EXPERIMENT 14: CALORIMETRY

Introduction: You will find the "specific heat" constant of a metal, "c," by the heat exchanged in a calorimeter, then use the Law of Dulong and Petit to find its atomic mass

Background: Energy is gained or lost by an object when it warms or cools. One unit of energy is the **joule**, **J,** ($1kg\text{-}m^2/s^2$.) 4.184 joules = **1 calorie** (the heat required to change the temperature of 1 g of water by 1^oC (or K) say from 4^oC to 5^oC). the SI uses joules. In the US, and especially in health science, calories are used. The nutritional calorie is actually a kilocalorie (kcal) or 1000 cal. To simplify our calculations, we can use calories and convert to Joules at the end

Heat flow, Q, measured in joules or calories, is proportional to the mass of the object, its change in temperature, and the **specific heat** constant "c".

$$\mathbf{Q = m \times c \times \Delta T} \quad \text{(note } \Delta T \text{ in K is the same as } ^oC)$$

The specific heat of water **c** = 1.00 cal/g K or 4.184 J/g K. When two objects at different T contact, heat flows from the hot to the cold object until the two reach the same temperature (Tf). The double Styrofoam cups in this experiment serve as a **calorimeter**
In this experiment, you will measure the specific heat of a metal. The metal is heated and placed in the calorimeter with water and the final temperature of the system is recorded .Thus the heat (calories) lost by the metal (Q_m) is equal to the heat gained by the water (Q_w)

$$Q_w = -Q_m \quad \text{thus,} \quad \mathbf{m_w \times c_w \times \Delta T_w = -(m_m \times c_m \times \Delta T_m)} \quad \text{use } C_w = 1.00 \text{ cal/g K}$$

All the values are known except $\mathbf{c_m}$. Note the negative sign cancels out since ΔT_m is a negative quantity ($T_f - T_i$ is negative). The specific heat of the metal is used to estimate its atomic mass. from **the Law of Dulong and Petit**, stating that the atomic mass of a solid element equals 26 divided by the specific heat, **Atomic mass = 26 / (specific heat)**

Two potential sources of error: a) heat lost by metal to the air as it is being transferred, and b) heat lost by the water to the calorimeter. Ideally, the T_m should be measured just as it is immersed in the calorimeter, but failing that – some initial experiments have shown that the metal loses about 0.2 degrees every second to the air. So timing the transfer process affords us a correction of for example 1 degree per 5 seconds – a typical transfer time. Subtract this from the initial T of the metal as a correction factor. Another experiment reveals that appx 0.3 degrees are lost to the calorimeter – so that must be added to the final temperature of the system.

Safety

Boiling water, and dropping pieces of metal into boiling water can be hazardous.. wear goggles

Materials Needed

Equipment	Chemicals
calorimeter (double Styrofoam cups), thermometer, thermometer clamp, stirring rod, utility clamp, burner or hot plate 600 mL beaker, crucible tongs or loop tool, iron ring, wire gauze	Unknown metal, with a hook

Procedure

1. Obtain a piece of unknown metal sample from the instructor and record its code number
   Get a calorimeter (2 Styrofoam cups),. Set up a 600-mL beaker and a thermometer clamp on a ringstand with an iron ring and wire gauze, above a Bunsen burner or on a hot plate if available. Weigh the unknown metal , then weigh the calorimeter to the nearest 0.01 g

2. Fill the 600-mL beaker with about 400 mL deionized water and place on a wire gauze on a ring stand over a burner or a hot plate and start heating it
3. While the beaker is warming up, pour about 100 mL of deionized water into the calorimeter. Weigh it with the water.
4. Using the tool with a loop, lift the metal by the hook and place it in the beaker of hot water. Don't drop it in.!! (The beaker may break.) Boil slowly for 5 minutes.
5. Measure the water temperature in the Styrofoam calorimeter to **the nearest 0.1°C,** then measure the temperature of the boiling water. (Use a thermometer clamp or hold carefully)
6. Have a piece of paper towel ready, to blot the metal briefly while using the loop tool to lift .. … the metal from the boiling water .Quickly place it into the calorimeter water. Estimate the … …. time required for the transfer. (Don't spend more than two seconds to blot the metal) Keep the boiling water simmering. Add water as needed if the water level decreases much
7. Measure the temperature of the water in the Styrofoam calorimeter with a thermometer or thermocouple. while gently swirling the water Read to the nearest 0.1 °C the highest temperature that is reached before it begins to drop again. This takes several minutes. This is the final temperature of water and metal (T_f).
8. Take out the metal, pour out the water from the calorimeter and refill with a new portion of water. Weigh the calorimeter with water. Place the metal back into the boiling water and heat for a second run. Do three runs,. At the end of the lab period, dry the metal piece and return it to the instructor..

2. Calculations

Calculate the specific heat of the metal for each run of the experiment, using the equation

$$Q_w = m_w c_w \Delta T = -\ Q_m = -\ m\ c_m \Delta T$$ where c_m is the only unknown. c_w = 1.00 cal/g K

You can convwert the c_m from cal/gK to J/g K with the factor 4.184 J = 1 cal

The instructor may give you the true value of the specific heat, in which case you can calculate the % error. Some of the metals may be alloys – not pure elements – so calculating the atomic mass from the Law of Dulong and Petit may or may not give a value which matches the ones on the table below.

$$\%\ error = \frac{experimental\ value - accepted\ value}{accepted\ value} \times 100$$

Specific Heat Values of Elements
(Joules / g-K)

Li	**Be**											**B**	**C**			
3.58	1.825											1.03	0.709			
Na	**Mg**											**Al**	**Si**	**P**	**S**	
1.23	1.02											0.900	0.70	0.769	0.71	
K	**Ca**	**Sc**	**Ti**	**V**	**Cr**	**Mn**	**Fe**	**Co**	**Ni**	**Cu**	**Zn**	**Ga**	**Ge**	**As**	**Se**	
0.757	0.647	0.568	0.523	0.489	0.449	0477	0.449	0.421	0.444	0.385	0.388	0.371	0.230	0.330	0.32	
Rb	**Sr**	**Y**	**Zr**	**Nb**	**Mo**	**Tc**	**Ru**	**Rh**	**Pd**	**Ag**	**Cd**	**In**	**Sn**	**Sb**	**Te**	**I**
0.363	0.3	0.3	0.278	0.265	0.25	0.24	0.238	0.242	0.244	0.232	0.233	0.233	0.228	0.207	0.202	0.145
Cs	**Ba**	**La**	**Hf**	**Ta**	**W**	**Re**	**Os**	**Ir**	**Pt**	**Au**	**Hg**	**Tl**	**Pb**	**Bi**		
0.24	0.204	0.19	0.14	0.14	0.13	0.137	0.13	0.13	0.13	0.128	0.140	0.129	0.129	0.122		

EXPERIMENT 14: REPORT **Name: ________________________________**
CALORIMETRY Section ___________ Due date: ______________
Date submitted: _____________

Data Table for Metal: Code # _____:

Run Number:	1	2	3
Mass of metal			
T of boiling water ($T_{i(m)}$)			
Mass of Calorimeter			
Mass of calorimeter & water			
Initial T ($T_{i(w)}$) of calorimeter water			
Final temperature of metal and water (calorimeter)			

Calculations and results: *Use the corrected ΔT^* values to calculate Q_w

Run Number:	**1**	**2**	**3**
Mass of water in calorimeter			
ΔT^* of water ($T_f - T_{i(w)}$) + 0.3			
ΔT^* metal ($T_f - T_{i(m)}$) – 1.0			
calories gained by the water $\mathbf{Q_w} = m \times c_w \times \Delta T_w = \mathbf{-Q_m}$ (c_w = 1.00 cal/g K)			
Specific Heat of metal ($\mathbf{c_m}$) solve for c_m $\mathbf{c_m = -\dfrac{Q_m}{m_m \cdot \Delta Tm}}$	cal/g K	cal/g K	cal/g K
use the factor 4.184 J = 1 cal to convert to J	J / g K	J/g K	J/g K
Average value of c_m J/g K	**True value c_m**	**% Error**	**Atomic mass (**from Law of Dulong &Petit**)**

Show the setups of all these calculations on a separate sheet.

Questions

Some of these should be done before coming to lab, as preparation, to save time, and increase your understanding of the complex calculations involved in this experiment.

1.. A student places 138 g of an unknown metal at 99.6 °C into 80.50 g of water at 22.1 °C. The entire system reaches a uniform temperature of 31.6 °C. Calculate the specific heat of the metal in J/g K

2… Look at the table of specific heat values of elements (page 2 of the instructions) Do you think the Law of Dulong and Petit is a good law to use for the heavier elements ? Why or why not ?

3 While transferring the piece of unknown metal to the calorimeter, the student drops the metal into the calorimeter roughly, and some water splashes out of the calorimeter. Why must this be avoided? Be specific – how would the loss of water from the calorimeter affect the calculated value of specific heat for the metal ?

4. "Global Warming" (or "climate change as it is called now) depends on the specific heat values of various gases. In a text or CRC Handbook,find a table of specific heat values for these gases : N_2 (g), H_2O (g), CH_4 (g) , CO_2 (g). Show units . Comment on these. If the handbook doesn't have them – try Google. The units may be a bit different – anyway try !

5. A graphical analysis of the Law of Dulong and Petit. Do this as a pre-lab exercise

Set up a table of specific heat values, atomic mass, and 1/atomic mass and fill in the data for at least 13 elements ranging from Na to Bi (see page 2, this experiment).

Element	Specific heat	Atomic mass	1/Atomic mass	note specific heat is in J/gK
Na	1.23	23.0	.	
Al	0.900	27.0	.	Atomic mass is in amu
K			.	
Ti			.	
Fe			.	
Cu			.	
Rb			.	note – if you can't
Nb			.	accommodate Na or Bi
Ag				on the graph – then start
La			.	with Al and finish w Hg
Au			.	
Bi			.	

You may plot more if you wish – but don't plot the non-metals or metalloids such as Ge or Sb

Graph 1. Plot specific heat (y axis) vs Atomic mass (x axis). Use a flexible drawing tool or French curve to draw the line. Stockroom has a few of these. Use 10 sq/in graph paper.
It would be useful to draw the symbols of the elements above the data points

Graph 2. Plot specific heat (y axis) vs 1/atomic mass (x axis). Use 3 sig figs for all data
Find the slope and equation for the line - Compare with the Law of D & P. (page 1).
Again – draw the symbols of the elements above the data points.

For extra credit (5 pts) do an Excel plot of graph #2. If you are not familiar with the Excel graphing program on your Microsoft Word , there are instructions available at the Chem Dept website. Get the equation of the line on the Excel-drawn graph.

Neatness, clarity, proper scale setup are important components of this exercise. Don't forget to properly label the axes and give the graph a title.

Question: What are some advantages and disadvantages to using a graphing program such as Excel.

PS if you have a better graphing program than Excel on your computer, by all means use it.