Matter and Motion Winter 2016

Lab 5: Calorimetry and Thermodynamics

Adapted from Dr. Dharshi Bopegedera, TESC

NOTE: This lab has three parts. Make sure to read through each part and notice the Pre-lab and Post-lab for Experiment I and Experiment II are listed separately.

Experiment I: Determination of the calorie content in nuts using bomb calorimetry

Bomb calorimetry (constant volume calorimetry) is often used to determine the calorie content in food products. In this experiment, we will use this technique to determine the calorie content of nuts. We did constant pressure calorimetry last quarter to determine heats of reaction. You may want to review Chapter 10.11 for general concepts of calorimetry.

Pre-Lab Assignment:

1. In this lab we will determine the energy content of food and compare it to the values given on the packaging. Do you think the energy content we measure in this lab is the same as the energy our bodies can extract from the food? Why or why not?
2. Draw a diagram of a bomb calorimeter. Why is it important to keep the volume constant when measuring energy via combustion in a calorimeter?

Procedure:

You will be given instructions on how to operate the bomb calorimeter.

1. Select a nut (use forceps only to handle it) and weigh it using the analytical balance.

2. Measure out about 10 cm of the wire provided for the bomb calorimeter. Record the exact length of the wire.

3. Place the nut in the bomb calorimeter as directed in lab.

4. Place 1.00 ml of distilled water into the bomb as directed in lab.

5. After closing up the bomb, charge it with 10 atm of oxygen gas.

6. Place 2000.0g of distilled water into the outer chamber of the bomb calorimeter as directed in lab.

7. Record the initial temperature of water as directed in lab. Continue recording the temperature for about 2 minutes.

8. Ignite the nut inside the calorimeter while continuing to record the temperature.

9. You will note that the temperature will increase and then begin to taper off. Continue recording the temperature for another 2 minutes. Save and print the temperature data (raw data as well as the temperature vs. time graph).

10. Disassemble the bomb calorimeter. Remove any leftover wire and measure the unburned length of the wire carefully. Record this in your lab notebook.

11. Read the nutrition label on the nut package carefully. Write down the calorie content of nuts as reported on the label. Write down the brand name on the package.

12. Collect data from students who did this experiment with other nuts. Be sure to read the nutrition label on the nut packages carefully. Write down the calorie content of nuts as reported on the label. Write down the brand name on the packages.

Post-Lab Assignment:

For your own data only:

1. Note that the bomb and the water in the calorimeter absorb heat. Calculate the heat absorbed by the water in the calorimeter (in Joules).

2. Calculate the heat absorbed by the bomb. In order to do so, you need the calorimeter constant and the temperature change. The value of the calorimeter constant will be given to you in lab.

   Note:
   calorimeter constant = (specific heat of the bomb) (mass of the bomb)
   heat absorbed by the bomb = (calorimeter constant) (ΔT in Kelvin)

3. The heat absorbed by the bomb and water came from the combustion of the nut and the combustion of the wire. Assuming that there is no heat loss to the environment, calculate the heat given off by the nut during its combustion (in calories).

4. Calculate the calories per gram of nut.

5. Calculate the kilocalories per gram of nut. Then express your answer in food calories.
   Note that a chemist's calorie is given the symbol cal, a kilocalorie is given the symbol kcal and a food calorie is given the symbol Cal. **Therefore 1000 cal = 1kcal = 1 Cal**

6. Compare the value you obtained above, with the calorie content reported on the nut package. You may have to do additional calculations in order to make a reasonable comparison. Calculate the percentage error.

$$\text{Percentage error} = \left[\frac{\text{experimental value - recorded value on the package}}{\text{recorded value on the package}}\right]100\%$$

7. Suggest reasons for the above error.

8. Now repeat the above steps for the other nuts collected by other students.

9. Compare the calorie content in all the nuts analyzed by your class.

<u>**Experiment II: Determination of the specific heat capacities of metals**</u>

Adopted from: Mary Laing & Michael Laing, Journal of Chemical Education, *83*, 1499, October 2006.

The specific heat capacity of a metal (*c*), is defined as the amount of energy required to raise the temperature of 1 gram of metal by 1°C. It is a characteristic physical property of a metal similar to its density and melting point. In this lab, we will set up an experiment to determine the specific heat capacity of metals. We will then compare them with the specific heat capacities calculated using Dulong-Petit Law.

<u>Pre-lab Assignment Experiment II:</u>

1. You are provided with the following data pertaining to metallic elements. Draw a graph of specific heat capacity (y axis) as a function of the atomic weight (x axis) using Microsoft Excel. If this is not a linear graph try other relationships until you get a linear graph (for example you can try specific heat capacity versus 1/atomic weight and other such combinations). Once you get a line graph, draw a line of best fit and use Excel to print the equation of the line and the R^2 value on your graph. Print all the graphs you generated and bring to lab.

Metal	**Atomic Weight (g/mol)**	**Specific heat capacity ($J\ g^{-1}K^{-1}$)**
Li	6.9	3.582
K	39.1	0.757
Mg	24.3	1.023
Ca	40.1	0.647
Al	27	0.897
Sc	45	0.568
Y	88.9	0.298
La	138.9	0.195
Ce**	140.1	0.192
Sm	150.3	0.197
Eu	152	0.182
Yb	173	0.155
Lu	175	0.154
Ti	47.9	0.523
Zr	91.2	0.278
Hf	178.5	0.144
V	50.9	0.489
Cr	52	0.449
Mo	95.9	0.251
Mn	54.9	0.479
Fe	55.8	0.449
Ru	101.1	0.238
Co	58.9	0.421
Rh	102.9	0.243
Ni	58.7	0.444
Pd	106.4	0.246
Pt	195.1	0.133
Cu	63.5	0.385
Ag	107.9	0.235
Au	197	0.129
Zn	65.4	0.388
Cd	112.4	0.232

Hg	200.6	0.14
Ga	69.7	0.371
In**	114.8	0.233
Sn	118.7	0.228
Pb	207.2	0.129
Sb	121.7	0.207
Bi	209	0.122
Th	232	0.113
U**	238	0.116

** The atomic weights of these three elements were corrected by Mendeleev in 1870 by the method of Dulong and Petit

2. Use the linear graph you obtained above to calculate the specific heat capacities of mercury and bismuth. Using the CRC Handbook, obtain values for the specific heat capacity of mercury and bismuth and determine percentage error. State your reference correctly.
3. What is Dulong and Petit's Law? Use a reference (a book is preferred over a web site) to find your answer and cite the reference correctly.

<u>Experiment 2 Procedure:</u>

4. Weigh a test tube to the nearest mg.
5. Place pellets of the metal into the test tube to a depth of about 30 mm, and reweigh the test tube to the nearest mg.
6. Heat the tube containing the metal pellets in a bath of boiling water, as described in lab for at least 15 mins.
7. Record the temperature of the boiling water accurately.
8. Using some ice chips, cool about 50 ml of water to about 10° below room temperature.
9. Accurately weigh approx 50 ml of this cold water into the nested polystyrene cup calorimeter. Record the temperature of the water accurately.
10. Pour the hot metal pellets into the cold water, while stirring gently with the thermometer. Note the highest temperature attained as accurately as possible.
11. Note the physical properties of your metal sample.
12. Repeat with one more metal if you have time.
13. Obtain data for at least two other metals from classmates before you leave the lab.

<u>Post-lab Assignment Experiment II</u>

1. For all the data (yours and others you borrowed) determine the specific heat capacity of the metals.
2. Using Dulong and Petit's Law determine the atomic weight of each of the metals.
3. Use the atomic weight as well as the physical properties of your metals to identify the metals in the sample.
4. Sodium is a metal that reacts violently with water. Describe how you would use the spreadsheet data from your pre-lab only to determine its specific heat capacity.
5. Describe how you would use your experience from this lab only to determine the specific heat capacity of sodium.

Experiment III: Tactile experiments with Thermodynamics

Adapted from Branan and Morgan, *J. Chem. Educ.*, **2010**, *87* (1), pp 69–72

While making observations for this part, keep this equation in mind:

$$\Delta G = \Delta H - T\,\Delta S$$

Where G is free energy, H is enthalpy, S is entropy and T is temperature in Kelvin. For a reaction to be spontaneous, ΔG must be negative.

****SAFETY****

Always wear eye protection. Rubber bands are not dangerous chemicals, but they can damage your eyes!

<u>Experiment 3 Procedure:</u>

You may start with the rubber bands (step 1) or the heat packs (step 3).

1. Hold a rubber band between two fingers and quickly stretch it and hold it stretched. Quickly apply the rubber band to your forehead, cheek, or moustache region. What do you observe?
2. From a stretched position, let the rubber band quickly contract and again hold it to your forehead or cheek. Describe your observations?
3. Initiate the heat pack reaction. Describe your observations. After you have a chance to record the relevant observations, return the heat pack to its original state as directed in lab. What do you observe?
4. Write an equation representing the rubber band process. Where does "heat" appear in the equation? Write heat into your equation where appropriate (product or reactant).
   a) In which direction is each process spontaneous?
   b) b) Are there any conditions under which the heat pack reaction would change its spontaneity? Use the equation for ΔG above to support why or why not.
5. For each system, consider the spontaneous process:
   a) What is the sign of ΔG?
   b) What is the sign of ΔH?
   c) What is the sign of ΔS?
6. Discuss: Will a rubber band stretch if you heat it? Why or why not?