

Name: _____
Partners: _____

PHYSICS 220 LAB #9: CALORIMETRY



If you pour cold cream into a hot cup of coffee, the mixture comes to an intermediate equilibrium temperature. If you put a piece of ice in a glass of water, some or all of the ice melts and the water will cool down. This lab will involve measuring three of the properties of materials that affect the final temperatures in these types of situations; a specific heat, a heat of fusion, and a heat of vaporization.

(Equipment: Ice, liquid Nitrogen, scale, electronic scale, thermos, gloves, paper towels; per station: calorimetry cup set & stopper, hot plate, 2 beakers, metal mass, computer, LabPro, temperature sensor)

OBJECTIVES

1. To learn how to perform calorimetric experiments.
2. To measure the specific heat of a metal.
3. To measure the heat of fusion for water.
4. To measure the heat of vaporization for liquid nitrogen.

PRE-LAB (to be completed before coming to lab)

Prior to coming to lab, read through this write-up and perform all the exercises labeled **Pre-Lab**. You will also want to copy this work onto the back pages of the lab, which I will collect during the first 5 minutes of lab.

OVERVIEW

Before the particle picture was used to describe gasses, liquids, and solids in terms of collections of atoms and molecules, transfer of internal energy was greatly misunderstood. The prevalent picture was that materials contained a 'caloric fluid' which could seep from a warm chunk of material into a cooler one (and thus cool the former and warm the latter) when the two were brought into contact. Though we now understand that 'warmth' reflects the thermal motion of the particles that make up the hot chunk of material and that the cool object is warmed through the interactions of the individual particles of the two chunks, we retain the old fashioned vocabulary and units. 'Heat' is internal energy that is transferred between objects. Heat 'flows' when an object's temperature (predominately internal kinetic energy) or phase (predominately internal potential energy) changes. When objects come

into thermal contact with each other, they will eventually reach thermal equilibrium, which means that they will have the same temperature (distribution of internal kinetic energies) and no more heat will 'flow'.

The internal energy of a system of particles is the sum of their individual kinetic energies and potential energies. As is argued in lecture, both the change in kinetic and potential energy is proportional to the change in temperature (as long as bonds are not completely rearranged as in a phase transition.) Gathering these two terms together we have the change in internal energy for a substance that does not undergo a phase transition is

$$\Delta E_{\text{int}} = N \langle \Delta K.E. \rangle_{\text{particle}} + N \langle \Delta P.E. \rangle_{\text{particle}}$$

$$\Delta E_{\text{int}} = Mc\Delta T$$

where c is the specific heat of the material and is material dependent (for water : $c_w = 4186 \text{ J/kg}^\circ\text{C}$). The energy change is positive if the temperature rises and negative if it drops. When a substance undergoes a phase transition, the strength of the bonds between particles, thus the particles' potential energy, greatly changes. This term looks like

$$\Delta E_{\text{int}} = N \langle P.E_{\text{bond.break}} \rangle$$

$$\Delta E_{\text{int}} = MH_f$$

where H_f is called the latent heat of fusion. If the material solidifies, the energy is negative because the particles are reducing their energy – transferring it out of the material. Similarly, when a substance changes between liquid and vapor, the size of the change in internal energy is

$$\Delta E_{\text{int}} = MH_v$$

where H_v is the latent heat of vaporization. If the material condenses, the energy change is negative because it is leaving the material.

For a well-insulated calorimeter, almost no energy is transferred from the device, i.e., the calorimeter forms an *isolated system* in the conservation-of-energy sense of the word. So the total change in energy is 0.

PART ONE: Specific Heats of Metals

You will put a hot piece of metal into cooler water in a calorimeter cup and make measurements to determine the specific heat of the metal.

1. Plug the temperature probe into Channel 1 of the Lab Pro. Load "Temp Sensor" from Physics Experiments / Phys 220 – 221 / Calorimetry.
2. Find the mass of the piece of metal, then put it in the boiling water.

$$m_m = \underline{\hspace{2cm}}$$

Pre-Lab: What will the temperature of the metal be after it comes into equilibrium with the boiling water on the hot plate? Explain.

- Find the mass of the calorimeter cup. Fill it about two thirds full with a tap water and use the scale again to find the mass of the water. Some of the calorimeter cups are aluminum and some are copper that has been plated with chrome or tin. Ask your instructor which you have if you are uncertain. The specific heats of aluminum and copper are given on the last page of the lab.

$$m_c = \underline{\hspace{2cm}}$$

$$m_w = \underline{\hspace{2cm}}$$

Pre-Lab: How will the initial temperatures of the water and the calorimeter cup (before the metal is added) compare with each other? Explain.

Pre-Lab: How will the final temperatures of the calorimeter cup, water, and metal compare with each other? Explain.

- Put the thermometer into the calorimeter cup and record the temperature of the water just before adding the hot piece of metal.

$$T_{wo} = \underline{\hspace{2cm}}$$

- One person should lift up the lid of the calorimeter while another person should carefully and quickly remove the metal from the boiling water, dry it, and gently put it in the calorimeter. Quickly replace the lid. Hit "Collect."
- Gently* stir the water for several minutes until you are certain that the temperature has stabilized. Keep the end of the thermometer near the middle of the water. The temperature may start to drop if you wait long enough because the cup is not perfectly insulated, so you are interested in the *maximum* temperature that the water reaches. This can be found by selecting the appropriate section of the plot and hitting the "STAT" button at the top of the window. Note: you can be fooled if you touch the thermometer to the metal chunk instead of just the water. Record the equilibrium (final) temperature.

$$T_f = \underline{\hspace{2cm}}$$

Pre-Lab: Describe the temperature changes and phase changes (if any) that will for each substance in this experiment. Indicate whether heat flows in or out of the substance for each change.

Pre-Lab: What is an equation without numbers that expresses that energy is conserved in this experiment? Express it in terms of temperatures, masses, and specific heats. Assume that no heat flows into or out of the cup from the outside environment. Be sure to use different labels for variables that are different. Have the instructor check your answer before you continue.

Question: According to your measurements, what is the specific heat of the metal? Show all of your work.

Questions: What is the number on your piece of metal? From the list of specific heats on the board, what do you think the metal is?

PART TWO: Heat of Fusion

You will drop a piece of ice into warm water so that it all melts and make measurements to determine the heat of fusion. You will want the final temperature to be less than room temperature so that you know when the cooling effect of the ice has ended.

1. Put about 150 ml (0.150kg) of water between 40 and 45°C in the calorimeter cup (mixture of hot water and tap water if necessary). Find the mass of the water (don't forget about the mass of the cup).

$m_w =$ _____

- Put the thermometer into the calorimeter cup and record the temperature of the water just before adding a piece of ice.

$$T_{wo} = \underline{\hspace{2cm}}$$

- One person should lift up the lid of the calorimeter while another person dries off a piece of ice (**from a standard store bought bag, 4-6 ice chips**) and gently put it in the calorimeter so that no water is splashed out. Replace the lid quickly.
- Gently stir the water for several minutes until you are certain that the temperature has stabilized. Keep the end of the thermometer near the middle of the water. The temperature may start to rise if you wait long enough because the cup is not perfectly insulated, so you are interested in the minimum temperature that the water reaches. If all of the ice does not melt or the final temperature is greater than room temperature, start the experiment over! Record the equilibrium (final) temperature.

$$T_f = \underline{\hspace{2cm}}$$

- Before you pour out the water, use the balance to find the mass of the ice that was added.

$$m_i = \underline{\hspace{2cm}}$$

Pre-Lab: Describe the temperature changes and phase changes that will occur for each substance in this experiment. Indicate whether heat flows in or out of the substance for each change.

Pre-Lab: What is an equation without numbers that expresses that energy is conserved in this experiment? Assume that no heat flows into or out of the cup from the outside environment. Be sure to use different labels for variables that are different. Have the instructor check your answer before you continue.

Questions: According to your measurements, what is the heat of fusion for water? How does your answer compare to the expected value of $3.35 \times 10^5 \text{ J/kg}$?

PRE-LAB: It has been suggested that eating ice would prevent a person from gaining weight because energy would have to be used to melt and heat the ice. How much ice would you have to eat to “burn off” of the energy from a 100-Calorie candy bar? Don’t forget that one dietary Calorie is 1000 calories! (It may be useful to know that: $T_C = \frac{5}{9}(T_F - 32)$, and that $1 \text{ cal} = 4.186 \text{ J}$.) Consider phase and temperature changes.

PART THREE: Heat of Vaporization

You will drop a piece of aluminum into liquid nitrogen measure how much boils off in order to determine its heat of fusion. The boiling temperature of nitrogen is -196°C .

1. Find the mass of the thermos.

$$m_t = \underline{\hspace{2cm}}$$

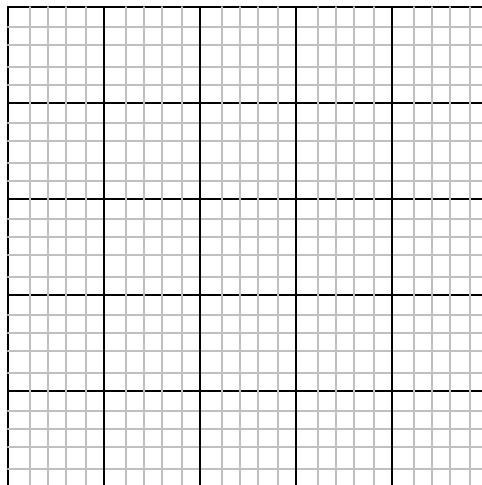
2. Find the mass of the aluminum cylinder.

$$m_a = \underline{\hspace{2cm}}$$

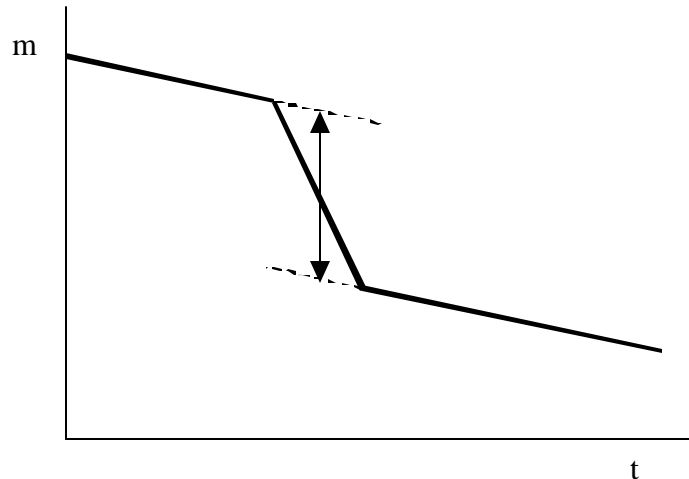
3. Add liquid nitrogen to the thermos and place it on the electronic balance. Be sure to leave the sip-spout open so the nitrogen vapor can escape (and not cause the thermos to explode). Measure the total mass every minute for five minutes. After the fifth measurement, put the cylinder into the thermos and replace the lid.. Continue to measure the total mass every minute for ten more minutes.

Time (mins.)	Total Mass (g)	Liquid N₂ Mass (g)

4. Subtract the mass of everything else on the balance to find the mass of liquid nitrogen at each time and plot that below.



5. The graph should look similar to the one below with the solid line. The more gradual decreases in liquid nitrogen at the beginning and end are due to the imperfect insulation of the thermos. To determine how much liquid nitrogen boiled because of the addition of the aluminum, extend those parts of your graph with dashed lines as shown. Find the mass that boiled because of the addition of the aluminum by measuring the difference between the dashed lines in the middle of the section where the mass is changing rapidly, as indicated by the arrow.



$$m_{\text{boil}} = \underline{\hspace{2cm}}$$

Pre-Lab: What are the initial and final temperatures of the aluminum? Explain. (Hint: There is still some liquid nitrogen left at the end of the experiment.)

Pre-Lab: Assume no heat flows into the thermos, since you have corrected for this. Describe the temperature changes and phase changes that occurred for each substance in this experiment. Indicate whether heat flows in or out of the substance for each change.

Pre-Lab: What is an equation without numbers that expresses that energy is conserved in this experiment? Assume that no heat flows into or out of the cup from the outside environment. Be sure to use different labels for variables that are different. Have the instructor check your answer before you continue.

Questions: The specific heat of aluminum varies with temperature, but the average between the boiling temperature of nitrogen and room temperature is $699 \text{ J/kg}^\circ\text{C}$. According to your measurements, what is the heat of vaporization for liquid nitrogen? How does your answer compare to the expected value of $2.01 \times 10^5 \text{ J/kg}$?

Specific Heats (near room temperature)

Lead	128J/kg•°C
Brass	385 J/kg•°C
Copper	387 J/kg•°C
Iron	452 J/kg•°C
Steel	502 J/kg•°C
Aluminum	900 J/kg•°C

Pre-Lab # 9

Name: _____

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