Expt. #10: Heat Capacity of Solids

Aim: a) To determine specific heat capacity of different metals

b) To estimate molar heat capacity of those metals and hence to verify Dulong-Petit law

Definitions and Laws:

- **a) Heat capacity:** If a body exchange ΔQ amount of heat with its surroundings and its temperature change by ΔT then its heat capacity is defined as $C = \Delta Q / \Delta T$. Heat capacity is proportional to the mass of the body and it is an extensive thermodynamic quantity.
- **b) Specific heat capacity:** Specific heat capacity is defined as heat capacity per unit mass, $c = C/m$, m being total mass of the body. It is an intensive thermodynamic quantity.
- **c) Molar heat capacity:** Molar heat capacity (c_M) is defined as heat capacity per unit mole of a body ($c_M = \text{specific heat capacity} \times \text{molar mass}$).
- **d) Dulong-Petit law:** Molar heat capacity of a solid substance is a constant, which means, it is same for all substance irrespective of the nature of the substance. The value of the constant is nearly 24.94 J/mol°C. Later on theoretical consideration (kinetic theory of gas and equipartition theorem) showed that the constant is $3R$, where R is the universal gas constant.

Principle of experiment: Known mass (m_1) of the experimental substance is heated to a known temperature (T_1). It is then put into a known mass (m_w) of water kept in a calorimeter **(Do you know what a *calorimeter* is? If not, read about it yourself or ask your teacher.)** at a known temperature (T_w). Heat exchange takes place between the water and calorimeter and experimental object and they together come to an equilibrium temperature (T_e) which is measured experimentally. Using the condition that heat lost by the experimental object is equal to the heat absorbed by the water and calorimeter, one can easily derive **(Do derive it yourself!)** the formula for the specific heat capacity of the experimental object as

$$c = \frac{(C + c_w m_w).(T_e - T_w)}{m_1.(T_1 - T_e)} \qquad (1)$$

where C = heat capacity of the calorimeter (supplied to be 80 J/°C)

and c_w = specific heat capacity of water, known to be 4.19 J/g°C.

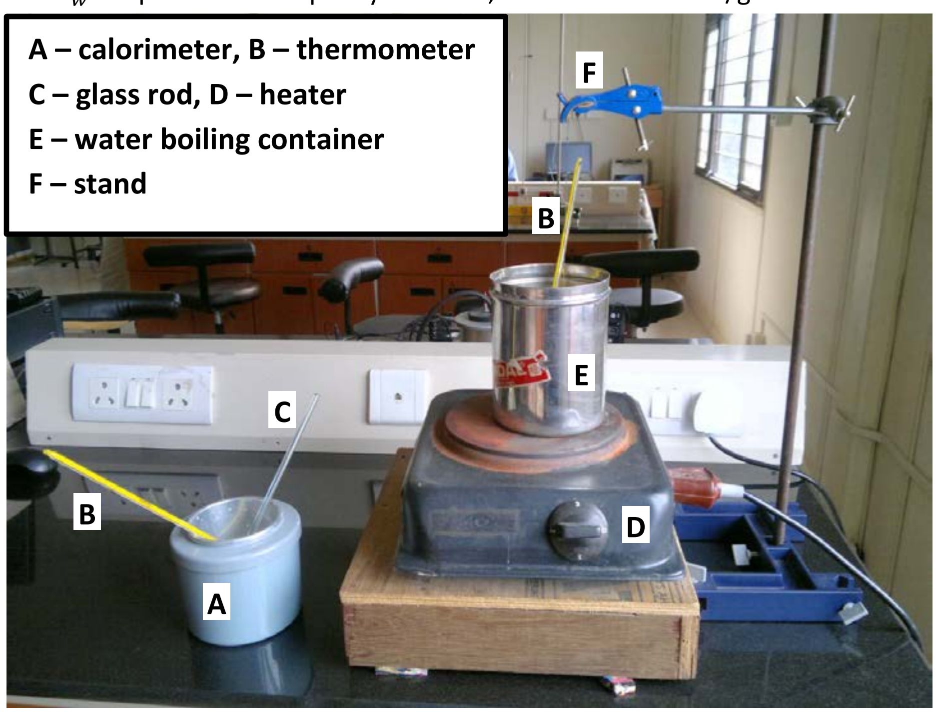

Figure 1: Photograph of the experimental setup

Procedure of experiment:

A. Preparing known mass of experimental body to a known temperature

1. In this experiment you will determine specific heat capacity and molar heat capacity of 3 different metals. You will be supplied with 3 blocks of each metal.
2. 3 blocks of a given metal will be tied together with a nylon thread, in a manner that you can hang them together from a supporting stand. If they are not tied in this manner, then do it yourself.
3. Weigh the tied blocks for all the 3 metals using a digital balance (You should learn the working principle of a digital balance!) and record the reading in tabular form. Digital balance should show *zero reading* when no weight is put on it. If empty balance is not showing *zero*, press the *tare/zero button*. It should then show zero.
4. Now you will heat the metal blocks to a known temperature by dipping them in the boiling water.
5. For this, fill up to 3 quarters of the water boiling metal container with tap water and place the container on a heater/ gas burner for heating.
6. Hang all 3 types of metal blocks from a stand in to the water in the container which is kept on the heater. **Ensure that metal blocks do not touch the metal container body.**
7. Turn on the heater/ gas burner and start heating the water (with metal blocks hanging in it). You have to heat the water to boiling and continue heating.

B. Preparing calorimeter with a known mass of water at known temperature

1. While metal blocks (dipped in water) are being heated, you have to weigh about 200 g of room temperature water (tap water) in the calorimeter.
2. For this, put the empty calorimeter on the digital balance and press the tare/zero button. Now, the digital balance should show zero reading with the empty calorimeter on it.
3. Slowly pour room temperature tap water from a beaker in to the calorimeter placed on the digital balance. You may use a dropper, if necessary. **Water should not drop on the balance!**
4. Measure about 200 g of water in the calorimeter and note it down in your lab book in tabular form as m_w. Put a glass rod in calorimeter water for stirring.
5. Put a thermometer, range –10°C to 110°C, in the calorimeter water. Wait for 1 minute and then read the temperature shown by the thermometer. Note it in tabular form as T_w in your lab book. Keep the thermometer in the calorimeter. **What is the working principle of the thermometer you are using?**

C. Mixing hot metal block to water in calorimeter

1. Put a thermometer, range –10°C to 110°C, in the water boiling container where metal blocks were heated up in the boiling water. Wait for 1 minute and then read the temperature shown by the thermometer. Note it in tabular form as T_1 in your lab book. **Do you find $T_1 = 100$°C? If not, do you have an explanation for this?** Remove the thermometer and keep it aside safely.
2. Take one type of metal blocks out of the boiling water and quickly put them into the water in the calorimeter. Ensure that all the blocks are completely inside water.
3. Stir vigorously with glass rod for 1 minute. **Be careful to** *not to break* **the glass thermometer which was already there in the calorimeter.** Read the temperature shown by the thermometer. Note it in tabular form as T_e in your lab book. Put back the metal blocks in the boiling water.
4. **Key assumption made in this experiment is that heat is exchanged only between the water + calorimeter and metal blocks. Can you justify it?** What about radiation loss to the environment?

Repeat this procedure for other type of metals. Keep the following points in mind.

1. The calorimeter and water in it should be at room temperature. For this, discard water from calorimeter from the previous experiment. Wash the calorimeter 2-3 times with room temperature water from tap. Then dry the calorimeter by wiping it with a dry cloth or tissue paper.
2. Measure again about 200 g of room temperature (tap) water and put it in the calorimeter.
3. All the temperatures ($T_1, T_w,$ and T_e) should be measured for experiment with each metals.
4. Pour additional amount of water in the water boiling container if required. Then wait for water to start boiling.
5. ***After completing one set of measurements with 3 different metals, repeat the cycle of measurements two more times.***

Calculation:

Use average values of $m_1, m_w, T_w, T_1,$ and T_e in Eq. (1) to calculate specific heat capacity. Do it for all 3 supplied metals and present the result in tabulated form. Also calculate molar heat capacity in the same table.

Results: (example tabulation)

Metal	Specific heat capacity (J/g°C)		Molar mass (g/mol)	Molar heat capacity (J/mol°C) [measured value]
	Measured value	Literature value		
Iron		0.452	55.85	
Brass		0.385	64.28**	
Aluminum		0.896	26.98	

** Brass is an alloy and its molar mass depends on composition. Here we have taken 3:2 weight ratio of copper and zinc as the composition.

Error analysis: Maximum possible relative error in c as calculated from Eq. (1) can be written as

$$\frac{\delta c}{c} = \frac{\delta m_w}{m_w} + \frac{\delta m_1}{m_1} + \frac{\delta T_e + \delta T_w}{T_e - T_w} + \frac{\delta T_1 + \delta T_e}{T_1 - T_e}$$

where $\delta m_w, \delta m_1, \delta T_1, \delta T_w$ and δT_e are maximum possible error in m_w, m_1, T_1, T_w and T_e.

You must calculate maximum possible relative error in estimate of specific heat capacity. You should also write some discussion on your measurement in the lab book.