$$

where  $m_i$  is the mass of the ice;  $L_f$  is the latent heat of fusion for water ( $L_f = 3.33 \times 10^5$  J/kg),  $c_w$  is the specific heat capacity of water ( $c_w = 4186$  J/(kg·°C)),  $T_f$  is the final temperature of the system, and  $T_0$  is the initial temperature of the ice after it has melted, which can be assumed to be 0°C.

The heat that melts the ice and raises its temperature afterwards 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 for cooling the water and calorimeter is

$$Q_{out} = m_w c_w (T_f - T_i) + m_c c_c (T_f - T_i), \quad (4)$$

where  $m_w$  is the mass of the water in the calorimeter,  $m_c$  is the mass of the calorimeter,  $c_c$  is the specific heat capacity of the calorimeter material, and the  $T_i$  is the initial temperature of the water and calorimeter.

Conservation of energy requires

$$Q_{in} + Q_{out} = 0 \quad \text{or} \quad Q_{in} = -Q_{out}. \quad (5)$$

If we substitute equations (3) and (4) into (5), we get:

$$m_i L_f + m_i c_w (T_f - T_0) = -(m_w c_w (T_f - T_i) + m_c c_c (T_f - T_i)) \quad (6)$$

We can rearrange (6), remembering that  $T_0 = 0$ , and solve for the final temperature of the system:

$$m_i L_f + m_i c_w T_f = m_w c_w (T_i - T_f) + m_c c_c (T_i - T_f)$$

$$m_i c_w T_f + m_w c_w T_f + m_c c_c T_f = m_w c_w T_i + m_c c_c T_i - m_i L_f$$

$$T_f (m_i c_w + m_w c_w + m_c c_c) = m_w c_w T_i + m_c c_c T_i - m_i L_f$$

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

We will be using equation (7) to calculate the final temperature of the melted ice and water, and compare the obtained result with experimental data. Similarly, one can use equation (6) to calculate latent heat of fusion,  $L_f$ , if final temperature of the system is known (measured).

**PROCEDURE**

- 1) Run LoggerPro 8.\*.\*
- 2) From the files menu open the Heat of Fusion experiment.(Chemistry With Vernier Experiments 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) Weigh the styrofoam cup and record its mass as  $m_c$  (with its experimental uncertainty) on your data table.
- 5) Fill the cup with at least 200g of water (this is about 200 cm<sup>3</sup> of water if using a graduated cylinder). Weigh the cup with water and record this mass as  $m_1$  (with its experimental uncertainty) on your data table.
- 6) Calculate the mass of the water in the cup and record on your data table as  $m_w$ .
- 7) Plug the Stainless Steel Temperature Probe into Channel 1 on the LabPro interface.
- 8) Place the Stainless Steel Temperature Probe into the water (DO NOT POKE A HOLE THROUGH THE BOTTOM OF THE STYROFOAM CUP). Make sure the bottom third or more of the temperature probe is under the surface of the water at all times.
- 9) Wait for about 5 minutes until the temperature displayed on the Logger Pro Software stabilizes. Record the temperature (with its experimental uncertainty) on your data sheet as  $T_i$ .
- 10) Quickly remove 3 or 4 ice-cubes from the cooler in the lab room. Dry off the ice cubes using the paper towels provided before placing them in the Styrofoam calorimeter cup. DO NOT SPLASH THE WATER WHEN DOING THIS!!
- 11) Carefully watch the temperature of the ice/water as you gently stir the water/ice mixture with the probe. You need 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). When the temperature has stabilized, record this temperature (with its experimental uncertainty) as  $T_{f,exp}$ .
- 12) Carefully weigh the Styrofoam cup and its contents on the Triple Beam Balance, find the total mass and record this value as mass  $m_2$  (with its experimental uncertainty) on your data table. Calculate the mass of the ice,  $m_i$ , and record it.
- 13) Calculate the predicted value for the final temperature using equation (7) and the constants given on your data page.
- 14) Find the percent difference between the calculated and experimental values of the final temperature of the water.

$$\% \text{ diff} = (|\text{calculated value} - \text{exp value}|/\text{calculated value}) 100\% \quad (8)$$

**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, it will change the mass of water in the cup.

**Data Analysis and Discussion Questions:**

1. Use your experimental value for the final temperature and equation (6) to calculate the experimental value for the latent heat of fusion for water. Find % difference between the experimental value and the accepted value. Show detailed derivation and calculations.
2. A Thought Experiment: In the heat balance equation, if heat flow from the temperature probe and from the stirring rod were ignored, how would this affect your prediction of the water's final temperature (i.e. would it be higher, lower, or not change)? Is this effect consistent with your data?
3. If we used the metal calorimeter with 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?
4. Calculate relative uncertainties (in %) for all your measurements ( $\sigma_x = \Delta x/x$ , %), and decide which variable will give the largest contribution in the difference between the calculated value of the final temperature and your experimental value?
5. 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? Use eq.7 and show the calculation. We assumed 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?

**DO NOT FORGET TO SHOW DETAILED CALCULATIONS FOR ALL VALUES!!!!.**