General Physics I Lab (PHYS-2011)
Experiment THERM-1:
Specific Heat

Objective:

The purpose of this experiment is to determine the specific heat of a metal object and see how that can help identity the metal. A Temperature Sensor is used to measure the change in temperature of a known quantity of water when a metal object of known mass and known initial temperature is put into the water. The precision of the Temperature Sensor is a few hundredths of a degree. This procedure allows the determination of the specific heat to an accuracy of 1-2%. The uncertainty in the measurement will be estimated and the student will see how this impacts identification of the material.

WARNING!!! **You will be working with hot water in this lab. Take extreme precautions when using the equipment for this lab!**

Specific Heat Theory:

The specific heat c of a substance is the amount of thermal energy (heat) that a single gram of the substance must absorb in order to change its temperature by one degree Celsius (or Kelvin). The specific heat of water, for example, is $c_W = 4.186$ J/g°C. That is: 4.186 J of heat are needed to raise the temperature of 1g of water by 1°C. In general, we have:

$$Q \;=\; c\, m\, \Delta T \tag{1}$$

where Q is the thermal energy (heat) required to produce a temperature change ΔT in a material with a specific heat c and a mass m. If there is no loss into the environment, when we add a warm metal to cold water, the heat gained by the water, Q_W, must equal the heat lost by the metal, $-Q_M$, and we have:

$$Q_W \;=\; -Q_M \;=\; c_W\, m_W\, \Delta T_W \;=\; -\, c_M\, m_M\, \Delta T_M \tag{2}$$

Solving for the specific heat of the metal gives:

$$c_M \;=\; c_W\, (m_W/m_M)\, (-\Delta T_W/\Delta T_M) \tag{3}$$

Since the specific heat of water is much higher than that of the metals we use, the water temperature change will be small and limits the precision of the experiment. To maximize ΔT_W , we need to keep the water mass as small as possible and the initial temperature difference between the warm metal and cold water as high as possible. However, for safety reasons we will limit the hot water temperature in the steam generator. We also note there are complications in energy loss as described in the example below for a similar experiment mixing warm water with a cold metal mass.

Corrections to temperature measurement should be made because the calorimeter is not totally isolated from the environment. This can be seen in Figure 1 below. The calorimeter cap is off the cup until the metal sample is added at about 301 s. The calorimeter is then capped and the system has come to equilibrium by 340 s. During this 40 s interval, the water in the calorimeter will have cooled by several tenths of a degree due to loss to the room. We correct for this by fitting a straight line to the data from 340 s to 400 s. We use this line to extrapolate back to 301 s to find the equilibrium temperature that would have occurred if equilibrium had occurred instantaneously, before any lose to the room could occur.

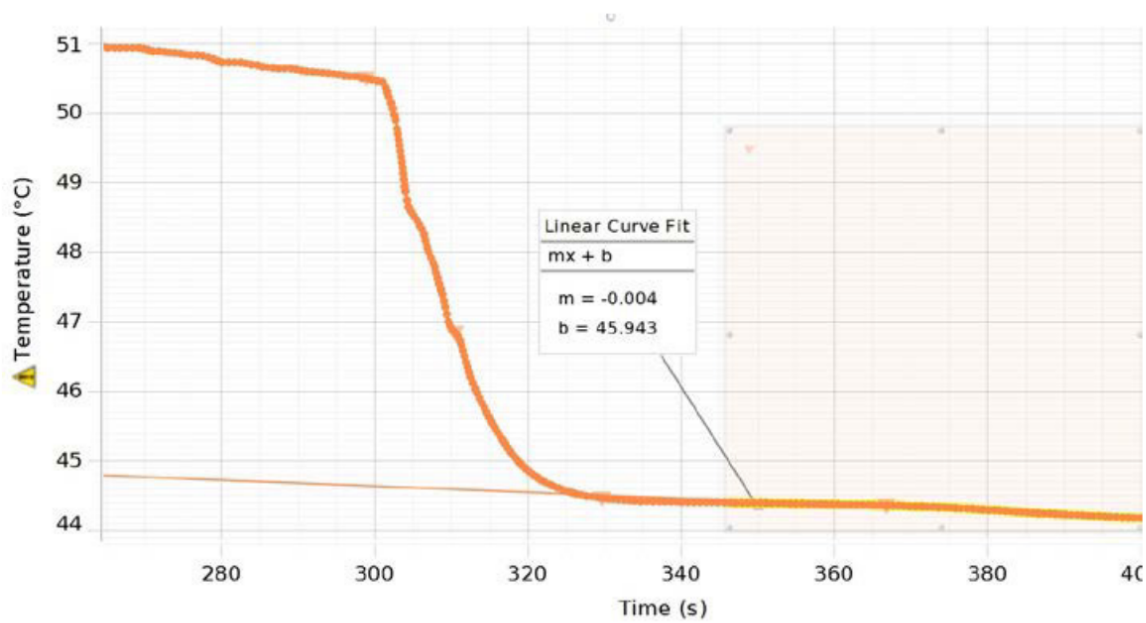


Figure 1: Cooling Curve for Aluminum added to hot water.

Experiment Procedure

(a) Steam Generator Heat Control (b) Masses in Steam Generator

Figure 2: Steam Generator

1. ***IMPORTANT!*** *FOLLOW INSTRUCTIONS FROM LAB INSTRUCTOR HERE!* If water in the Steam Generator is at room temperature, turn on the generator and set the control to **MAXIMUM FOR 5 MINUTES ONLY!** *SET THE CONTROL BACK TO MIDWAY BETWEEN 3 AND 4 TO STABILIZE WATER TEMPERATURE AROUND 60°C FOR THE EXPERIMENT.* If water is already warm from previous lab, Leave Control Set at Midway between 3 and 4 (Figure 2).

2. Mass each of the metal samples provided - stamped with a letter (A, B, C, D, and E). Note support the paper clip so it is NOT included! Record the masses, $\underline{m_M}$ in Table 3.

3. The metal samples have a 15 cm piece of string with a paper clip attached. Submerge the metal samples in the Steam Generator with the paper clip hanging over the side to keep the string out of the water. (See figure 2(b) above).

   NOTE: The water temperature in the steam generator needs to be fairly stable and the masses submerged in the water for at least 5 minutes to reach an equilibrium temperature. You can monitor the water temperature with the temperature probe as described below.

4. Set Temperature Probe Sensor Rate to 10 Hz. Open a "Graph" and choose "Temperature °C" for the Y-axis measurement. Open a "Digits Display" to view the current temperature value. Click on "Record" at the bottom of the screen to begin temperature measurement. It is recommended that you monitor the warm water temperature to establish if it has reached an equilibrium.

5. Mass the Styrofoam Calorimetry Cup (without cap). Record this mass, $\underline{m_C}$ in Table 3.
6. While the water in the Steam Generator is stabilizing, fill the plastic beaker about 2/3 full of ice cubes and add just enough cold water to cover the ice, creating an "ice bath". Some ice should be floating in the water at all times as you want to maintain the water at a temperature just a degree or two above 0° Celsius.

Figure 3: Specific Heat Calorimeter Setup.

7. **Once the warm water temperature is sufficiently stable, STOP the Recording. You may want to Delete that Data Run to avoid confusion with the Graph you will create for the temperature changes to be measured below. With Both the Warm Water and Ice Water now Stable, follow the steps below.**
8. Place the metal probe of the Temperature Sensor so it is in good contact with the metal sample you are going to use while the sample is still in the Steam Generator. The best way to do this is to gently push the tip of the probe into the hole (where the string attaches) in the metal.
9. Click the Record button. Keep the metal probe in contact with the metal for at least 60 s until the reading remains steady (see Figure 1 on page 2). DO NOT STOP THE RECORDING!
10. Transfer water from the ice bath to the Calorimetry Cup. If you are doing sample B, use about 125 ml of water (use the graduated markings on the side of the plastic beaker to estimate this). For all other cases use about 100 ml of water. You need enough water to cover the sample, but will get better results if you use as little water as possible.
11. Put the metal Temperature Probe through the outside hole in the cap. Insert the metal probe into the water, but leave the cap rotated around so it does not cover the Calorimetry Cup (see Figure 3 above). It is probably best to angle the probe across the cup so as much of the probe as possible is under water.

12. Watch the Temperature on the graph. Once it has reached equilibrium (a few °C) allow it to continue for at least 60 s. DO NOT STOP THE RECORDING!

13. This part must be done quickly! Using the string, remove the metal sample from the Steam Generator. DO NOT TOUCH THE METAL WITH YOUR HANDS! Using a paper towel quickly dry off the metal and then use the string to lower it into the Calorimetry Cup, tipping the metal over on its side so the water completely covers it. Cap the Calorimetry Cup immediately.

14. Gently swirl the water around in the Calorimetry Cup until it reaches equilibrium. Allow the reading to continue for at least 120 s.

15. Click on STOP.

16. Click the Data Summary button at the left of the page. Double Click on the Run number and type Sample A (or B or whatever the sample letter was) to label the run. Click Data Summary again to close it.

17. Remove the cap and metal Temperature Probe from the Calorimetry Cup trying to shake all the water on the probe back into the cup. Find the total mass of the cup, $\underline{m_T}$ (without cap) plus metal sample plus water and enter the value in Table 3. Calculate the mass of the cold water, $\underline{m_W}$ using Equation 4 below. Record your results in the column corresponding to the letter on your sample.

$$m_W = m_T - m_M - m_C \tag{4}$$

18. Remove the mass and empty and dry the calorimeter cup. Then repeat steps 8-18 for each sample you are testing.

Data Analysis

1. Open the Graph tab. (same Temperature vs. time graph as on Procedure tab).

2. Click the Data Display Icon (). Select one of your runs (Sample B for example).

3. Click on the Data Selection icon () on the top toolbar. Drag the handles on the Selection Box that appears to highlight the data where the metal Temperature Probe was in contact with the metal sample in the ice water.

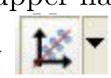
4. Click on the Re-size Tool () in the upper left. This will increase the scale so this section of the data fills the screen. You will probably find that the temperature is drifting somewhat when viewed at this scale. This is not critical since are results are not highly

sensitive to this value and knowing it within a tenth of a degree or so is adequate. Read the temperature of the metal at the time you removed the probe or estimate what it probably would have been by the time you removed the metal from the ice water. Enter this value in the Metal Temp, $\underline{T_M}$ row in Table 3. Make sure you get it in the column corresponding to the letter on your sample.

5. Click anywhere in the Selection box to highlight it, then click the Remove Active Element icon () to delete the Selection Box. Click the Re-size Tool. You should now see the entire graph.

6. Click on the Data Selection icon. Drag the Selection box handles to select the 10 s before you added the metal and including 10 seconds after you added the metal. Click the Resize tool. Click the Remove Active Element icon to delete the Selection box. Now repeat the process. Click on the Data Selection icon. Drag the Selection box handles to select the 1 s before you added the metal and including 1 seconds after you added the metal. Click the Re-size tool. Click the Remove Active Element icon to delete the Selection box. You should now be able to read the time and temperature when the metal went in the water. Record the temperature to the nearest 1/100 of a degree and record in the Water Temp, $\underline{T_W}$ row and the column for your sample. Note the time to the nearest 0.1 second at the point of T_W.

7. Click the Re-size tool to return to the full screen view. Click on the Data Selection icon. Drag the Selection box handles to select the data from just before you added the metal to the end of the data. Click Re-scale. Click the Remove Active Element icon to delete the Selection box.

8. Click the Data Selection icon. Drag the handles on the box to select the data from where the system has reached equilibrium to the end of the data. Make sure the upper handles are just above the line. Click on the black triangle in the Curve Fit tool () and select Linear. Click outside the black box to get rid of it.

9. Read the temperature for the straight line at the time you noted in Step 6 above when the metal was added. This is the temperature the system would have had if equilibrium had occurred very rapidly before any heat was lost into the room. It is helpful to expand the vertical scale. Move the hand cursor over one of the numbers at the bottom of the vertical scale. A pair of parallel plates should appear. Click and drag upward until the range of the vertical scale is about 1 degree. You should now be able to read the temperature when the metal was added to within a few 1/100 of a degree. Record this value in the Equil. Temp row, $\underline{T_{EQ}}$ and the column for your sample in Table 3.

10. Uncertainty: the uncertainty here is almost entirely due to the uncertainty in the Equilibrium Temperature. When you examine the expanded graph from part 8 above, the temperature after equilibrium probably does not look very straight when viewed at this scale. Adjust the handles on the Selection box to select different portions of the curve after equilibrium and see how this would affect the value you measured in step

11. From this, estimate the uncertainty in your measurement of the Equilibrium Temperature. For example, you might take the highest value you find minus the lowest value and divide by two to get an estimate of the uncertainty. You might also replace the value you measured for the Equilibrium Temperature in step 8 with the value at the center of the range in step 9. Record your estimate of the uncertainty, $\underline{\sigma_T}$ in Table 3.

12. Calculate the temperature change of the water, -ΔT_W using Equation 6 below. Record this value in the $\underline{-\Delta T_W}$ row and the column for your sample in Table 3.

$$-\Delta T_W = T_W - T_{EQ} \tag{5}$$

13. Calculate the change in temperature of the metal sample, ΔT_M using Equation 5 below. Record this value in the $\underline{\Delta T_M}$ row and the column for your sample in Table 3.

$$\Delta T_M = T_{EQ} - T_M \tag{6}$$

14. Calculate the specific heat $\underline{c_M}$ of the metal using Equation 3 from the Theory section. Record this value in Table 2 in the row corresponding to your sample.

15. Since -ΔT_W is small, the uncertainty in the specific heat is almost entirely due to this measurement and the % uncertainty in the specific heat equals the % uncertainty in -ΔT_W. Similarly, the uncertainty in $-\Delta T_W$ is almost totally due to the uncertainty in Equil. Temp., thus the Temperature Uncertainty. This means:

$$\frac{\sigma_{c_M}}{c_M} = \frac{\sigma_T}{-\Delta T_W}$$

    Or solving for the uncertainty in the specific heat, Uncert c, we have:

$$\sigma_{c_M} = c_M \frac{\sigma_T}{-\Delta T_W} \tag{7}$$

16. Calculate the uncertainty in the specific heat, $\underline{\sigma_{c_M}}$ using Equation 7 above. Record this value in the σ_{c_M} column in Table 2 and row corresponding to your sample.

17. Click the Curve Fit black triangle and turn off Linear. Click anywhere in the Selection box to highlight it, then Click the Delete Active Element icon to remove the Selection box. Click the Re-size tool to return to the full page view.

18. Repeat steps 1-14 for each of your samples.

Lab Report: Specific Heat

Name: ______________________ Lab Section: ________

Conclusions

Table 1: Specific Heat of Common Metals

Metal	**Specific Heat (J/g°C)**	**Metal**	**Specific Heat (J/g°C)**
Aluminum	0.901	Silver	0.234
Steel	0.450	Gold	0.129
Zinc	0.390	Lead	0.128
Copper	0.386	Brass	0.350

1. Table 1. above shows the specific heat of some common metals. Using only your results for the specific heat, try to identify each of your metal samples. Enter your identification in the Type of Metal column in Table 2. If there is more than one possibility, enter them both. If nothing fits enter "none".

2. Why is it important to estimate an uncertainty when you make a measurement of specific heat?

3. Why is it important to make the change in the water temperature as large as possible? Hint: Consider Equation 5 from Analysis. Why are other measurements not as important?

4. What does the specific heat tell you about how easy it is to change the temperature of a material?

5. Why is it important that the specific heat of water is so high? Hint: What is the Earth's surface mostly composed of?

6. If all of your values for the specific heat are too low, how would you explain it?

Data

Table 2: Specific Heat of Common Metals

Identifier	**Specific Heat,** c_M **(J/g°C)**	**Uncert.** c_M**,** σ_{c_M} **(J/g°C)**	**Type of Metal**
A			
B			
C			
D			
E			

Table 3: Specific Heat Data

Identifier	**A**	**B**	**C**	**D**	**E**
Metal Mass, m_M **(g)**					
Cup Mass, m_C **(g)**					
Total Mass, m_T **(g)**					
Water Mass, m_W **(g)**					
Metal Temp, T_M **(°C)**					
Water Temp, T_W **(°C)**					
Equil. Temp, T_{EQ} **(°C)**					
Temp Uncert, σ_T **(°C)**					
-ΔT_W **(°C)**					
ΔT_M **(°C)**					

Table 4: Latent Heat of Fusion

m_{CW}	m_W	m_{CWI}	m_{ice}	T_i	T_f	L_f	$\%_{Error}$

Specific Heat of Water, $(c_W) = 1.00$ cal/(g°C)
Accepted Value for the Latent Heat of Fusion of ice, $L_{f_{ice}} = 80.0$ cal/g

Latent Heat of Fusion Experiment - optional

When a solid reaches its melting point, additional heat will melt the solid without a temperature change. The temperature will remain constant at the melting point until ALL of the solid has melted. The amount of heat needed to melt the solid depends on the mass of the solid and bonding property of the material. That is:

$$Q = ML_f \tag{8}$$

where Q is the amount of heat absorbed by the solid, M is the mass of the solid and L_f is the latent heat of fusion measured in cal/g. Ice will be added to a calorimeter containing warm water. The heat energy lost by the water and calorimeter does two things:

1. Melts the ice.
2. Warms the water formed by the melting ice from zero to the final temperature.

Heat lost by warm water = heat needed to melt ice + heat needed to warm water that was once ice

$$m_W c_W (T_i - T_f) = m_{ice} L_f + m_{ice} c_W (T_f - 0) \tag{9}$$

where m_W is the mass of the warm water initially in calorimeter, c_W is the specific heat of water, m_{ice} is the mass of the ice and water from melting, L_f is the heat of fusion of ice, T_i is the initial water temperature and T_f is the final water temperature.

Experiment Procedure

1. Add ∼150 grams of warm water (∼25°) to the calorimeter cup.
2. Measure the mass of the calorimeter cup and water, $\underline{m_{CW}}$. Record the value in Table 4.
3. Calculate the mass of the added water, $\underline{m_W}$ = m_{CW} - m_C. Record the value in Table 4.
4. Measure and record the initial temperature of the water, $\underline{T_i}$ in Table 4. Use procedure steps 11-12 as for c_M data.
5. Using a paper towel, transfer the ice cubes to the cup. Ice should be at 0°C, *i.e.*, the point of melting.
6. When all the ice is melted - as in Step 14 but monitor ice melting, measure and record the final equilibrium temperature, $\underline{T_f}$.
7. Measure the mass of the cup, water and ice, $\underline{m_{CWI}}$ and record this value in Table 4. Again steps 11-12, the STOP!
8. Calculate the mass of the ice. Record in Table 4. $\underline{m_{ice}}$ = m_{CWI} - m_{CW}.
9. Calculate the Latent Heat of Fusion, $\underline{L_f}$ using Equation 9. Compare it with the accepted value of $L_{f_{ice}}$ using Equation 10 below.

$$\%_{Error} = \left(\frac{L_f - L_{f_{ice}}}{L_{f_{ice}}} \right) \times 100 \tag{10}$$