EXPERIMENT 15
HEATS OF FUSION AND VAPORIZATION

I. THEORY

When heat is added slowly to a chunk of ice that is initially at a temperature below the freezing point (0 °C), it is found that the ice does not change to liquid water instantaneously when the temperature reaches the freezing point. Instead, the ice melts slowly. Precise measurements show that 79.7 calories of heat must be added to one gram of ice at the freezing point to convert it to liquid water at the same temperature. This **heat of fusion**, L_f, is the energy needed to break up the crystal structure of the ice.

Similarly, it is found that 539 calories of heat must be added to one gram of liquid water at the boiling point (about 100 °C, depending on the atmospheric pressure) to convert it to steam at the same temperature. This **heat of vaporization**, L_v, is the energy required to overcome the cohesive forces of the molecules of liquid water, plus the work of expansion against the confining pressure of the atmosphere.

The purpose of this experiment is to measure the heats of fusion and vaporization of water.

To determine L_f experimentally, we will add a measured mass of ice at the freezing point to a measured mass of liquid water in a calorimeter of known mass and known specific heat capacity, both of which are at a known initial temperature. We will then record the final temperature. To determine L_v experimentally, we will add steam at the boiling point instead of ice.

The following precautions must be taken in order to minimize errors of measurement: The masses of ice and steam must be large enough for precise measurement; the temperature changes must be large enough for precise measurement; and the flow of heat to or from the air in the room must be minimized. The last objective is realized partly by using a covered insulated calorimeter, partly by having the final temperature as far below (or above) the room temperature as the initial temperature is above (or below) the room temperature, and partly by causing the temperature changes to occur in as short a time interval as possible.

If heat exchange with the room air is minimized as described in the previous paragraph, we can assume that the total energy of the system remains constant, as described by the Law of Conservation of Energy. Then the heat absorbed by one part of the system must equal the heat lost by the remainder of the system.

In this experiment, heat terms may involve (1) temperature changes, (2) the melting of ice, or (3) the condensing of steam.

When a body of mass m and specific heat capacity c undergoes a temperature change ΔT, the heat absorbed is $Q = mc\Delta T$. When ΔT is negative, Q is negative indicating a heat loss.

When a mass m of ice melts, the heat absorbed is $Q = mL_f$.

When a mass m of steam condenses, heat is lost by the steam so the heat absorbed is $Q = -mL_v$.

In this experiment we will make use of a calorimeter with an inner cup of aluminum and a stirrer of stainless steel. Heat energy gained or lost by these bodies must be included in the heat exchange equation.

It will be left to the student to deduce the detailed form of the heat exchange equations for the two parts of the experiment, fusion and vaporization.

Although the boiling point of water is often taken as 100 °C, the boiling point actually varies with pressure. We will use a mercury barometer to measure atmospheric pressure, and calculate the boiling point by using the equation $T = 71.5 °C + (0.375 °C/cmHg) P$. The pressure unit cmHg stands for centimeters of mercury.

II. LABORATORY PROCEDURE

CAUTION: You will be working with steam from the steam generator. Be careful. Avoid touching metal and glass vessels containing boiling water or steam.

If you are doing the Heat of Fusion AND Heat of Vaporization, complete step 7 below before starting the Heat of Fusion.

HEAT OF FUSION

1. Record the room temperature, using the thermometer from your box of equipment.

2. Measure the mass of the empty inner calorimeter cup and the ring-shaped stirrer, separately.

3. Fill your inner calorimeter cup approximately 1/3 full with tap water. Pour in hot water from one of the electric kettles in the room so that the cup is about 2/3 full. Check the temperature of your water. The water should be about 20 C° above room temperature. If it is not, add water as appropriate pouring out excess so your cup is about 2/3 full.

4. Place the stirring rod in the inner calorimeter cup and measure the mass of the cup, which now contains warm water and the stirrer. The stirrer should be in the cup during this measurement and the measurements in steps 8, 9 and 12. Place the inner cup back in the outer cup. Place the calorimeter cover on the calorimeter, insuring that the stirring rod fits through the small hole. Using glycerin, place a stopper on the thermometer. Place the stopper in the hole of the cover so that the thermometer extends well into the water. Record the temperature.

5. Dry several pieces of ice with paper towels and drop them into the water. Stir gently by moving the stirrer up and down slowly. CAUTION: Rapid stirring may spill water,

throwing the mass measurements off. DO NOT STIR WITH THE THERMOMETER. Monitor the temperature continually. Continue this process until, as the last bit of ice melts, the final temperature is about as far below room temperature as the initial temperature was above room temperature. Record the final temperature.

6. Measure the mass of the inner calorimeter cup and the water contained in it, again with the stirring rod in it to avoid removing water. Save the cold water for the vaporization part of the experiment.

HEAT OF VAPORIZATION

7. Prepare the steam generator for the vaporization part of the experiment, as follows: Set up a tripod base, a vertical rod, a right angle clamp, and a three-prong clamp. Use the three-prong clamp to support the condensate trap with the single outlet at one end upward. Using glycerin, connect a length of thin-wall rubber tubing from that single outlet of the trap to the metal tube in the steam generator stopper. Fill the generator about half full, put the stopper on, plug it in and turn it on. Again using glycerin, connect a length of thin-wall tubing to the diagonal outlet of the trap (the drain), and a length of thick-walled tubing to the remaining outlet (the steam outlet). Let these two lengths of tubing hang into the beaker.

8. If the inner cup is nearly full, pour some water out and measure the mass again (including the stirrer).

9. Place the inner cup back in the outer cup. Replace the stirrer and cover. Without using excessive force, remove the stopper from the thermometer. Place the thermometer in the inner cup, through the hole in the cover. Alongside the thermometer pass the thick-walled tube from the trap. The bulb of the thermometer should not be placed near the end of the thick-walled tube, as that would cause the thermometer to give a misleading reading in the next step. Record the temperature.

10. Place a pinch clamp on the drain (diagonal) tube from the trap and tighten it, so that steam is forced through the thick-walled tube into the water. Stir gently with the stainless steel stirrer. DO NOT STIR WITH THE THERMOMETER. Continue adding steam until the final temperature is about as far above room temperature as the initial temperature was below room temperature. Remove the thick-walled tube. Continue stirring for several seconds and record the final temperature. Turn off and unplug the steam generator. WARNING: If you turn off the steam generator with the thick-walled tube still in the calorimeter and the tubing clamp on the drain tube, as the steam cools and condenses water will be sucked out of your calorimeter and into the trap and you will have to repeat the experiment.

11. Measure the mass of the inner calorimeter cup (including the stirrer) and the water contained in it.

12. Adjust the knob at the bottom of the mercury barometer so that the pointer just touches the surface of the pool of mercury. Move the vernier scale so that the lower edge of the metal marker is even with the top of the mercury meniscus. Record the atmospheric pressure to the nearest hundredth of a centimeter, noting that the vernier scale runs downward, even though the main scale runs upward.

13. Empty the steam generator and wipe up all spilled water. Do not use excessive force to remove lengths of tubing from the trap. If you have difficulty removing any of the tubing, consult your instructor.

III. CALCULATIONS

HEAT OF FUSION

1. Make a table containing the mass of the empty inner calorimeter cup, the stirrer, the initial water, and the ice added. Assign a symbol to each mass. Make a table containing the water temperature before the ice was added, the initial temperature of the ice (assumed to be 0 °C) and the final equilibrium temperature. Assign a symbol to each temperature. Let the symbol L_f represent the latent heat of fusion for water and the symbols c_w, c_a, and c_s represent the specific heat capacities of water, aluminum, and stainless steel, respectively. Write out the heat exchange equation for fusion using ONLY symbols. Include NO numbers. Assume that the stirrer was fully immersed during the entire experiment and neglect heat lost by the system.

2. Solve your heat equation symbolically for the latent heat of fusion of water.

3. Substitute numerical values into your solution using the masses and temperatures from your table and the following specific heats for water, aluminum and steel: 1.00 cal/g·°C, 0.215 cal/g·°C and 0.107 cal/g·°C. Find the percent error in your heat of fusion.

HEAT OF VAPORIZATION

4. Use the measured atmospheric pressure to calculate the boiling point temperature for water.

5. Make a table containing the mass of the empty inner calorimeter cup, the stirrer, the initial water, and the steam added. Assign a symbol to each mass. Make a table containing the water temperature before steam was added, the initial temperature of the steam (the boiling temperature of the water) and the final equilibrium temperature. Assign a symbol to each temperature. Let the symbol L_v represent the latent heat of vaporization for water. Again, use the symbols c_w, c_a, and c_s represent the specific heat capacities of water, aluminum, and stainless steel, respectively. Write out the heat exchange equation for vaporization using ONLY symbols. Include NO numbers. Again, assume that the stirrer was fully immersed during the entire experiment and neglect any heat lost by the system.

6. Solve your heat equation symbolically for the latent heat of vaporization of water.

7. Substitute numerical values into your solution using the masses and temperatures from your table and the specific heats for water, aluminum and steel. Find the percent error in your heat of vaporization.