Heating Curve of Water

If water is heated under atmospheric pressure two kinds of physical changes can take place: the temperature can increase and the phase can change (from ice to liquid or from liquid to steam). In this experiment, we will observe how these changes are related and use the data to estimate the heat of fusion and the heat of vaporization.

As you may know from the study of specific heat capacity, the quantity of heat "Q" required to achieve a certain temperature change is the product of three factors: the mass of the substance, its specific heat "c" (the specific heat of water is 4186 J/kgC° in SI units or 1.00 cal/gC° in non-SI units.) and the number of degrees the temperature changed, so

$$Q = M\,c\,\Delta T. \qquad (1)$$

Since Power is defined as the amount of energy used every second (Joules per sec), and in this case the amount of heat Q transferred over some period of time Δt, we can measure that time during which a substance is heated using a stopwatch and use it to find the thermal power P and finally Q. If the power is held constant over the time interval Δt, then the quantity of heat can be calculated with the formula:

$$Q = P\,\Delta t \qquad (2)$$

Combining equations (1) and (2) gives:

$$P\,\Delta t = M\,c\,\Delta T$$

Or:

$$P = M\,c\,(\Delta T/\Delta t) \qquad (3)$$

If the temperature reading is recorded over time as the sample is heated, and temperature is plotted versus time, then $(\Delta T/\Delta t)$ is the slope of the graph.

The heat of fusion L_f (represented by L because it is often called the "latent heat of fusion") of water is the amount of heat required to transform a unit mass (kilogram) of solid ice (already at a temperature of 0°C) into a liquid, so

$$L_f = Q/M \qquad (4)$$

The standard value of L_f for water is 334944 J/kg.

The heat of vaporization L_v is the amount of heat required to transform a unit mass of liquid water already at 100°C into the gas phase. With this definition,

$$L_v = Q/M \qquad (5)$$

The standard value of L_v for water is 2260872 J/kg.

Experimental Procedure

0. Plug in the empty hot plate to pre-heat. If it has a control knob, turn fully clockwise to maximum. Use caution to avoid burns.

1. Handle the large stainless steel can as little as possible to reduce the transfer of your body heat to the can. Measure the mass of the dry empty can with lid and record that value in grams and kilograms. (Label all values clearly with symbols and units as you record them!)

2. Working quickly, fill the can almost to the top with “dry” ice (no liquid), cover and then rapidly determine the combined mass of the can, lid, and ice. ***Work quickly*** so the ice is still un-melted and solid when you start taking the time and temperature data.

3. *Immediately* and simultaneously, place the can on the hot plate and start the clock timer from zero. Remove cover sheath and insert thermometer in the ice so that the tip of the metal probe is just barely (~1 mm) above the bottom of the can. (Use the ring stand and test tube clamp to support the thermometer in this position.) Press the “LAP” button on the timer and record the actual time from the timer and associated Temperature from the thermometer in neat columns on letter paper provided. As always, use as many significant figures as the measurement tools allow. Hit “LAP” again to return to the live running clock display. ***DO NOT STOP THE CLOCK UNTIL YOU ARE CERTAIN IT’S APPROPRIATE. STOPPING THE CLOCK EARLY COULD WRECK YOUR EXPERIMENT AND COST HOURS OF TIME TO RE-DO!***

4. Continue recording the temperature and corresponding time about every minute or so all the way to the end of the class period or until instructed otherwise. Don’t worry about taking data at equal intervals and don’t write down any times in advance. Occasionally stir the contents of the container and check that the thermometer stem is still properly immersed. Carefully watch the ice disappear, and **at the very moment that the last pieces of ice vanish, quickly record the time**. Note that this is the time when all solid water has made the transition to liquid.

5. As heat (Q) continues to be added to the water by the hot plate, keep recording temperature and time data about every minute. When small bubbles first begin steadily rising to the surface, note the time. Then, at the first sign that the surface of the water is definitely agitated by boiling (a “rolling” boil), again note the time. To help offset the great uncertainty in a visual determination of the boiling point, figure the time halfway between these two as the “official” start of boiling.

6. Once the instructor tells you that enough water has been lost to vaporization, cover with lid, immediately record the time and quickly measure the final mass. The cork sheath will protect you from the heat. Unplug the hotplate.

Analysis

1. On high-resolution graph paper, plot T vs. t and find the slope considering only the data points between 30° C and 80° C. Convert the slope (rise/run) to units of C°/s. Then calculate the thermal power, P transferred to the water. The m, c, ΔT, and Δt you use must all describe the same single material undergoing the same event. (T spans a greater range, so a typical graph scale is 0.05 min/mm for the horizontal time axis and 0.2˚C/mm on the vertical Temp axis.)

2. The electrical power used from the wall outlet is marked on the hot plate (probably 330 J/s = 330 Watts). Calculate the heating transfer efficiency of the apparatus by using the definition:

$$e = \frac{P_{in}}{P_{wall}} \text{ x } 100\ \%$$

3. Estimate the time interval Δt_f during which the sample transformed from ice at 0° C to liquid water at 0° C. Assuming that the thermal power P remained constant throughout the experiment, calculate the heat, Q to melt the ice. Then use this Q to melt and the mass melted to calculate heat of fusion of water, L_f.

4. Estimate the time interval Δt_v that elapsed from the start of boiling until you put the lid on the container. Boiling should've begun when temperature reached 100˚C, but in this case, trust your eyes and assume it started more than halfway between the observed first signs and the definite boil. Again assuming that the thermal power P remained constant throughout the experiment, calculate the heat, Q to vaporize the water that escaped. Then use this Q to vaporize and the mass vaporized to calculate heat of vaporization of water, L_v. Use the difference in mass between the ice and the remaining water at the very end of the experiment to find the mass of the liquid that transformed into vapor.

5. Which of your latent heat results is closest to the accepted value? Why do you think that one result was more accurate than the other? What other sources of error are distinct to this particular experiment?