Experiment: Heat of Fusion (H_f) for Water

Minneapolis Community and Technical College

v.4.16

I. Introduction

The heat of fusion (H_f) is the amount of energy required to melt or freeze a specific amount of substance. It is often expressed on a "per gram" or "per mole" basis. In this experiment, you will be determining the heat of fusion for ice and comparing it to the known value 6.020 kJ/mol.

H_f is determined by adding a known amount of 0°C ice to a known amount of hot water in an insulated container known as a calorimeter that you will build before coming to lab. Obviously, the hot water loses heat energy as it cools down to a final temperature, T_f. However, the ice gains heat in two steps.

1. Melting: Because the initial temperature of the ice is 0°C, it will take heat from the hot water and melt.

2. Warming: After the ice has melted, it leaves behind water at 0°C that must be warmed by the hot water that surrounds it to the final temperature of the mixture T_f.

Calorimeter

You will construct the calorimeter used in these experiments before coming to class. The calorimeter and lab report are both worth 10 points and will be graded separately. Note that whether you do the experiment or not, you must turn in a calorimeter for credit and the 10 points.

At the end of class, your calorimeter will compete against others in the calorimeter contest. In "heats" of four, each contestant will receive ~75 mL of hot, near-boiling water. LoggerPro will be used to monitor the temperature of each calorimeter and the calorimeter that keeps its water hot the longest will advance to compete with other finalists to determine the overall winner. Some calorimeters will be selected for display in the display cases in the front of the Science Building.

Heat Loss

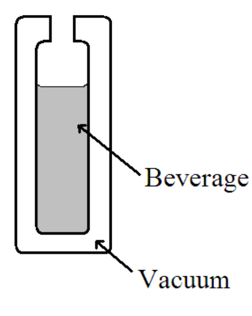
Heat energy is lost by ***conductive*** and ***radiative*** processes. ***Conductive heat loss*** occurs as heat energy is transferred through a material to the surroundings. For example, if you cook with pots & pans that have metal handles, heat energy will be conducted into the handles making them too hot to hold. An oven mitt (insulator) will block the conductive flow of heat from the handle and protect your hand as you remove the pot from the stove.

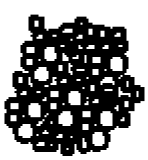
Radiative heat loss occurs when objects emit or receive invisible infrared light. Sitting around a campfire you feel warm because of the infrared light that shines on you. A similar effect is used in restaurants where infrared heat lamps are used to keep food warm until they are served to customers.

The Mylar survival blanket (picture at right) is used to eliminate radiative heat loss in emergency situations where the infrared light produced by the person is reflected back keeping them warmer.

What is a good insulator?

One of the best insulators is actually nothing at all… a vacuum! A cup of hot chocolate in a porcelain mug cools down because circulating, ***convective***, air around the mug quickly carries away heat energy. In an insulating Thermos bottle (figure at right), the inner beverage container is surrounded by a vacuum jacket. In this case there is no air in contact with the container to circulate and carry away heat and the beverage stays hot (…or cold) much longer. Of course the opening at the top of the Thermos bottle is a potential heat leak but a well designed plug or stopper can minimize the losses.





Air by itself is actually a pretty good insulator <u>as long as it isn't allowed to circulate</u>. This is the principle behind insulating foams. By trapping air in small bubbles (left), convective circulation can be kept to a minimum while still taking advantage of air's insulating properties. Generally speaking, most common insulation materials take advantage of the effect by trapping the air in small bubbles/pockets and thus prevents it from circulating.

What insulator should I choose for my calorimeter?

Good question. Here are some of the materials that have performed well in the past: fiberglass, rock wool, spray foam***** and Styrofoam. Other materials that didn't do very well (Why?) include jello, sand and rice. Also, try to design your calorimeter so that the inner enclosure doesn't absorb very much heat energy. For example, don't use a metal inner container as it will absorb a lot of heat energy and lower the temperature of the hot water prematurely.

****Spray foam must be exposed to air to properly cure. It will be a big sticky mess if you don't provide enough air.***

Heat Transfer Calculations

Some of the heat energy that melts the ice comes from the hot water. The amount of heat energy **lost** by the hot water is given by the following formula:

$$Q_{\text{hot water}} = m_{\text{hot water}} \times c_{H_2O} \times (T_F - T_i) \qquad \textbf{Equation \#1}$$

where Q is the energy lost by the hot water, m is the mass of the hot water, c is the specific heat of water (4.184 J/g ^{o}C)., and T_F and T_i are the final and initial temperatures of the hot water respectively.

As the ice melts its temperature *remains constant at 0 ^{o}C*. The energy required to melt the ice is given by:

$$Q_{\text{melt}} = m_{\text{ice}} \times H_f \qquad \textbf{Equation \#2}$$

where Q is the energy **gained** by the ice, m_{ice} is the mass of the ice, and H_f is the unknown heat of fusion in this experiment.

Note also that energy is also **gained** by the water formed when the ice cube melts. This water is initially at 0 ^{o}C and must be warmed up to the final temperature of the mixture. The energy required for this step is also furnished by the hot water & calorimeter and is given by the following formula:

$$Q_{\text{cold water}} = m_{\text{ice}} \times c_{H2O} \times (T_f - 0.00) \qquad \textbf{Equation \#3}$$

Where m_{ice} is used since the ice has now melted and exists as additional liquid water. Note that the initial temperature of the water formed via this process is 0^{o}C (i.e. the ice that melts forms liquid water at 0^{o}C)

In today's experiment, you will measure all masses and temperatures. The only unknown will be the heat of fusion, H_f. You can then calculate actual values for the amount of heat lost by the warm water, the calorimeter, and the amount of heat gained by the ice water via the equations above.

The amount of heat required to melt the ice is then calculated via the following formula describing conservation of energy for this process:

$$Q_{lost} = -\,Q_{gained} \qquad \textbf{Equation \#4}$$

$$\underbrace{Q_{\text{hot water}}}_{\textit{Known}} = -\,(\underbrace{Q_{\text{melt}}}_{\textit{Unknown}} + \underbrace{Q_{\text{cold water}}}_{\textit{Known}})$$

Values for $Q_{\text{hot water}}$, $Q_{\text{cold water}}$ are calculated and used to determine the value for Q_{melt} and H_f.

Calculations:

1. Calculate the masses of the hot water and ice from your experimental measurements.
2. Use equations 1 & 3 to determine the heat lost by the hot water ($Q_{\text{hot water}}$) and the heat gained by the ice water ($Q_{\text{cold water}}$).
3. Calculate the heat required to melt the ice (Q_{melt}) via equation 4.
4. Determine the value of H_f using equation 2 in both Joules per gram and Joules per mole units.
5. Determine how closely your value of H_f compares to the known value by performing a Δ% calculation for both trials.

II. Prelab Exercise… ***Clearly answer these questions in INK in your lab notebook before coming to lab.***

1. What was the insulation you used in your calorimeter and why do you think it is a good insulator?

2. The friendly chemist finds herself stranded on a cold winter day in the forest. She has a both a Mylar survival blanket and a good winter coat that she plans to use to keep her warm. Specifically, what is the purpose of each of the items in terms of heat related concepts?

3. In today's experiment, why is it necessary to have the ice at 0 ºC before adding it to the hot water?

III. Word processed report

<u>Page 1:</u>

1. **Upper right corner:** Your name, Your lab section number, Date of experiment

2. **Data table:** Obtain a copy of the data table from the lab-handout web site and type in your values. Don't round until you determine the value for H_f.

<u>Page 2:</u> Answers to the following questions:

1. Handwritten sample calculations for one of your H_f determinations.

2. Your calculated value for H_f will be lower than the accepted value. This error is most likely due to your initial ice sample not being completely dry. Recalculate your trial #1 H_f (kJ/mol) value assuming that 5.00 grams of your ice sample was actually liquid water. Show your work.

3. What experimental and calculation changes would be necessary to avoid the problems described in question 2?

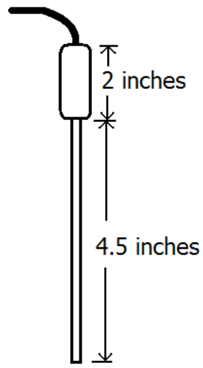
4. Now that you've tested your calorimeter, describe one change you would make to improve its performance.

IV. Procedure

Calorimeter Construction

The mass of the calorimeter plus water & ice must be below the weight limit of the laboratory balances (400 grams).

The stainless steel Vernier temperature probe shown at right (note dimensions) will be used to monitor the temperature of the solution and to stir the ice/water mixture. Make sure that it can easily reach the ice/water mixture at the bottom of your calorimeter.



Temperature Probe

If your calorimeter uses a lid, make sure to provide a hole for the temperature probe. The temperature probe must be able to reach the ice/water mixture at the bottom of the calorimeter.

Calorimetry

Place approximately 30 grams of ice in a beaker to warm. The ice must be melting slightly to guarantee that its temperature is 0^{o}C.

Pour approximately 50 mL of hot tap water (~ 45°C) into your dried, pre-weighed calorimeter. Reweigh the water filled calorimeter and record the mass.

> ***These amounts are only approximate and it may be necessary to use more or less water/ice depending on the volume of your calorimeter and how deep it is.***

Insert the temperature probe into your calorimeter and click on the “Collect” button in Logger Pro.

Do NOT stop collecting data until the entire experiment is finished (approx. 6 minutes total time).

Stir well at all times. Inadequate stirring leaves the temperature probe in hot or cold pockets and produces erratic temperature behavior.

After collecting data for ~ 2 minutes , pour off any water that has formed in the ice-containing beaker, dry the ice with a paper towel and add approximately 10 grams to the calorimeter. Continue collecting temperature data and try to keep the temperature probe immersed in the hot water for best results.

Collect data for another 3-4 minutes stirring at all times. The ice should be completely melted at the end of the data collection run.

A successful trial will be one with a final temperature between 5^{o}C and 12^{o}C. If your final temperature isn’t in this interval, perform another trial using more or less ice.

After stopping the data acquisition, touch the end of the temperature probe to an inside surface of the calorimeter to transfer any water clinging to the probe. **Reweigh the calorimeter/water and record the mass in your note book.**

Use the Logger Pro graph to determine the initial and final temperatures for each successful trial and record these values in the data table.

Repeat the procedure for the calorimeter as many times as necessary to get two good trials for your calorimeter. Repeat the procedure for your partner’s calorimeter.

V. Data Table: **Cut and paste this data table into your lab notebook using glue and transparent tape.**

Do not round until you calculate a value for H_f.

	Calorimeter Trial #1	**Calorimeter Trial #2**	**Calorimeter Trial #3 (optional)**
$\mathbf{m_{calorimeter}}$ **(g)**			
$\mathbf{m_{calorimeter}}$ **+ hot water (g)**			
$\mathbf{m_{calorimeter}}$ **+ hot water + ice (g)**			
$\mathbf{m_{ice}}$ **(g)**			
$\mathbf{m_{hotwater}}$ **(g)**			
$\mathbf{T_i}$ **(°C)**			
$\mathbf{T_f}$ **(°C)**			
$\mathbf{Q_{hotwater}}$ **(J)**			
$\mathbf{Q_{cold\ water}}$ **(J)**			
$\mathbf{Q_{melt}}$ **(J)**			
Calc. $\mathbf{H_f}$ **(J/g**$_{\mathbf{ice}}$**)**			
Calc. $\mathbf{H_f}$ **(kJ/mol)**			
$\mathbf{H_{f\ known}}$ **(kJ/mol)**	6.02 kJ/mol	6.02 kJ/mol	6.02 kJ/mol
$\mathbf{H_f\ \Delta\%}$			