LABORATORY 8

Heat and Change of State

Goals

Measure a temperature change of water when ice or steam is added .
Calculate the heat of fusion for water.
Calculate the heat of vaporization for water.
Use the nutrition data on food products to determine their caloric values.

Lab Questions

1. What is a change of state?
2. Is the freezing of water an endothermic or exothermic process?
3. How does ice in a soft drink cool down the liquid?
4. What is measured by the Calories on the nutritional data label of foods?
5. What are a calorie, a kilocalorie, and a dietary Calorie?

Concepts to Review

Changes of state
Specific heat
Measuring heat energy
Calories
Heat of vaporization
Heat of fusion
Kilocalories
Caloric values for food

Discussion

When two substances are in contact, the heat from one can be transferred to the other. The temperature drops for the substance that loses heat. The temperature increases for the substance that gains heat. Because the amount of heat that is transferred is the same we can express the following equality:

heat lost = heat gained

In this experiment, we will use the heat lost by the warm water to determine the amount of heat used to melt ice. In a second experiment, we use the temperature change of water to determine the amount of heat that is transferred when steam condenses.

Heat of Fusion

In Experiment 7, we saw that when a solid is melting (or freezing), the temperature remains constant. At the freezing point, the amount of heat required to melt (or freeze) a substance is called the ***heat of fusion***. For water, the energy needed to melt 1 g of ice (0°C) is 80. calories.

melting $H_2O(s) + \text{heat}_{\text{fusion}} \longrightarrow H_2O(l)$ Heat of fusion water = 80. cal/g

freezing $H_2O(l) \longrightarrow H_2O(s) + \text{heat}_{\text{fusion}}$

In this experiment, water will be cooled by melting ice. From the temperature change, we can determine the amount of heat lost by water. The amount of heat lost by the warm water is equal to the amount of heat that melted the ice.

heat (cal) lost by water = g water x ΔT x 1.0 cal/g°C
= heat gained (to melt ice)

By lowering the temperature to about 0°C, the heat needed to raise the temperature of the resulting ice water can be considered negligible. Thus, the experimental heat of fusion is calculated from the heat needed to melt the ice divided by the number of grams of ice that melted.

$$\text{heat of fusion} = \frac{\text{calories to melt ice}}{\text{grams of ice}}$$

Heat of Vaporization (*demonstration*)

When a substance changes from a liquid to a gas at the boiling point, the heat or energy required to separate the molecules is called the ***heat of vaporization***. Because the attraction between liquid water molecules is rather strong, the energy required to vaporize 1 g of water at 100°C is 540 calories.

boiling $H_2O(l) + \text{heat}_{\text{vaporization}} \longrightarrow H_2O(g)$ Heat of vaporization water = 540 cal/g

condensation $H_2O(g) \longrightarrow H_2O(l) + \text{heat}_{\text{vaporization}}$

In the reverse process called *condensation*, 540 calories of heat are released for each 1 g of steam that changes to liquid water at 100°C. Because this large quantity of heat could cause burns, this part of the experiment may be done as a demonstration. Steam from a steam generator will be run through tubing into a measured quantity of water.

In this experiment, water will be warmed by heat given off by condensing steam. From the mass of water, the temperature change of the water, and the specific heat of water (1.0 cal/g°C), the quantity of heat used to warm the water can be calculated. The heat that warms the water is equal to the heat lost by the condensing steam.

heat gained (by water) = mass x ΔT x specific heat

=heat lost (by condensing steam)

Because the heat of vaporization is so large, we will ignore the loss of heat by the condensed steam as it cools from 100°C. To calculate the experimental heat of vaporization, the heat lost by the condensation of steam is divided by the number of grams of steam added to the water.

$$\text{heat of vaporization} = \frac{\text{calories released by condensing steam}}{\text{grams of steam}}$$

Caloric Values

In nutrition, we determine the energy of food in terms of Calories, which are the same as 1000 cal or 1 kilocalorie.

Calorie (nutrition) = 1000 calories = 1 kcal

Calorimetric experiments have established the caloric values for the three food types: carbohydrates, 4 kcal/g; fats, 9 kcal/g and proteins, 4 kcal/g. From the mass of each food in a serving , we can calculate the kilocalories for one serving. For example, 12 g of carbohydrate will provide 48 kcal. Usually the values are rounded to the nearest tens.

$$12 \text{ g ~~carbohydrate~~} \times \frac{4 \text{ kcal}}{1 \text{ ~~g carbohydrate~~}} = 48 \text{ kcal or } 50 \text{ kcal}$$

Laboratory Activities

A. Heat of Fusion

Materials needed: Calorimeter (Styrofoam cup and cardboard cover), 50- or 100-mL graduated cylinder thermometer, ice cubes, laboratory balance

A.1 Weigh an empty calorimetry (Styrofoam) cup.

A.2 Add 100 mL of water to the cup and weigh. Record the total mass in grams.

A.3 Measure the initial temperature of the water in the calorimeter. See Figure 8.1 Record. Place a medium-sized ice cube in the calorimeter. Stir gently. If necessary, add another piece of ice. When the temperature has dropped below 5°C, *remove* any unmelted ice. Record the final temperature of the water.

A.4 Weigh the calorimetry cup and water. The increase in mass is due to the ice that melted.

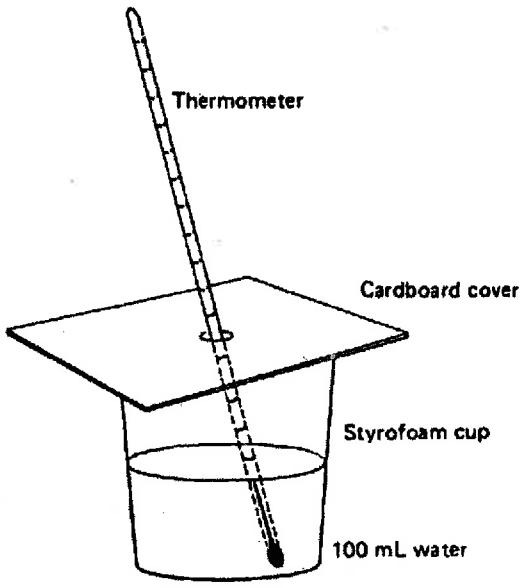

Figure 8.1 Calorimetry setup with water, a thermometer, Styrofoam cup, and a cardboard cover

Calculations:

A.5 Calculate the mass of water placed in the calorimeter (A.2 - A.1).

A.6 Calculate the temperature change (ΔT) for the water ($\Delta T = T_{initial} - T_{final}$).

A.7 Calculate the calories lost by the water. This value is equal to the heat that melted the ice.

heat (cal) lost by water = mass of water x ΔT x specific heat (1.0 cal/g°C)
= heat (cal) gained to melt ice

A.8 Calculate the grams of ice that melted. Subtract the mass of the cup and water from the mass of the cup, water, and water from the melted ice (A.4 - A.2).

A.9 Calculate your experimental value for the heat of fusion for ice by dividing the calories by the mass of the ice that melted.

$$\text{heat of fusion} = \frac{\text{calories to melt ice (A.7)}}{\text{grams of ice (A.8)}}$$

A.10 Calculate the percent error. Subtract your *experimental* value from the known value (80. cal/g), divide by the known value (80. cal/g), and multiply by 100. Ignore any negative sign.

$$\text{percent error} = \frac{\text{80. cal/g - experimental cal/g}}{\text{80. cal/g}} \times 100$$

B. Heat of Vaporization (Instructor Demonstration)

Materials needed: Ring stand, buret clamp, 50- or 100-mL graduated cylinder, 250-mL Erlenmeyer flask with 1-hole stopper fitted with small glass tube attached to rubber tubing (15-20 cm), hot plate (or Bunsen burner) a calorimeter (Styrofoam cup and cardboard cover), tongs, and thermometer, laboratory balance

A steam generator will be set up by your instructor that consists of a 250-mL Erlenmeyer flask fitted with a stopper (1-hole) and a small piece of glass tubing attached to a long piece of rubber tubing. Fill the flask about one-half full of water. The flask may be heated on a hot plate or with a Bunsen burner using an iron ring with a wire screen. Hold the flask in place by a buret clamp attached to a ring stand. Turn on the hot plate or light the burner and allow the water to boil. ***CAUTION:*** When the water begins to boil, steam will escape from the tubing. Use tongs to handle. See Figure 8.2 .

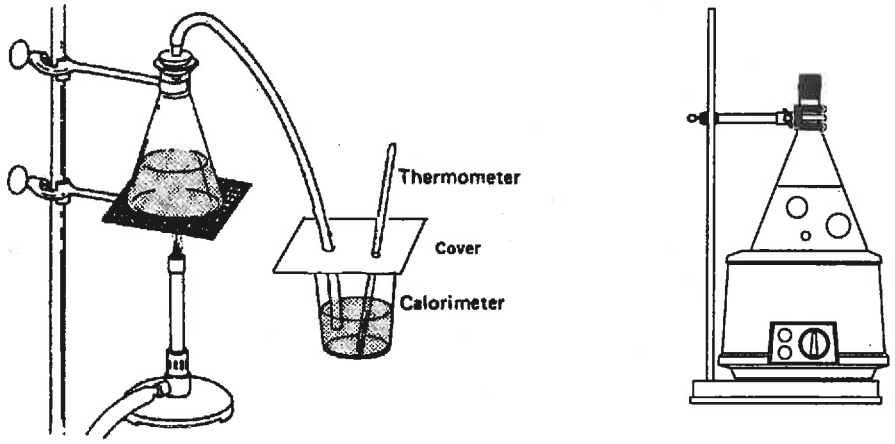

Figure 8.2 Apparatus for measuring the heat of vaporization.

B.1 Weigh an empty calorimetry cup.

B.2 Place 100 mL of water in the cup and weigh. Record the total mass.

B.3 Record the initial temperature of the water in the calorimeter.

CAREFUL! THE HOT STEAM COMING OUT OF THE TUBING HAS A HIGH HEAT OF VAPORIZATION AND CAN CAUSE BURNS. THIS WILL BE DONE BY YOUR INSTRUCTOR.

When the water is boiling and steam comes out of the tubing, ***use tongs*** to place the end of the tubing in the water in the calorimeter. Watch the rise in temperature as steam condenses. When the temperature gets to 70° or 75°, remove the tubing. Stir the water and condensed steam in the calorimeter and record the highest temperature reached.

B.4 After the water has cooled, weigh the cup and its contents and record the total mass. The increase in mass is due to the water formed when the steam condensed.

Calculations:

B.5 Calculate the initial mass of water placed in the calorimeter (B.2 - B.1).

B.6 Calculate the temperature change (ΔT) after steam was added. ($\Delta T = T_{final} - T_{initial}$)

B.7 Calculate the calories gained by the water.

calories = mass of water x ΔT x specific heat (1.0 cal/g°C)

The heat gain by the water is equal to the heat lost by the condensing steam.

heat gain (to warm water) = heat lost (by condensing steam)

B.8 Calculate the mass of steam that condensed. Subtract the mass of the calorimetry cup and water from the mass of the cup, water, and water from the condensed steam (B.4-B.2).

B.9 Calculate your experimental value for the heat of vaporization by dividing the calories by the mass of the steam that condensed.

$$\text{heat of vaporization} = \frac{\text{calories released by steam (B.7)}}{\text{grams of steam (B.8)}}$$

B.10 Calculate the percent error by subtracting your experimental value from 540 cal/g, dividing by 540 cal/g, and multiplying by 100. Ignore any negative sign.

$$\text{percent error} = \frac{\text{540 cal/g - experimental cal/g}}{\text{540 cal/g}} \times 100$$

C. Food Calories (Extension)

Materials needed: Food products with nutrition data on labels

Obtain a food product that has a **Nutrition Facts** label. Indicate the serving size, the grams of fat, carbohydrate and protein. From the mass of each food type, use caloric values (see discussion) to calculate the Calories (kcal) of each. Add the total Calories (kcal) and compare to the **Calories** listed on the upper portion of the label. Usually these totals are rounded to the nearest tens place. Complete the table and questions in the lab report.