Roll No: 20PH20014
Name: Jessica John Britto

General Properties of Matter Lab
PH29001

EXPERIMENT-4

To measure the specific heat of different metals and hence to verify Dulong-Petit law

Aim: To measure the specific heat of different metals and hence to verify Dulong-Petit law.

Apparatus: A calorimeter, small blocks of given metals (aluminium, brass, copper, iron), a balance

Theory: The specific heat (**c**) of a substance is the amount of heat that one unit of mass of that substance absorbs for its temperature to rise by one unit of temperature.

Working Formula-

The **heat loss** by the hot object(s) = the **heat gain** by the cold object(s)

or, $$- M_S c_S (T_{eq} - T_{iS}) = M_w c_w (T_{eq} - T_i) + M_{Cu} c_{Cu} (T_{eq} - T_i)$$

or, $$- M_S c_S (T_{eq} - T_{iS}) = [M_w c_w + M_{Cu} c_{Cu}] * (T_{eq} - T_i)$$

The above equation has an unknown which can be solved. The result will be the measured value. Using the values of c_S; for given metals; the specific heat capacities can be calculated.

Dulong-Petit law- Regardless of the nature of the crystal, the molar specific heat capacity (measured in joule per Kelvin per kilogram) is equal to 3R, where R is the gas constant (measured in joule per Kelvin per mole) and is the molar mass (measured in kilogram per mole). In other words, the dimensionless heat capacity is equal to 3. Despite its simplicity, Dulong-Petit law offers a fairly good prediction for the molar specific heat capacity of solids with relatively simple crystal structure at high temperatures. It fails, however, in the low-temperature region, where the quantum mechanical nature of the solid manifests itself. There, the Debye model works well.

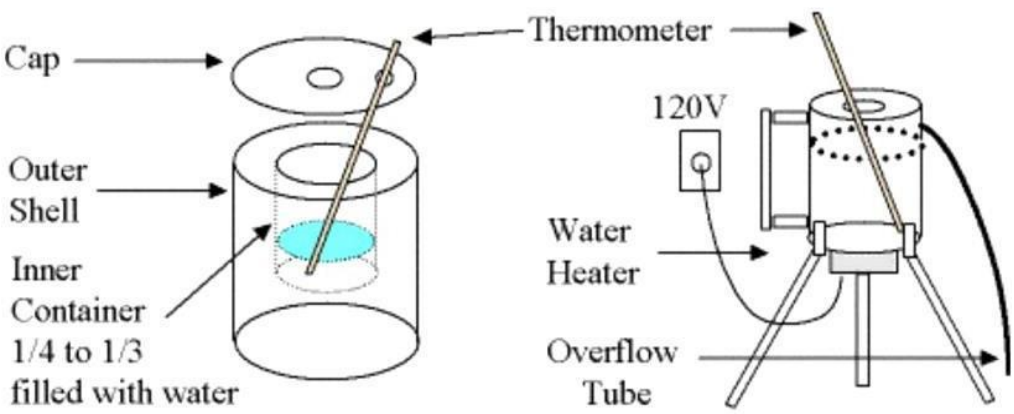

Fig. 1 : Calorimeter and water heater (Not to scale)

Observations:

- The temperature of the laboratory while taking the measuring the values of the parameters = 31˚C
- Specific heat capacity of water C_W = 1 cal/gm-K
- Specific heat capacity of copper calorimeter C_{Cu} = 0.092 cal/gm-K
- Mass of calorimeter (M_{Cu}) = 115.1 *gm*
- Mass of iron (M_{Fe}) = 179.1 *gm*
- Mass of aluminium (M_{Al}) = 179.6 *gm*
- Mass of copper-zinc alloy ($M_{Cu/Zn}$) = 179.2 *gm*
- Least count of thermometer = 1°C
- Least count of weighing balance = 0.1 gm
- Mass of calorimeter + water = $M_{Cu} + M_W$
- Mass of water$MW = (M_{Cu} + M_W) - M_{Cu}$
- The initial temperature of calorimeter and water = T_i
- The initial temperature of metal = T_{is}
- The final temperature of the system at equilibrium = T_{eq}
- Now specific heat capacity of metal at equilibrium condition can be written as

$$C_S = \frac{(M_W C_W + M_{Cu} C_{Cu})(T_{eq} - T_i)}{M_S(T_{is} - T_{eq})}$$

where M_S is the mass of the given metal/alloy.

Table-1-

For the specific heat of aluminium $\boldsymbol{C_{Al}}$ (Cal/gm-K)-

SI. No.	M_W (in gm)	T_{is} (°C)	T_i (°C)	T_{eq} (°C)	SP. heat of aluminium C_{Al} (Cal/gm-K)	Mean C_{Al} (Cal/gm-K)
1	129.2	99	31	46	0.2203	0.2327
2	146.9	99	31	46	0.2482	
3	135.1	99	31	46	0.2296	

Table-2-

For the specific heat of iron $\boldsymbol{C}_{\mathrm{Fe}}$ (Cal/gm-K)-

SI. No.	M_W (in gm)	T_{is} (°C)	T_i (°C)	T_{eq} (°C)	SP. heat of iron C_{Fe} (Cal/gm-K)	Mean C_{Fe} (Cal/gm-K)
1	100.1	99	31	41	0.1066	0.1101
2	120.3	99	31	40	0.1115	
3	140.1	99	31	39	0.1122	

Table-3-

For the specific heat of copper-zinc alloy $\boldsymbol{C}_{\mathrm{Cu/Zn}}$ (Cal/gm-K)-

SI. No.	M_W (in gm)	T_{is} (°C)	T_i (°C)	T_{eq} (°C)	SP. heat of copper-zinc alloy $C_{Cu/Zn}$ (Cal/gm-K)	Mean $C_{Cu/Zn}$ (Cal/gm-K)
1	100.0	99	31	40	0.0941	0.0959
2	120.2	99	31	39	0.0973	
3	139.8	99	31	38	0.0963	

Calculations-

Molar specific heat capacity of Aluminium:

From table-1, the mean calculated value of specific heat capacity of aluminium C_{Al} is 0.2327 (Cal/gm-K).

Therefore, the molar specific heat capacity of Aluminium is 0.2327 x 26.981539 = 6.278 Cal/mol-K.

Molar specific heat capacity of Iron:

From table-2, the mean calculated value of specific heat capacity of iron C_{Fe} is 0.1101 (Cal/gm-K).

Therefore, the molar specific heat capacity of Iron is 0.1101 x 55.845 = 6.149 Cal/mol-K.

Molar specific heat capacity of copper-zinc alloy:

From table-3, the mean calculated value of specific heat capacity of copper-zinc alloy $C_{Cu/Zn}$ is 0.2327 (Cal/gm-K).

The molecular weight of alloy = $M_{Cu}P_{Cu} + M_{Zn}P_{Zn}$

Where M_{Cu} and M_{Zn} correspond to the molecular weight of copper and zinc. P_{Cu} and P_{Zn} are proportion by weight of copper and zinc in alloy.

In given alloy P_{Cu} = 65% and P_{Zn} = 35 %.

Molecular weight of alloy = $M_{Cu}P_{Cu} + M_{Zn}P_{Zn} = 63.55 \times 65\% + 65.38 \times 35\% = 64.19\ gm$.

Therefore, the molar specific heat capacity of copper and zinc in the alloy is Y = 0.0959 x 64.19 = 6.156 Cal/mol-K.

According to Dulong-Petit's law molar specific heat of solid $C_m = 3R$ = 5.9616 Cal/mol-K.

Clearly from above, the values of molar specific heat capacities of Aluminium, Iron and Copper-zinc alloy are approximately equal to the molar specific heat of solid C_m found using Dulong-Petit's Law. Hence, Dulong-Petit's Law is verified.

Error Analysis:

$$C_S = \frac{(M_W C_W + M_{Cu} C_{Cu})(T_{eq} - T_i)}{M_S (T_{is} - T_{eq})}$$

For aluminium-

$$\frac{\Delta C_S}{C_S} = \frac{\Delta M_W}{M_W} + \frac{\Delta M_{Cu}}{M_{Cu}} + \frac{\Delta M_{Al}}{M_{Al}} + \frac{\Delta T_i}{T_i} + 2\frac{\Delta T_{eq}}{T_{eq}} + \frac{\Delta T_{is}}{T_{is}}$$

$$\Delta M_W = \Delta M_{Cu} = \Delta M_{Al} = 0.1gm, \Delta T_i = \Delta T_{eq} = \Delta T_{is} = 1°C$$

$$M_W = 129.2gm, M_{Cu} = 115.1gm, M_{Al} = 179.6gm, T_i = 31°C, T_{eq} = 46°C, T_{is} = 99°C$$

$$\frac{\Delta C_S}{C_S} = \frac{0.1}{129.2} + \frac{0.1}{115.1} + \frac{0.1}{179.6} + \frac{1}{31} + 2 \times \frac{1}{46} + \frac{1}{99} = 0.0880369$$

$$\frac{\Delta C_S}{C_S} \times 100 = 8.80369\% \approx 8.804\%$$

Therefore the standard error in $\mathbf{C_{Al}}$ **= 8.804%**

For Iron-

$$\frac{\Delta C_S}{C_S} = \frac{\Delta M_W}{M_W} + \frac{\Delta M_{Cu}}{M_{Cu}} + \frac{\Delta M_{Fe}}{M_{Fe}} + \frac{\Delta T_i}{T_i} + 2\frac{\Delta T_{eq}}{T_{eq}} + \frac{\Delta T_{is}}{T_{is}}$$

$$\Delta M_W = \Delta M_{Cu} = \Delta M_{Fe} = 0.1gm, \Delta T_i = \Delta T_{eq} = \Delta T_{is} = 1°C$$

$$M_W = 129.2gm, M_{Cu} = 115.1gm, M_{Fe} = 179.1gm, T_i = 31°C, T_{eq} = 41°C, T_{is} = 99°C$$

$$\frac{\Delta C_S}{C_S} = \frac{0.1}{129.2} + \frac{0.1}{115.1} + \frac{0.1}{179.1} + \frac{1}{31} + 2 \times \frac{1}{41} + \frac{1}{99} = 0.093340713$$

$$\frac{\Delta C_S}{C_S} \times 100 = 9.334071325\% \approx 9.334\%$$

Therefore the standard error in $\mathbf{C_{Fe}}$ = **9.334%**

For Cu-Zn alloy-

$$\frac{\Delta C_S}{C_S} = \frac{\Delta M_W}{M_W} + \frac{\Delta M_{Cu}}{M_{Cu}} + \frac{\Delta M_{Cu/Zn}}{M_{Cu/Zn}} + \frac{\Delta T_i}{T_i} + 2\frac{\Delta T_{eq}}{T_{eq}} + \frac{\Delta T_{is}}{T_{is}}$$

$$\Delta M_W = \Delta M_{Cu} = \Delta M_{Cu/Zn} = 0.1gm, \Delta T_i = \Delta T_{eq} = \Delta T_{is} = 1°C$$

$$M_W = 129.2gm, M_{Cu} = 115.1gm, M_{Cu/Zn} = 179.2gm, T_i = 31°C, T_{eq} = 40°C, T_{is} = 99°C$$

$$\frac{\Delta C_S}{C_S} = \frac{0.1}{129.2} + \frac{0.1}{115.1} + \frac{0.1}{179.2} + \frac{1}{31} + 2 \times \frac{1}{40} + \frac{1}{99} = 0.094559913$$

$$\frac{\Delta C_S}{C_S} \times 100 = 9.455991387\% \approx 9.456\%$$

Therefore the standard error in $\mathbf{C_{Cu\text{-}Zn}}$ = **9.456%**

Results-

1. The specific heat capacity of aluminium C_{Al} is 0.2327 (Cal/gm-K).
2. The molar specific heat capacity of Aluminium is 6.278 Cal/mol-K.
3. The standard error in the specific heat capacity of aluminium C_{Al} is 8.804%
4. The specific heat capacity of iron C_{Fe} is 0.1101 (Cal/gm-K).
5. The molar specific heat capacity of Iron is 6.149 Cal/mol-K.
6. The standard error in the specific heat capacity of iron C_{Fe} is 9.334%
7. The specific heat capacity of copper-zinc alloy $C_{Cu/Zn}$ is 0.2327 (Cal/gm-K).
8. The molar specific heat capacity of copper and zinc in the alloy is 6.156 Cal/mol-K.

9. The standard error in the specific heat capacity of copper-zinc alloy $C_{\mathrm{Cu/Zn}}$ is 9.456%
10. According to Dulong-Petit's law molar specific heat of solid $C_m = 3R =$ 5.9616 Cal/mol-K.
11. Dulong-Petit's Law is verified.

Precautions-

1. To reduce statistical error in measurements, at least 3-5 readings must be taken.
2. The temperature of the laboratory where the experiment is being performed must be noted as the parameters are/may be temperature-dependent. It is a good practise to note down the temperature of the laboratory where the experiment is being performed.
3. Parallax and back-lash errors during measurement must be avoided.
4. Zero error must be noted in the measuring instruments.

Discussions:

1. Dulong–Petit law, statement that the gram-atomic heat capacity (specific heat times atomic weight) of an element is a constant; that is, it is the same for all solid elements, about six calories per gram atom.
2. At very low temperatures, the quantum mechanical energy stored within solids manifests itself with a larger and larger effect. The Dulong-Petit law then fails for substances in the cryogenic region.