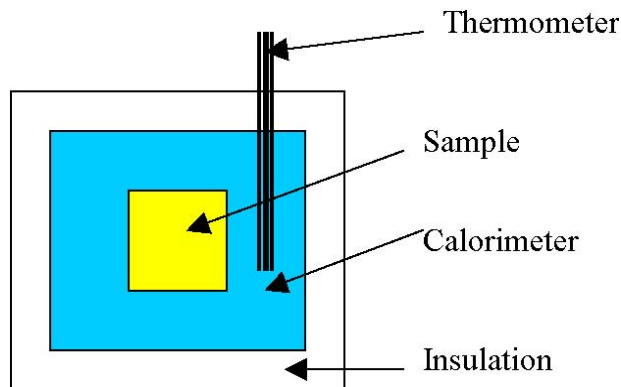


AREN 2110: Thermodynamics

ITLL LAB #1: MEASUREMENT OF SPECIFIC HEAT IN A CALORIMETER

Calorimetry is a basic technique for measuring thermodynamic quantities, especially those involving heat transfer: specific heats of various materials, heat of fusion, heat of vaporization and heat of chemical reactions. It is one of the oldest experimental methods in thermodynamics. Benjamin Thompson used a calorimeter in 1798 to show that work could be converted to heat, and Joule conducted elegant experiments in the 1840s to measure the mechanical equivalent of heat. People who count "calories" can look up the energy value of various foods in their diet, such as the fact that three Chips Ahoy cookies (~ 32 grams) supply 169 Calories (kcal) of energy, because someone, in this case Nabisco, Inc., conducted calorimetry experiments. Another application of increasing importance is that specific heat determines the ability of materials to absorb heat without changing temperature – with high specific heat, a material can absorb a lot of heat and not change temperature much – a good example of this kind of material is water with a specific heat of 4.18 kJ/kg-K, so sometimes a large water body, like the ocean, is called a good heat reservoir, which can absorb or release high amounts of heat and maintain a constant temperature. Good building insulating material would have similar specific heat characteristics.

INTRODUCTION: A CALORIMETER IS AN ADIABATIC SYSTEM:



When a sample of different temperature than the calorimeter vessel is put in the calorimeter, heat transfer between the sample and calorimeter takes place. Consider the combined sample and calorimeter to be the system. According to the first law for a stationary system:

$$Q - W = \Delta U \quad (1)$$

Assuming that the system is adiabatic, $Q = 0$. For an incompressible sample, it can also be assumed that there is no boundary or other kind of work, so $W = 0$. Therefore

$$\Delta U_{\text{system}} = 0 \quad (2)$$

but

$$\Delta U_{\text{system}} = \Delta U_{\text{calorimeter}} + \Delta U_{\text{sample}} \quad (3)$$

For an incompressible substance, assuming that the specific heat does not change much over the temperature interval in the experiment:

$$U \approx \Delta C_{\text{av}}(T_2 - T_1) \quad (4)$$

If both the sample (sam) and calorimeter (cal) are incompressible:

$$\Delta U_{\text{cal}} = m_{\text{cal}} C_{\text{cal,av}}(T_2 - T_0)_{\text{cal}} \quad (5)$$

and

$$\Delta U_{\text{sam}} = m_{\text{sam}} C_{\text{sam,av}}(T_2 - T_1)_{\text{sam}} \quad (6)$$

Then in the case where the sample is hotter than the calorimeter initially, after thermal equilibrium between the sample and calorimeter is reached:

Net heat gained by calorimeter = Net heat lost by sample

Or:

$$C_{\text{cal}} m_{\text{cal}}(T_2 - T_0) = C_{\text{sam}} m_{\text{sam}}(T_1 - T_2) \quad (7)$$

where: C_{cal} = specific heat of calorimeter ($\text{cal}/(\text{g} \cdot ^\circ\text{C})$); C_{sam} = specific heat of sample ($\text{cal}/(\text{g} \cdot ^\circ\text{C})$); T_0 = initial temperature of calorimeter ($^\circ\text{C}$); T_1 = initial temperature of sample ($^\circ\text{C}$); T_2 = initial temperature of calorimeter and sample ($^\circ\text{C}$) after thermal equilibrium is reached; m_{cal} = mass calorimeter (gram); m_{sam} = mass sample (gram). For determining specific heat of a sample, if the specific heat of the calorimeter, initial and final temperature and mass of both the sample and the calorimeter are known:

$$C_{\text{sam}} = \frac{m_{\text{cal}} C_{\text{cal}}(T_2 - T_0)}{m_{\text{sam}}(T_1 - T_2)} \left(\frac{\text{cal}}{\text{g} \cdot ^\circ\text{C}} \right) \quad (8)$$

Here are the specific heats of several common materials at room temperature (20°C):

Material	C or C_p [J/(kg °C)]	C_v [J/(kg °C)]
Helium	5200	3715
Water (H ₂ O)	4180	-
Air	1000	714
Aluminum Alloy 2024	875	-
Window Glass	750	-
Steel	435	-
Copper	385	-
Lead	130	-

LAB EXPERIMENT OBJECTIVE

In this experiment you will determine the specific heat for two materials, copper and aluminum, using a dry calorimeter.

MATERIALS AND METHODS

Materials:

1. Calorimeter, copper and aluminum sample blocks. The calorimeter you have is made of aluminum alloy 4024.
2. Thermometer with digital temperature readout
3. Balance (g/mg precision)
4. Boiling water bath with thermometers to measure T_1 values
5. Stopwatch
6. Tongs

Methods

For both samples follow the procedure below:

1. Weigh and record the mass of the calorimeter (the aluminum block and cap only, NOT the insulation or plastic cap.)
2. Weigh and record the mass of the aluminum and copper samples.
3. Immerse both samples in the boiling water for at least 10 minutes so it can come to equilibrium with the temperature of the boiling water.
4. Record the initial temperature of the calorimeter with the thermometer. Take several readings over a few minutes to make sure the initial calorimeter temperature is stable
5. Remove the aluminum sample from the boiling water. As quickly as possible, place the sample in the calorimeter, put on the aluminum cover and the yellow plug. Record the temperature of the boiling water and assume that is the initial sample temperature. (Might be the cause of experimental errors if you do not leave the sample in the water long enough or move it to the calorimeter too slowly.)

6. Wait until the calorimeter temperature stops changing and record the final temperature of the system. Be careful to catch the highest temperature reading, after a while the calorimeter temperature may begin to drop if heat is lost.
7. Repeat for two more runs for a total of three (3) runs per sample. The calorimeter will be at a higher initial temperature at the beginning of the next run.

Calculate specific heat of the copper and aluminum samples, C_{sam} , using equation 8.

RESULTS AND DISCUSSION

1. Show calculations for determination of specific heat values for copper and aluminum. Your final value of C for each sample should be an average of your data, unless you state a reason of eliminating a data point. In addition to the average, show the standard deviation (“stdev” function in excel) for your sample runs as well as the average.
2. A large standard deviation is an indication that your results were not consistent over multiple runs? If your standard deviation was greater than 15% of the average value for specific heat for either or both samples, explain why the high variability of the data.
3. What are the sources of error associated with temperature measurements and with estimates of T_0 and T_2 ? Be specific, give examples from your lab session.
4. What are the sources of heat loss between the calorimeter and its surroundings (room)? How do they affect the estimates of specific heat for each material?
5. Compare your estimates of specific heats with values from those in the Appendix of your textbook or another source. To compare quantitatively, calculate a an the term:

$$\text{Difference from published specific heat} = |(C_{\text{experimental}} - C_{\text{reference}}) / C_{\text{reference}}|$$

6. Ideally, the difference should be 25% or less. What factors do you think account for difference between your estimates and those in the reference tables?
7. Describe one other use for a calorimeter besides determination of specific heat.

YOUR LAB REPORT (1 PER GROUP) SHOULD FOLLOW THE FORMAT:

Abstract: This should be a brief (150-200 words) summary of the experiment and your findings.

Problem Statement (short, 1 - 3 paragraphs). What are you trying to find out? Why is it important?

Background/Approach/Hypothesis(es). In calorimetry, it is often considered good practice to have the calorimeter mass significantly greater than the sample mass. Was that the case with your calorimeter? Why is that beneficial? Your calorimeter mass is aluminum: what are important characteristics of calorimeter material? What were the independent variables in your experiment? What were the dependent variables?

Methods and Materials: You can reference this handout for Methods and Materials. Describe any departures from the manual procedure that happened in your lab session, including why they were necessary. If you refer to the handout, put the it in the appendix. Describe any statistical methods you used (e.g., averaging data).

Presentation of Results: results can be presented in graphs, tables or numbers along with written observations. Clearly label each equation, figure and table with a number and include a descriptive caption for all figures and a descriptive title for all figures and tables.

Graphs. Do these with a spreadsheet or other graphing program. Be sure to label axes, give units and provide a caption such as: "Comparison of specific heat of copper cylinder with reference values."

Tables. DO NOT put detailed spreadsheets used for making calculations in the report body. Tables should be summaries of data highlighting results. Spreadsheet calculations should be in an appendix. Label the table columns and rows clearly and use units.

Text. Don't just present numerical and/or graphical results. You should have text pointing out significant features of graphs and tables. You should write any observations that relate to numerical results. Text should be word-processed.

Calculations. For repetitive calculations, you only need to show one sample calculation in the text. Be sure to define all variables and show units. The replicate calculations should be in the appendix. Be sure to use an appropriate number of significant digits. Probably the precision of your equipment will allow no more than 3 significant digits.

Discussion. Compare your results, between duplicate runs and with the literature (textbook) values for specific heats for copper and aluminum. Pay special attention to error analysis. Sources of errors might be random such as instrument noise or variation, or experimenter error (such as, "I dropped the sample on the floor and it might have gotten dirty.") Comment on the variability between duplicate measurements. More important are the systematic errors that might invalidate assumptions such as an adiabatic process or temperature equilibrium. Discuss what effect these errors would have had on your estimates of specific heat. Specific heat is a function of temperature, depending on the temperature changes during the process. Do you think that the temperature dependency of specific heat affected your results?

Conclusions (short "bullets"). These should just state the results and your conclusions about the experiment briefly and clearly.

Appendix containing your actual lab data, lab handout, calculations, spreadsheets, etc.

Data Sheet

$$m_{cal} = \underline{\hspace{2cm}} \text{ (g)}$$

$$m_{Al} = \underline{\hspace{2cm}} \text{ (g)}$$

$$m_{Cu} = \underline{\hspace{2cm}} \text{ (g)}$$

COPPER	Run 1	Run 2	Run 3
Initial calorimeter temperature, T_0 ($^{\circ}\text{C}$)			
Initial sample temperature, T_1 ($^{\circ}\text{C}$)			
Final equilibrium calorimeter temperature T_2 ($^{\circ}\text{C}$)			

ALUMINUM	Run 1	Run 2	Run 3
Initial calorimeter temperature, T_0 ($^{\circ}\text{C}$)			
Initial sample temperature, T_1 ($^{\circ}\text{C}$)			
Final equilibrium calorimeter temperature T_2 ($^{\circ}\text{C}$)			