LATENT HEAT

Purpose:
1. To determine experimentally the latent heat values of water for the processes of fusion and vaporization.
2. To become familiar with the temperature probe as a means of measuring temperature.
3. To study the way uncertainties combine.

Materials:
- Calorimeter with outside insulating container and stirrer
- Boiler with hot plate, Balance, Warm water and ice.
- Thermometer or Thermometer sensor (Lab Pro, Logger Pro software)

PART 1: THEORY

When a substance changes state, a certain amount of heat is exchanged between each unit mass of the substance and its surroundings. Heat of fusion \( L_f \) is the term applied to the ratio of exchanged heat \( Q_f \) per unit mass, \( m \), when a substance melts, or:

\[
L_f = \frac{Q_f}{m}
\]  

\( L_f \) has the units calories/gram. If melting occurs, heat is being absorbed by the substance from the surroundings; freezing, on the other hand, implies a reverse process where heat flows from substance to surroundings.

A similar expression, \( L_v \), heat of vaporization is associated with the liquid-to-vapor process, or its opposite; again, the same rationale applies:

\[
L_v = \frac{Q_v}{m}
\]

PART 2: EXPERIMENTAL DETERMINATION OF \( L_f \)

To experimentally determine the heat of fusion of water, one uses a calorimeter container of a given mass, \( m_c \), and specific heat, \( C \). Water of mass \( m_w \) is poured into an insulating container. The initial temperature \( T_o \) of water and container is then measured. Ice with mass \( m_i \) is then added to the container where melting takes place. You may assume that the ice temperature during the melting process remains at \( 0^\circ \) C.

The law of conservation of energy may be applied during the above mixing/melting process. The result is:

\[
\text{Heat gained by } m_i = \text{Heat lost by } m_w \text{ and } m_c.
\]
This may be expressed as

\[ m_i(L_f + C_w(T_f - T_0)) = m_wC_w(T_o - T_i) + m_cC_c(T_o - T_i) \]  \hspace{1cm} (4)

The two terms on the left represent the heat gained by 1) the ice in melting and 2) the melted ice water in going from 0°C to \(T_f\). The two terms on the right side are, respectively, heat loss by 1) water originally in calorimeter and 2) calorimeter. The symbols \(C_w\) and \(C_c\) stand for the specific heats of water and aluminum, respectively, for which the numerical values are 1.00 and 0.22 cal/°C·gm.

Equation 4 readily yields a value for \(L_f\) when all other quantities appearing in the expression have been measured or are given.

PART 3: EXPERIMENTAL DETERMINATION OF \(L_v\).

A similar approach to that above is followed in determining the heat of vaporization. In this instance steam of mass \(m_s\) from a boiler is directed into the calorimeter where it mixes with the water already in the container and brings the temperature of the system from an initial temperature \(T_i\) to a final temperature of \(T_f\). A parallel statement to Equation 3 reads:

Heat lost by \(m_s\) = Heat gained by \(m_w\) and \(m_c\), \hspace{1cm} (5)

or,

\[ m_sL_v + m_sC_w(T_{bp} - T_i) = m_wC_w(T_f - T_o) + m_cC_c(T_f - T_o) \]  \hspace{1cm} (6)

The two left hand terms represent, respectively, heat loss by 1) steam in condensation and 2) condensed steam, as liquid, in changing temperature from \(T_{bp}\) to \(T_f\). It will be noted that \(T_{bp}\) denotes the boiling point temperature. The above equation yields a value for \(L_v\) where all other quantities are measure or given.

The boiling point of water, \(T_{bp}\) is a function of the barometric pressure. As atmospheric pressure varies so does the boiling temperature of water. Table 1 gives values of \(T_{bp}\) with corresponding barometric pressures.

PART 4: EXPERIMENTAL MEASUREMENTS

As shown above several measurements must be plugged into a complicated formula in order to compute the final result. (There is a more complete discussion of these calculations at the end of the lab.) This will therefore require the student to combine uncertainties. In this lab we will use the spreadsheet to aid in the computation of uncertainty. This is an important focus for this week's lab. Take time to setup the entry of data into your spreadsheet so that you can calculate uncertainties. Proceed in steps. As shown above you will need to take a temperature difference \((T_f - T_o)\). Perform this single calculation, \(\Delta T\), and calculate the uncertainty in \(\Delta T\). You can then calculate the product \(m_c\Delta T\). Because some of the rules for combining uncertainties require fractional uncertainties and some require absolute uncertainties, it will be convenient to provide a column for both types of uncertainty. It will also be useful to name the cells so that the formulas are easier to enter and understand. For example, for the mass of water must be computed and an uncertainty calculated. The example below illustrates one way to accomplish this task. Note several cells have been named.
In this experiment we will be using either the temperature probe or a thermometer. Both determine the temperature and your instructor will announce which device will be used.

There are two good calibration points for checking and calibrating thermometers for today’s lab.
- 0 °C - freezing point, ice-water equilibrium temperature (at atmos. pressure, 760 mm of Hg).
- 100 °C - boiling point, water-steam equilibrium temperature (at 760 mm of Hg). Try not to let the bottom of the thermometer touch the bottom of the boiler. Be careful one can easily burn your hand.

For temperature sensor:
- Startup Logger Pro.
- Load setup file heat.
- Check the setup to ensure the configuration is sensible (rate, duration).
- Calibrate.

For a thermometer:
- Use care thermometers are easy to break.
- Examine the scales and be sure you can read properly.
- Check that the thermometer reads correctly.

In addition to the thermometer we will use a device called a calorimeter. A calorimeter is an insulated container designed to minimize thermal transfer between the experiment and the outside world. A diagram of the calorimeter and its components is given in Figure 1.

<table>
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<tr>
<th>comment</th>
<th>name</th>
<th>value</th>
<th>units</th>
<th>abs. unc.</th>
<th>fractional unc.</th>
<th>comment</th>
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<td>MWC</td>
<td>55</td>
<td>gm</td>
<td>2</td>
<td>=E2/MWC</td>
<td>Unc. based on…</td>
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<td>MC</td>
<td>4</td>
<td>gm</td>
<td>2</td>
<td>=E3/MC</td>
<td>unc. based on…</td>
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<tr>
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<td>MW</td>
<td>=MWC-MC</td>
<td>gm</td>
<td>=E2+E3</td>
<td>=E4/MW</td>
<td>unc. calculated</td>
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</table>

A. Heat of fusion procedure

Measure the mass of the empty inner calorimeter and stirrer. Record this value on the data table as $m_c$. Estimate the uncertainty in this measurement.
Record the room temperature as $T_r$. Add water at about $10^0 \text{ C}$ above room temperature to your inner calorimeter container so that the latter is filled to about 60% of capacity. You easily increase or decrease water temperature by adding a bit of hot or cold water. Be sure to stir well so that the water is all at the same temperature.

Measure the mass of the inner container (with stirrer) with water, and record this as $m_{(c+w)}$. Now subtract $m_c$ to get the mass of the water and record this as $m_{w}$.

Place the inner container within the outer insulated container as shown in Figure 1. Place the lid on the container so that the stirrer handle is sticking out and place the stopper and temperature probe in the large hole on the top of the container. The probe should be positioned so that the tip is between 1 and 2 cm below the surface of the water inside. Record the temperature of the water. Wait until you get a few stable readings. Remove an ice cube from the insulated container on the side table, holding it in a paper towel. Place the cube in the inner calorimeter container, replace the lid and gently start stirring the water until the ice has completely melted. Monitor the temperature of the water until it reaches its lowest value. Record this as $T_f$.

Now measure the mass of the inner container and record this as $m_{(c+w+i)}$ and use this value and previous measurements to find the mass of the now melted ice, $m_i$.

Use Equation 4 to determine your experimental value of $L_f$. Determine the uncertainty associated with this value by properly propagating your uncertainties through the equation. Check to see if you exclude the theoretical value of 80 cal/g to 95% or better. A very thorough example of the spreadsheet manipulations that are required to analyze this data can be found at the end of the appendix Establishing Uncertainty.

B. Heat of Vaporization

Refill your container with cool water and record the mass as in the previous part. Calculate the mass of the water alone. Record the initial temperature as $T_o$.

Allow the water in the pot to come to a boil. Wait at least one minute after the steam starts to emerge from the tube before plugging it into the 1 cm hole in the calorimeter lid. Make sure the tube is positioned as in Figure 2a so that the steam does not condense inside the tube. Also, while waiting for the water to boil place the end of the tube into a beaker. As the steam is entering the calorimeter gently stir the water and monitor the temperature. When the temperature reads about $15^0 \text{ C}$ above room temperature, remove the tube and continue to monitor the temperature until it peaks. Record this value as $T_f$. 


Remove and weigh the inner container. Record this value as $m_{(c + w + s)}$. Use this value and your previous measurements to calculate the mass of the now condensed steam. Record this as $m_s$.

Read the current barometric pressure from the room barometer and record this in your data table. With this value use Table 1 to find the boiling point of water and record this value as $T_{bp}$.

Use your data and Equation 6 to find your experimental value of $L_v$. Use proper technique in the propagation of uncertainty through the equation to determine the uncertainty in $L_v$. Determine if your experimental value excludes the theoretical value of 539 cal/g to 95% or greater.

Make sure to fill out the data sheet completely and answer the questions at the end.

### Table 1: Boiling Temperature of Water vs. Barometric Pressure

<table>
<thead>
<tr>
<th>TEMP</th>
<th>P mm of Hg</th>
<th>TEMP</th>
<th>P mm of Hg</th>
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<td>Comparison with theory.</td>
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