Lab #8) Calorimetry

Heat & Calorimetry – *heat* is defined as energy that flows from a hotter object to a colder one due to the temperature difference alone…therefore, since energy is always conserved, the study of processes in which heat is transferred between objects by using conservation of energy concepts is called *calorimetry*.

In calorimetry, we will deal with heat transfer that causes one of two things to happen…either a material undergoes a temperature change, or a phase change (the solid-liquid phase change is called fusion & the liquid-gas one is called vaporization):

\[ Q = mc\Delta T, \text{ where } c \equiv \text{specific heat capacity} \]
\[ Q = mL, \text{ where } L \equiv \text{“latent heat” of fusion or vaporization} \]

“Heat capacity” is a measure of an object’s “ability to absorb/release heat”, meaning the heat it absorbs or releases in going through a 1°C temperature change…the “specific heat capacity” is similar, but is the heat capacity per unit mass, so that it is a property of the material that doesn’t depend on its size. Latent heat is termed that way because it refers to the amount of heat per unit mass that is required to cause a phase change before the material can undergo any further temperature change.

Note: one assumption we will be making throughout this section is that we are working under “standard conditions”…basically meaning here that the pressure remains constant at atmospheric pressure.

So, since our concept is based on conservation of energy, if the only changes in energy that occur are due to heat transfer, the total heat transfer must be zero, or, put another way:

\[ |Q_{\text{gain}}| = |Q_{\text{lost}}| \]

where \( |Q_{\text{gain}}| \) is the magnitude of heat gained by whatever is absorbing it & \( |Q_{\text{lost}}| \) is the magnitude of heat lost by whatever is releasing it.

Note: a convenience of writing it this way is that every term will be positive…therefore, you must be careful with terms that include a temperature change as they will be “higher minus lower” instead of “final minus initial”…you could just write the equation as \( Q_{\text{total}} = 0 \), but in that case you have to be very careful with getting the correct signs in each term.

In today’s lab, you will investigate calorimetry concepts by dropping a small brass sample into liquid nitrogen (\( \text{\textit{LN}}_2 \)), then warming it back up to approximately room temperature and using conservation of energy to determine the latent heat of vaporization for \( \text{\textit{LN}}_2 \) at its boiling point of 77K.

*Note: the specific heat of brass, like all materials, is not constant over very large temperature changes, so we’ll have to figure out a way to account for that.*
I) Determining the Theoretical Equations

Here, you’ll be setting up the equations that your measurements will be based on...in the end, you should be able to use your results along with these equations to determine an average value of the specific heat of brass, as well as the latent heat of $\ell N_2$.

a) Consider inserting a brass sample, initially at room temperature, into a cup of liquid nitrogen at 77K. Determine a theoretical equation for how you could solve for the latent heat of $\ell N_2$ if the specific heat of brass were a known constant (ignoring any heat transfer with the surroundings & labeling the mass of $\ell N_2$ as $m_N$, the mass of the sample as $m_S$, room temperature as $T_R$, etc.).

b) Recognizing that this equation won’t work (& hopefully why), we can use the following approach: since the heat necessary to cool the sample from room temperature to 77K is the same magnitude of heat necessary to warm it back from 77K to room temperature, we can measure that instead by placing the cold sample directly into warm water (label its initial temperature $T_W$). Use this idea to come up with a theoretical equation that represents warming the sample up from 77K to $T_F$ (label as such, since the final temperature won’t necessarily be room temperature...don’t fret, we’ll account for the difference) when it is placed in an aluminum calorimeter containing warm water.

II) Cooling the Sample

Determine the mass of $\ell N_2$ that boils away due to the addition of the sample alone

a) Record the mass of the sample & set up the LoggerPro temperature sensor to determine room temperature (while you’re at it, use the sensor to make sure the sample is at room temperature).

b) Ask your friendly instructor nicely for a cup of liquid nitrogen...BE CAREFUL...it’s pretty darn cold (drinking it would probably kill you & leaving a finger in it for a few seconds would probably mean the end of that finger). Place the cup on the scale & cover it with the note card provided. Note that the measured mass slowly decreases (have the sample on the scale as well, so that you don’t have to adjust the mass readings later, but make sure that card prevents the $\ell N_2$ “fog” from rolling off onto the sample)...note that your mass measurements will actually be including the styrofoam cup as well as the note card, but we’ll just be concerned with the change in mass, so as long as those objects remain on the scale, their masses can be ignored.

c) In LoggerPro, under “Data Collection,” set the total time (labeled “Length”) to 1,000s & the Sampling Rate to 15 seconds per sample. Begin data collection.

d) After about 150s, carefully lower the sample into the cup, trying to avoid splashing, & replace the card on top of the cup (try to do this immediately after a data point is taken to avoid the next data point being invalid). Once the vigorous boiling stops & the normal boiling rate resumes (this will likely take a few minutes), wait at least another 150s before stopping data collection.

e) Insert best-fit lines to the (hopefully) linear ranges just before the sample was inserted & just after the vigorous boiling ended...print a copy of the “m vs. t” curve, and be sure to record the beginning and ending times corresponding to the “vigorous boiling”
(i.e., the last time that corresponded to a point on the first best-fit line & the first time that corresponded to a point on the last). Use this knowledge in a creative (and hopefully reasonable) way to determine the mass of $\ell N_2$ that boiled away due to the addition of the sample alone...feel free to ask your exceptionally friendly lab instructor for help, but try not to take too long here, so that the sample remains completely submerged in $\ell N_2$, as it should for use in part III.

### III) Warming the Sample

*Determine the change in temperature of the system due to the addition of the sample alone.*

a) Fill the calorimeter approximately 75% full with warm water making sure to record the mass of the aluminum cup & the water, separately.

b) Begin a temperature scan for the calorimeter with LoggerPro. After about 150s, quickly (but carefully) transfer the sample from the $\ell N_2$ to the calorimeter. Once the system has clearly come to an equilibrium temperature (or at least the rate of temperature change has decreased dramatically), allow LoggerPro to keep taking data for at least another 150s, then stop the scan.

c) Use similar concepts to those in part II, with the “m vs. t” curve, to determine the change in temperature of the system due to the addition of the sample alone.

### IV) Testing Your Results

*Here, you’ll check to see whether your results were reasonable or not, by comparing them with accepted values.*

a) Use your results and the equation you found in part I(b) to determine the average value of the specific heat of brass over the relevant temperature range. Ideally, your value should be close, but not quite as large as that given below...any ideas why?

b) Similarly, use your results and the equation you found in part I(a) to determine the latent heat of vaporization for $\ell N_2$, and compare it with the accepted value (make sure to account for the difference between the final temperature of the calorimeter and room temperature).

*Are your measured values reasonably close to the theoretical values? If so, finish the lab write-up (make sure to show all derivations of theoretical equations in your notebook and include a copy of the completed data tables and graphs), otherwise politely check in with your ever-friendly lab instructor.*

<table>
<thead>
<tr>
<th>Accepted values (under standard conditions):</th>
</tr>
</thead>
<tbody>
<tr>
<td>$c_{brass} = 0.092 \text{ cal g}^{-1} \degree C^{-1}$</td>
</tr>
</tbody>
</table>

*Note: in calorimetry problems & experiments, calories and grams are often used for convenience as opposed to our standard units of Joules & kilograms.*

---

General Physics I Lab – Last Updated: Spring 2012 3