PH1202

Physics Laboratory II

Experiment Number - 6

To determine the specific heat capacity of different metals

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1 Aim

To determine the specific heat capacity of different metals

2 Objective

A 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, 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, the formula for the specific heat capacity of the experimental object may be derived as

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

Where, C = heat capacity of the calorimeter and c_w = specific heat capacity of water.

3 Apparatus Required

- Calorimeter
- Stirrer
- A lid and outer jacket
- Solid metals (3 types – Aluminium, Iron & Brass) in small pieces
- Balance
- Weight Box
- Two half-degree thermometer
- Cold Water
- Clamp Stand
- Burner

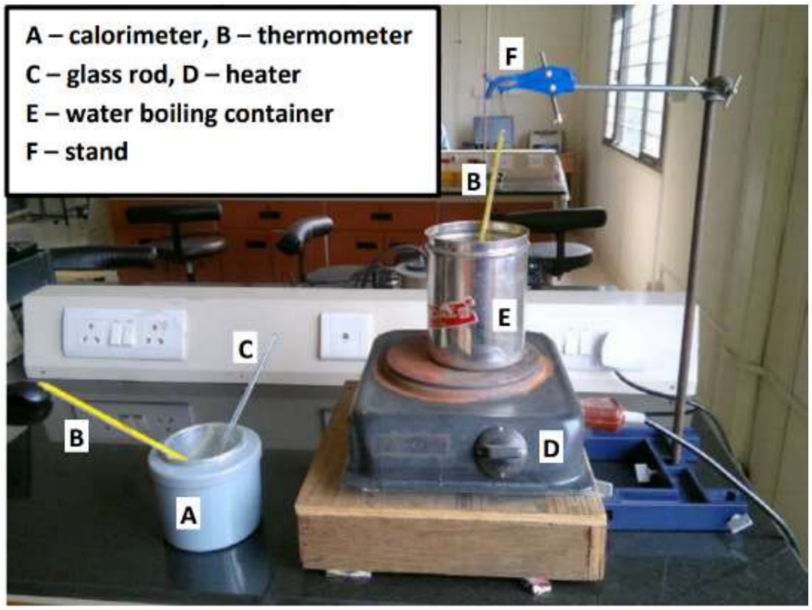

Figure 1: Experimental Setup

4 Theory

Definitions and Laws:

- **Heat Capacity**: If a body exchanges ΔQ amount of heat with its surroundings and its temperature change by ΔT then its heat capacity is defined as $C = \frac{\Delta Q}{\Delta T}$. Heat capacity is proportional to the mass of the body and it is an extensive thermodynamic quantity.
- **Specific heat capacity**: Specific heat capacity is defined as heat capacity per unit mass, $c = \frac{C}{m}$, m being the total mass of the body. It is an intensive thermodynamic quantity.
- **Molar heat capacity**: Molar heat capacity (c_M) is defined as heat capacity per unit mole of a body (c_M = specific heat capacity $\times$ molar mass).
- **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.

Working Principle:

A 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 at a known temperature (T_w). Heat exchange takes place between the water and calorimeter and the 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 the formula for the specific heat capacity of the experimental object as below :

Heat lost by experimental substance = Heat gained by the calorimeter + Heat gained by water

$$\begin{aligned} m_1 c \Delta T_1 &= m_w c_w \Delta T_w + C \Delta T_{Calorimeter} \\ \Rightarrow m_1 c (T_1 - T_e) &= m_w c_w (T_e - T_w) + C(T_e - T_w) \\ \Rightarrow m_1 c (T_1 - T_e) &= (m_w c_w + C)(T_e - T_w) \\ &= \frac{(C + c_w m_w) \times (T_e - T_w)}{m_1 \times (T_1 - T_e)} \end{aligned}$$

Thus, the specific heat capacity of the experimental object is given as below :

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

5 Procedure

1. Bringing the known mass of experimental body to a known temperature
   (a) In this experiment we need to determine the specific heat capacity and the molar heat capacity of 3 different metals. We will be supplied with 3 blocks of each metal.
   (b) 3 blocks of a given metal will be tied together with a nylon thread, in a manner that they can be hung together from a supporting stand.
   (c) Weigh the tied blocks for all the 3 metals using a digital balance and record the readings in a tabular form. The digital balance should show zero reading when no weight is put on it. If the empty balance is not showing zero, press the tare/zero button. It should then show zero.
   (d) Now heat the metal blocks to a known temperature by immersing them completely in the boiling water.
   (e) 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.
   (f) Hang all 3 types of metal blocks from a stand into the water in the container which is kept on the heater. Ensure that metal blocks do not touch the metal container body.
   (g) Turn on the heater/gas burner and start heating the water (with metal blocks hanging in it). Heat the water to boiling and continue heating.

2. Preparing the calorimeter with a known mass of water at known temperature
   (a) Weigh about 200 g of room temperature water (tap water) in the calorimeter.
   (b) For this, put the empty calorimeter on the digital balance and press the tare/zero button. The digital balance should show zero reading with the empty calorimeter on it.
   (c) Slowly pour tap water from a beaker into the calorimeter placed on the digital balance. You may use a dropper, if necessary. The water must not drop on the balance.
   (d) Measure about 200 g of water in the calorimeter and note it down in your lab book in tabular form as m_w. Keep a glass rod in calorimeter water for stirring.
   (e) 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.
3. Mixing hot metal block to water in calorimeter
   (a) Put a thermometer in the water boiling container where metal blocks are 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. Remove the thermometer and keep it aside safely.
   (b) 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.
   (c) Stir vigorously with a glass rod for 1 minute. Be careful not to break the glass thermometer which is 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.
   (d) Key assumption made in this experiment is that heat is exchanged only between the water, calorimeter and metal blocks.

Repeat this procedure for other metals too.

6 Measurements and Data Tables

- Least count of the thermometer : 0.1 $°C$
- Least count of the digital balance : 0.01 gm
- Heat Capacity of the calorimeter, C = 80 J/K
- Specific heat capacity of water, $c_w = 4.19\ Jg^{-1}K$

1. **Calculation of Specific Heat Capacity of different materials**

Metal Blocks (Molar Mass in g mol^{-1})	Sl. No.	Mass of the metals (M_1) gm	Mass of the Water (M_w) gm	T_w (°C)	T_1 (°C)	T_e (°C)	Specific heat Capacity (J/g°C)	Molar Heat Capacity (J/mol°C)
Aluminium (M.M. = 55.85 g mol^{-1})	1	180	200	25.2	99.1	37.3	0.999	55.794
	2	180	200	26.2	99.3	36.2	0.808	45.127
	3	180	200	28.4	99.2	38.2	0.819	45.741
Average Specific Heat Capacity of Aluminium:							0.875	48.887
Brass* (M.M. = 64.28 g mol^{-1})	1	181	200	25.4	99.2	32.2	0.514	33.040
	2	181	200	28.7	99.3	32.2	0.265	17.034
	3	181	200	27.8	99.1	32.2	0.334	21.470
Average Specific Heat Capacity of Brass:							0.371	23.848
Iron (M.M. = 26.98 g mol^{-1})	1	181	200	25.7	99.4	29.7	0.291	7.851
	2	181	200	26.5	99.2	32.3	0.440	11.871
	3	181	200	28.8	99.1	33.8	0.388	10.470
Average Specific Heat Capacity of Iron:							0.373	10.063

Figure 2: Calculation of Specific Heat Capacity of Metals

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.

2. **Calculation of Molar Heat Capacity of different materials**

Metal	Specific heat capacity (J/g°C)		Molar mass (g/mol)	Molar heat capacity (J/mol°C) [measured value]
	Measured value	Literature value		
Aluminium	0.875	0.896	26.98	23.608
Brass	0.371	0.385	64.28	23.848
Iron	0.373	0.452	55.85	22.776

Figure 3: Molar Heat Capacity of different materials

3. **Verification of Dulong-Petit Law**

   Dulong-Petit law says that the molar heat capacity of different metals is approximately the same and is 3 times the 'Universal Gas Constant, R' $\approx 24.94 Jmol^{-1}K$. In the table above, the values of molar heat capacities for Aluminium and Brass are pretty close to the value predicted by Dulong-Petit law. The value of molar heat capacity for iron deviates a bit more though.

   Still, we can say that the law can fairly give a rough estimation of the molar heat capacity of different metals.

7 Error Analysis

1. Absolute Error Percentage (i.e. deviation from the literature value)

Metal	Specific Heat Capacity (in J/ gK)		Absolute Error	Percentage Error
	Measured value	Literature value		
Aluminium	0.875	0.896	0.021	**2.34 %**
Brass	0.371	0.385	0.014	**3.64 %**
Iron	0.373	0.452	0.079	**17.48 %**

Figure 4: Percentage error in measuring the Specific Heat Capacity of different materials

2. Degree of Precision

Using the knowledge of partial derivatives, we may write :

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

(a) **For Aluminium**:

$$\frac{\delta c}{c} = \frac{\delta m_w}{m_w} + \frac{\delta m_1}{m_1} + \frac{\delta T_e + \delta T_w}{T_e - T_w} + \frac{\delta T_1 + \delta T_e}{T_1 - T_e}$$
$$= \frac{0.01}{200} + \frac{0.01}{180} + \frac{0.1+0.1}{10.63} + \frac{0.1+0.1}{62.0} = \mathbf{2.21\ \%}$$

(b) **For Brass**:

$$\frac{\delta c}{c} = \frac{\delta m_w}{m_w} + \frac{\delta m_1}{m_1} + \frac{\delta T_e + \delta T_w}{T_e - T_w} + \frac{\delta T_1 + \delta T_e}{T_1 - T_e}$$
$$= \frac{0.01}{200} + \frac{0.01}{181} + \frac{0.1+0.1}{4.93} + \frac{0.1+0.1}{67.0} = \mathbf{4.12\ \%}$$

(c) **For Iron**:

$$\frac{\delta c}{c} = \frac{\delta m_w}{m_w} + \frac{\delta m_1}{m_1} + \frac{\delta T_e + \delta T_w}{T_e - T_w} + \frac{\delta T_1 + \delta T_e}{T_1 - T_e}$$
$$= \frac{0.01}{200} + \frac{0.01}{181} + \frac{0.1+0.1}{4.93} + \frac{0.1+0.1}{67.3} = \mathbf{4.36\ \%}$$

3. Deviation of the experiment from the Dulong-Petit law:

Metal	Experimental Value (J/mol K)	3 × R ~ 24.94 (J/mol K)	Absolute Error	Percentage Error
Aluminium	23.61	24.94	1.33	5.3 %
Brass	23.85	24.94	1.09	4.4 %
Iron	20.83	24.94	4.11	16.5 %

8 Sources of Error

- There are energy losses to the surroundings when the hot metal blocks are transferred from the boiling water to the calorimeter. These losses have not been taken into account.
- There are clearly human errors while taking measurements for Iron blocks. We can say so because the percentage errors in the calculated values of specific heat capacity of Aluminium and Brass are only 2.34 % and 3.64 % respectively. On the other hand, the error for Iron abruptly jumps to 17.48 % indicating an error in taking the experimental readings for iron.
- Errors arising due to limited precision of the instrumental errors.
- Again the deviation of the Aluminium and the Brass blocks from the Dulong-Petit law isn't much, but the Iron block deviates a lot (= 16.5 %), The causes behind this are human errors. If instead of the experimental values we take the literature values for comparison with the Dulong-Petit law, we see that the deviation from the law isn't much for any of the metal blocks and thus, the law is pretty much valid.

9 Conclusion

The Specific Heat Capacity of Aluminium, Brass and Iron are calculated to be 0.875, 0.371 and 0.373 J/mol K with a deviation of 2.34 %, 3.64 % and 17.48 % respectively.

Also, the Dulong-Petit law is satisfactorily verified for the literature values of the three metals.