T3a: Temperature & Specific Heat of Matter

Introduction:

Every material, from steel to iron to water to mercury, has a specific heat, a constant which represents the amount of energy required to increase the temperature of a substance. Now, contrary to the first thought that may occur, the specific heat of water is not 100° Celsius. 100° Celsius does represent the boiling temperature of water, but it is important to note that temperature is not congruent with heat, and, although an increase in temperature is a by-product of an increase in heat, heat is measured differently than temperature, using units of the calorie (as is explained in the **Discussion** section on the next page).

In light of the fact that each and every material has its own specific heat, it becomes possible to determine the composition of an object simply by measuring the heat transference of that object within a closed environment. And that is exactly the purpose of this experiment. By measuring the heat gains and heat losses of three objects, two of which are known objects (the aluminum calorimeter cup and the water), it becomes possible, using the equations and table featured within the **Discussion** section, to determine the composition of an unknown object, simply by heating it and then cooling it.

Apparatus:

- Burner (or stove, heating unit)
- Boiler (Boiling Flask)
- Auxiliary Erlenmeyer Flask
- Double-walled Calorimeter
- Solid Samples &/or Liquid Sample
- Computer Temperature Probe

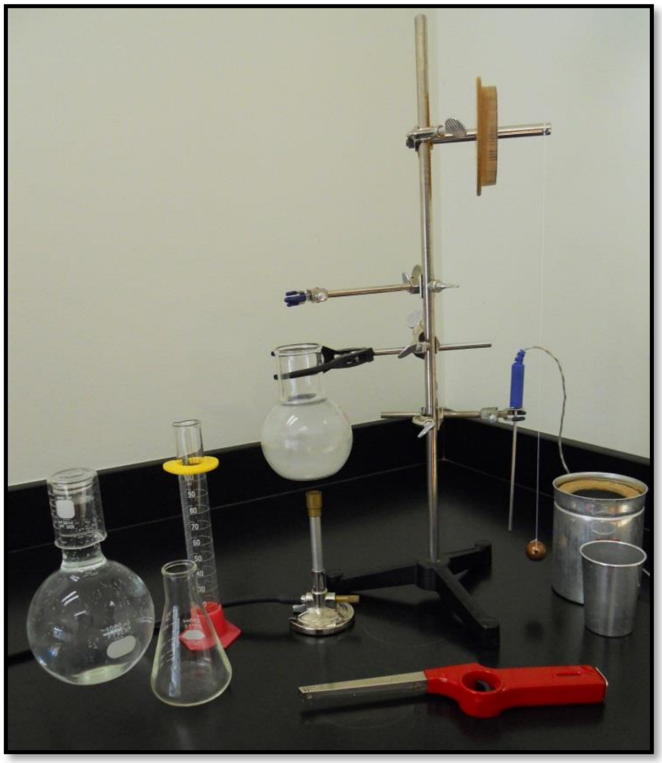

Figure 1

Please see the laboratory personnel for preliminary computer & apparatus instructions. DO NOT ATTEMPT TO START THIS LAB WITHOUT FIRST

CONSULTING A LAB INSTRUCTOR!

Discussion:

The basic unit for a quantity of heat in the metric system is the calorie. Today the calorie is defined to be exactly 4.1860 Joules; with Joules being the SI unit for heat. A calorie was originally defined to be the amount of heat needed to raise the temperature of 1 gram of water from 14.5^{o}C to 15.5^{o}C. Historically, heat was defined and measured by its ability to raise the temperature of water, because at that time heat was not thought of as a form of energy. However, since 1948 the basic unit for heat has been the joule, with no reference to the heating of water. Some areas of chemistry still use the calorie, and nutrition still uses the Calorie, where a Calorie is equal to 1 kilocalorie of heat. For this laboratory exercise only units of joules will be used.

The heat capacity of an object represents the proportionality constant between the heat added to an object and the change in temperature that ensues. Symbolically we have:

$$C = \frac{Q}{\Delta T}$$

where C is the heat capacity, Q is the heat added, and ΔT is the change in temperature.

The specific heat capacity references heat capacity per unit mass. For water this value was defined to be 1 calorie per gram per degree Centigrade. (Today it is defined to be 4190 joules per kilogram per degree Kelvin.) Other substances were then defined relative to water. The ratio of the heat needed for any substance compared to the heat needed for water is referred to as the specific heat capacity, ***c***. When expressed in equation form:

$$c = \frac{Q}{m\Delta T}$$

where ***c* is the specific heat capacity**, Q is the heat added, m is the mass of substance, and ΔT is the change in temperature.

The specific heat capacity is a constant relative to a material. Its measurement allows for the determination of the purity of a substance. Specific heat capacity's use in balancing equations of energy is crucial. It is so important that beginning students are asked to learn how to measure it, and, in the process of doing so, are expected to learn how to use it quantitatively. That is the purpose of this laboratory activity.

When several different objects at different temperatures are mixed together and allowed to come to thermal equilibrium, those that began with a temperature greater than the final equilibrium temperature lose heat. Those that began with a temperature less than the final equilibrium temperature gain heat. The combination of materials, in a closed environment, exchange heat until the entire group is in thermal equilibrium.

In equation form this heat gain vs heat loss, can be written as:

$$\Sigma \text{ Heat Gains} + \Sigma \text{ Heat Losses} = 0 \quad \textit{or} \quad \sum_{\text{gains}}(mc\Delta T) + \sum_{\text{losses}}(mc\Delta T) = 0$$

Discussion (Cont.):

Since each mass has its own specific heat, each mass must be identified by a separate $(m\ c\ \Delta T)$ term in the above equation. If there were 6 masses involved in the experiment, there would be 6 $(m\ c\ \Delta T)$ terms in the equation.

$$m_1 c_1 \Delta T_1 + m_2 c_2 \Delta T_2 + m_3 c_3 \Delta T_3 + \cdots + m_n c_n \Delta T_n = 0$$

Note that this equation assumes no change of state occurs to any of the masses involved. This is the fundamental heat energy equation that is used to determine the specific heats of the unknowns for this laboratory activity.

Some generally accepted standard values of specific heats are: (units of $\frac{\text{J}}{\text{g}^\circ\text{C}}$)

Lead	0.128		Zinc	0.389
Copper	0.387		Aluminum	0.900
Steel	0.452		Glass	0.837
Water	4.186		Ethyl Alcohol	2.430

Procedure:

1. Watch the videos.
2. Determine and record the mass of the sample being used and the mass of the ***inner*** calorimeter cup.
3. Attach a string to the sample and to the horizontal bar holding the calorimeter lid. Adjust the string length so that the sample hangs in the inner calorimeter cup 1 cm from the bottom. The sample ***must not*** touch the bottom of the cup.
4. Set up the boiling flask. Put the attached sample inside carefully that it does not touch the bottom or sides of the flask. Practice how are you going to move the sample from the flask to the calorimeter in 2 seconds as shown in the video.
5. **Ask a lab instructor to check your set up before continuing.**
6. Fill the calorimeter cup with 100 ml of room temperature water and measure the mass again. **Then subtract the mass of the calorimeter cup by itself from the mass of the calorimeter cup and the water**, in order to obtain the mass of the water in the cup. Record both measurements (the calorimeter cup and the water together and the water by itself).
7. Place the inner calorimeter cup (with water) back into the calorimeter.
8. Fill the boiling flask with approximately 400 ml of water. Carefully light the gas burner and adjust it for a small flame. Place the burner under the boiling flask.
9. Using the string lower the sample into the boiler, but do not let it touch the bottom or sides. The sample should be fully submerged in the water.
10. Fill the auxiliary flask with cold water for cooling.
11. Once the sample has been **<u>BOILING</u>** in the water for 5 minutes (*the sample must actually be boiling, which will take longer than 5 minutes of heating time*) measure the temperature of the water, leaving the sample in the water. Take the temperature of the water by inserting the temperature probe into it, being careful not to touch the container or the sample. Start the computer monitoring of temperature after the probe is properly inserted. Allow 1 minute until a stable final maximum temperature can be observed. Once a stable final maximum temperature is observed, stop the computer monitoring.
12. Remove the probe from the boiling water and place it into the auxiliary flask of water for at least five minutes to cool. Do not stop boiling the sample.
13. Important Note: Do not delete any of the data runs collected by the computer during the experiment.
14. Next, place the temperature probe into the calorimeter cup containing water, making sure not to touch the container. The temperature probe should be reaching no more than ***1 mm*** beneath the water's surface. Start the computer monitoring of temperature. Allow the combination of (probe-water-container) to come to thermal equilibrium by observing a leveling off of the temperature as observed on the graph. Collect at least 2 minutes of data and then stop the computer monitoring.
15. Make sure the sample ***boils*** for at least 10 minutes. Then, acting quickly and carefully, remove the sample from the boiling water bath and place it into the calorimeter cup containing water. Place the lid on the calorimeter and insert the temperature probe through the hole in the lid. Start the computer monitoring of temperature. **Turn the gas burner off** as soon as the sample is moved to the calorimeter. Watch the computer graph of temperature over a period of 10 minutes. When the combination comes to thermal equilibrium a leveling off of the temperature will be observed on the monitor. After 10 minutes stop the computer monitoring.

Analysis:

Analyze the three separate plots on the graph to obtain the three different temperatures with their standard deviations. Analyze Plot 1, the initial boiling water with the sample, for 20 seconds of data with a standard deviation of less than 0.1. Analyze Plot 2, the initial calorimeter with water, for 30 seconds of data beginning after the first minute, again with a standard deviation of less than 0.1. For Plot 3, the final calorimeter with water and sample, analyze the data to find the final equilibrium. Beginning after 3 minutes, find the first interval of 100 seconds that has a standard deviation of less than 0.1.

When recording the data, be sure to include a reference time and also the standard deviation for each of the temperature values. For example, if a temperature is measured and found to be 95 degrees, with a standard deviation of ±0.06, over a time period of 35 seconds to 55 seconds, then it would be necessary to include all of this data in the table provided on the next page.

Calculate the specific heat of the sample. In order to do so, first set up a balanced Σ Heat Gains + Σ Heat Losses = 0 equation. Solve for the value of the unknown quantity and determine the accuracy of the experiment. Check with the lab instructor to determine if additional trials are necessary. Be sure to take the time to try and determine what might have contributed to the error in the experiment before proceeding with the second trial. This experiment might take multiple trials, especially if the instructions are not followed.

Experiment T3a: Temperature and Specific Heat

Student Name____

*Lab Partner Name*____

*Lab Partner Name*____

Physics Course____

Physics Professor______________________________________

Experiment Start Date__________________________________

Lab Assistant Name	*Date*	*Time In*	*Time Out*

Experiment Stamped Completed

Data Sheets: T3a: Temperature and Specific Heat

NAME: ____________________________ DATE: _________________

Specific Heat of Water: __________________________

Calorimeter Cup material: ________________________

Specific Heat of Calorimeter Cup: __________________

Trial 1

Mass of calorimeter with water (g): ___________

	Mass (g)	Beginning Temp. (^{o}C)	Standard Dev. and Time Ref.	Ending Temperature (^{o}C)	Standard Dev. and Time Ref.	Temperature Difference (^{o}C)
Sample			±		±	
			to		***to***	
Calorimeter			±		±	
			to		***to***	
Water			±		±	
			to		***to***	

Trial 2

Mass of calorimeter with water: ___________

	Mass (g)	Beginning Temp. (^{o}C)	Standard Dev. and Time Ref.	Ending Temperature (^{o}C)	Standard Dev. and Time Ref.	Temperature Difference (^{o}C)
Sample			±		±	
			to		***to***	
Calorimeter			±		±	
			to		***to***	
Water			±		±	
			to		***to***	

Specific Heat of Unknown Material (experimental): ____________

Unknown Material & Specific Heat: _________________________

Percent Error: _____________%