Experiment #7

CALORIMETRY AND THE SPECIFIC HEAT OF METALS

PURPOSE:

To experimentally determine the specific heat of a metal.

INTRODUCTION

When a substance is heated, the motion of its individual particles increase, resulting in an increase in temperature. The more heat is added per gram of substance, the greater the temperature change. The relationship between the heat that is added, the mass of a substance, and the temperature change it undergoes, is known as **specific heat capacity**, or simply called **specific heat**. Mathematically

$$Q = cm\left(T_{final} - T_{initial}\right),$$

Or rearranged to calculate specific heat

$$c = \frac{Q}{m(T_{final} - T_{initial})}$$

Where

c is the specific heat of a substance measured in $\frac{\text{Joules}}{\text{g°C}}$

m is the mass of the substance measured in grams (g)

$\mathbf{T_{final}}$ is the final temperature of the substance measured in degrees Celsius (°C), and

$\mathbf{T_{initial}}$ is the initial temperature of the substance measured in degrees Celsius (°C).

We have then that **specific heat** of a substance is the amount of heat (Q) needed to raise the temperature of 1 g of a pure substance by 1 °C. The specific heats of different substances vary, and therefore this quantity may be useful to identify an unknown material. The measurement of heat changes is known as **calorimetry** and the device used to measure heat changes is known as a **calorimeter**.

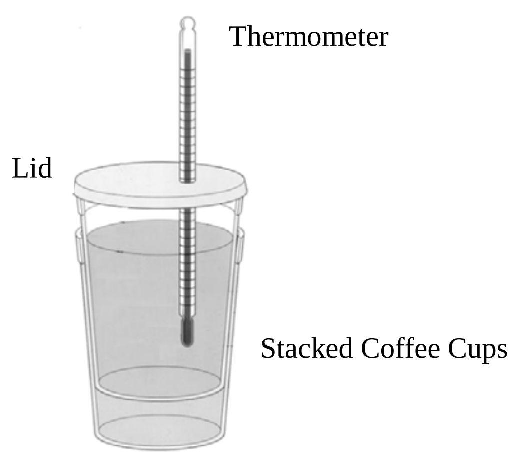

Figure 1. Simple Coffee Cup Calorimeter.

The calorimeter is insulated in order to minimize any loss of energy to the surroundings, so when a substance is placed inside of it, all of the energy can be accounted for. When hot and cold substances are mixed in the calorimeter, heat (energy) will flow from the hot substance to the cold substance. This is based on the **law of conservation of energy** which states that energy is neither created nor destroyed.

ENERGY RELEASED BY ONE SUBSTANCE = ENERGY GAINED BY ANOTHER SUBSTANCE

Since in our experiment we will determine the heat capacity of metal using an unknown metal and water we have then that

ENERGY RELEASED BY THE METAL = ENERGY GAINED BY THE WATER

Or as a general equation

$$\boldsymbol{Q_{metal} = Q_{water}}$$

In order to determine the specific heat of the unknown metal, we must take the measurement of five other quantities:

1. Mass of the metal sample (m_{metal}),
2. The temperature of the metal after it has been heated in boiling water ($T_{(metal)initial}$)
3. Mass of the water inside the calorimeter (m_{water}),
4. The temperature of the water in the calorimeter before adding the hot metal ($T_{(water)initial}$),
5. The highest temperature reached by the water after the metal has been added to the calorimeter which is also the final temperature of the metal ($T_{(water)final} = T_{(metal)final}$).

We will also need the specific heat of the substance that is gaining heat, in other words the water. The specific heat of water is 4.184 Joules/g°C. So we have that

$$\boldsymbol{Q_{metal} = Q_{water}}$$

Or

$$c_{metal} \times m_{metal} \times \left(T_{(metal)final} - T_{(metal)initial}\right) = c_{water} \times m_{water} \times \left(T_{(water)final} - T_{(water)initial}\right).$$

If we simplify

$$c_{metal} = \frac{c_{water} \times m_{water} \times \left(T_{(water)final} - T_{(water)initial}\right)}{m_{metal} \times \left(T_{(metal)final} - T_{(metal)initial}\right)}$$

PROCEDURE

1. Obtain 2 coffee cups and stack them as in Figure 1 to make a simple calorimeter.
2. Weigh your simple calorimeter using the centigram balance.
3. Add 100 mL of water to the calorimeter and reweigh it with the water inside.
4. Measure the temperature of the water inside the calorimeter. This is the initial temperature of the water ($T_{(water)initial}$).
5. Weigh an empty and dry 25 mm x 200 mm test tube.
6. Take an unknown metal from your instructor and gently add all of it into the 25 mm x 200 mm test tube and reweigh it.
7. Set up a water bath as in Figure 2 using a 600 mL beaker and place the test tube with your unknown sample. Make sure the water level is above the level of your metal inside your test tube. Heat the water until the water has boiled for at least 10 minutes. Make sure that the water level is always higher than the level inside the test tube.

Figure 2. Water bath set up with unknown sample.

8. After the water has boiled for at least 10 minutes, measure its temperature. This will be considered the initial temperature of the metal ($T_{(metal)initial}$).
9. Once you have measured the temperature of the boiling water, immediately remove the test tube using hot hands and carefully transfer your unknown metal sample into the calorimeter by gently sliding it out of the test tube. Use a glass rod to guide it, if necessary. Be careful not to allow any water from the test tube to enter the calorimeter or to make any water inside the calorimeter to splatter out and quickly complete your calorimeter set up as in Figure 3. Make sure the thermometer does not touch the metal.

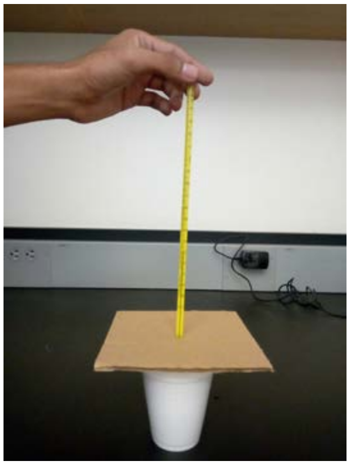

Figure 3. Final Calorimeter Set Up

10. Record the temperature every 10 seconds until the temperature of the water inside the calorimeter starts to decrease. Make sure you write this information in your laboratory notebook. The highest temperature recorded will be the final temperature of both the metal and the water.

$$(T_{(water)final} = T_{(metal)final})$$

11. Calculate the temperature change for the water ($T_{(water)final} - T_{(water)initial}$) and the unknown metal sample ($T_{(metal)final} - T_{(metal)initial}$).
12. Calculate the mass of unknown metal (m_{metal}) by subtracting the weight of the 25 mm x 200 mm test tube from the weight of the test tube with the unknown metal.

13. Calculate the mass of water (m_{water}) by subtracting the weight of your simple calorimeter from the weight of your simple calorimeter with water.
14. Organize your date and calculate the specific heat of your unknown metal (c_{metal}) using the appropriate equation. Remember c_{water}= 4.184 Joules/g°C.

$$c_{metal} = \frac{c_{water} \times m_{water} \times \left(T_{(water)final} - T_{(water)initial}\right)}{m_{metal} \times \left(T_{(metal)final} - T_{(metal)initial}\right)}$$

15. Determine the identity of your unknown metal by comparing the specific heat that you calculated with Table 1.

Table 1.

Specific Heat and Density of Selected Materials

Element	**Specific Heat (J/ g°C)**	**Density (g / mL)**
Aluminum	0.90	2.7
Copper	0.385	8.9
Iron	0.442	7.9
Lead	0.13	11.4
Magnesium	1.0	1.7
Tin	0.22	7.3
Zinc	0.388	7.1
Water, liquid	4.184	1.0

Name___________________________________

Partner's name ___________________________________

DATA

1. Water Data

a. Mass of simple calorimeter ___________________________

b. Mass of simple calorimeter and water ___________________________

c. Mass of water (m_{water}) ___________________________

(Mass of simple calorimeter and water) – (Mass of simple calorimeter)

d. Initial temperature of water in calorimeter ($T_{(water)initial}$) ___________________________

e. Final temperature of water in calorimeter ($T_{(water)final}$) ___________________________

It is the highest temperature read of thermometer after adding the metal to the water in the calorimeter.

2. Metal Data

a. Mass of 25 mm x 200 mm test tube ___________________________

b. Mass of test tube and unknown metal ___________________________

c. Mass of metal (m_{metal}) ___________________________

(Mass of test tube and metal) – (Mass of 25 mm x 200 mm test tube)

d. Initial temperature of metal ($T_{(metal)initial}$) ___________________________

It is the temperature of the boiling water.

e. Final temperature of the metal ($T_{(metal)final}$) ___________________________

It is the same as the final temperature of the water in the calorimeter.

3. Calculations (Show work)

a. Temperature change of water $\left(T_{(water)final} - T_{(water)initial}\right)$ ___________________________

b. Temperature change of metal $\left(T_{(metal)final} - T_{(metal)initial}\right)$ ____________________

c. Specific heat of unknown metal ____________________

$$c_{metal} = \frac{c_{water} \times m_{water} \times \left(T_{(water)final} - T_{(water)initial}\right)}{m_{metal} \times \left(T_{(metal)final} - T_{(metal)initial}\right)}$$

4. Conclusion

a. Unknown metal number ____________________

b. Identity of unknown metal ____________________

Additional Questions

1. Which metal would cause the greatest increase in the temperature of the water inside the calorimeter: the one with the higher specific heat or the one with the lower specific heat?

2. Relative to metals, how does the specific heat of water compare, is it higher or lower?

3. If equal masses of two metals are heated to a temperature of 100 °C, which would cause a more severe burn, the one with the higher specific heat or the one with the lower specific heat?

4. What mass of water can be heated from 5 °C to 52 °C with 100 cal of heat energy? The specific heat of water is 1.00 calorie/g°C and $Q = cm(T_{final} - T_{initial})$.