CALORIMETRY

The heat energy of a system is its internal energy and it can be either heat capacity or latent heat.

The amount of heat energy H needed to change the temperature of a body depends on:

- The material of a body.
- The mass m of the body
- The change in temperature θ

$\therefore H = mc\theta$, where c is the specific heat capacity of the material

HEAT CAPACITY

This is the amount of heat required to raise the temperature of any mass of a substance by 1Kelvin.

Its units are joules per Kelvin [JK^{-1}]

Heat supplied = Heat capacity X Temperature change

$H = c\Delta\theta$

SPECIFIC HEAT CAPACITY

This is the amount of heat required to raise the temperature of 1kg mass of substance by 1kelvin.

Its S.I units are joules per kilogram per Kelvin [$Jkg^{-1}K^{-1}$].

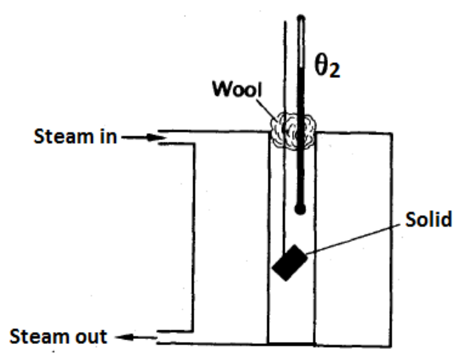
Heat supplied = Mass X Heat Capacity X Temperature change

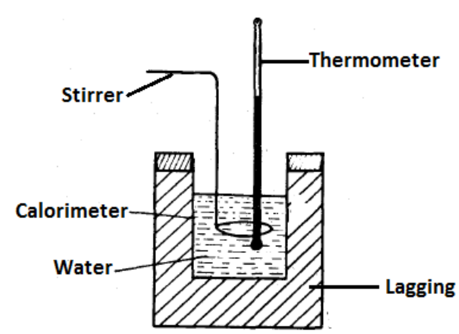
$H = mc\Delta\theta$

Determination of specific heat capacities for Solids and Liquids.

(a) For Solids

(i) Method of mixtures





- Mass **m** of the solid is measured and recorded.
- Water of mass $m_1$and specific heat capacity c_1 is poured in a Calorimeter of mass m_2 and specific heat capacity c_2.
- Using a thermometer, the initial temperature $\theta_1$of water in a calorimeter is measured and recorded.
- The solid is heated to temperature θ_2 using steam.
- The solid is then quickly transferred into the water in the calorimeter and the content stirred.

- The final steady temperature θ of the mixture is measured and recorded.
- Assuming no heat losses to the surrounding;

$$\begin{pmatrix}Heat\ lost\ by\ the\\ solid\end{pmatrix} = \begin{pmatrix}Heat\ gained\ by\\ water\end{pmatrix} + \begin{pmatrix}Heat\ gained\ by\ the\\ Calorimeter\end{pmatrix}$$

$$mc(\theta_2 - \theta) = m_1c_1(\theta - \theta_1) + m_2c_2(\theta - \theta_1)$$

$$c = \frac{(m_1c_1 + m_2c_2)((\theta - \theta_1))}{m(\theta_2 - \theta)}$$

Precautions

- Properly lag the calorimeter or use a highly polished one.
- Quickly transfer the solid unto water.
- Gently place the solid into water without splashing.
- Stir the mixture to ensure uniform temperature of the mixture.
- Cater for specific heat capacity for the stirrer and the thermometer.

Example.

200g of solid at temperature of 100°C is dropped in a calorimeter of mass 120g containing 100g of water at 20°C. If the specific heat capacity of water is 4200Jkg^{-1}K^{-1} and that of the calorimeter is 400Jkg^{-1}K^{-1} and the final temperature of the mixture is 40°C. Find the specific heat capacity of the solid assuming no heat is lost to the surrounding.

Solution

$m_s = 200g, \theta_s = 100, m_c = 120g, m_w = 100g, c_w = 4200, c_c = 400, \theta_f = 40, c_s = ?, \theta_c = \theta_w = 20$

$$\begin{pmatrix}Heat\ lost\ by\ the\\ solid\end{pmatrix} = \begin{pmatrix}Heat\ gained\ by\\ water\end{pmatrix} + \begin{pmatrix}Heat\ gained\ by\ the\\ Calorimeter\end{pmatrix}$$

$$m_sc_s(\theta_s - \theta_f) = m_wc_w(\theta_f - \theta_w) + m_cc_c(\theta_f - \theta_c)$$

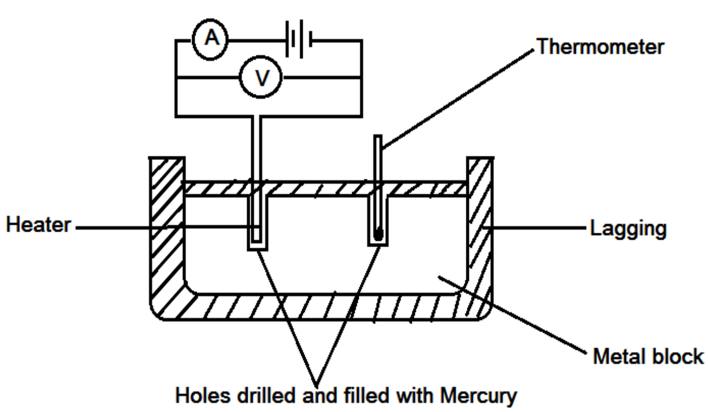
$$0.2 \times c_s(100 - 40) = 0.12 \times 400(40 - 20) + 0.1 \times 4200 \times (40 - 20)$$

$$12c_s = 960 + 8400$$

$$c_s = 780Jkg^{-1}K^{-1}$$

∴ the specific heat capacity of the solid is $780Jkg^{-1}K^{-1}$

(ii) Electrical method.



- A thick cylindrical metal block of metal having two holes one for electric heater and the thermometer is used.

- The mass m and initial temperature $\theta_1$of the block are measured and recorded.
- A suitably steady current is switched on and a stop clock is started simultaneously.
- The voltmeter and ammeter readings V and I are noted.
- When the temperature has risen appreciably, the current is stopped and the time t for which it has passed is noted and also the maximum observed temperature θ_2 of the block is recorded.
- Assuming no heat losses to the surroundings:
  Electric energy supplied by the heater = the heat absorbed by the block

$$IVt = mc_s(\theta_2 - \theta_1)$$

$$c_s = \frac{VIt}{m(\theta_2 - \theta_1)}$$

Where c_s is the specific heat capacity of the solid.

Precautions

- Lag the solid.
- Fill the holes with mercury for good thermal contact.
- Stop clock is started simultaneously with closing the switch.

Assumptions made

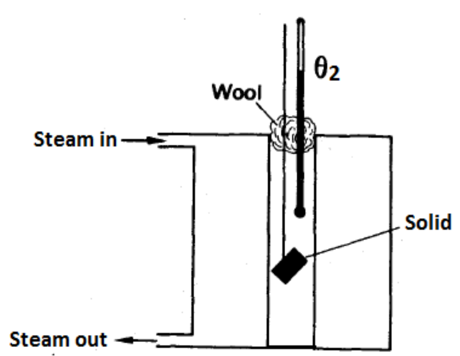
- No heat is lost to the surrounding.
- The small amount of heat gained by the thermometer and heater is negligible.
- Volume of metal is constant.

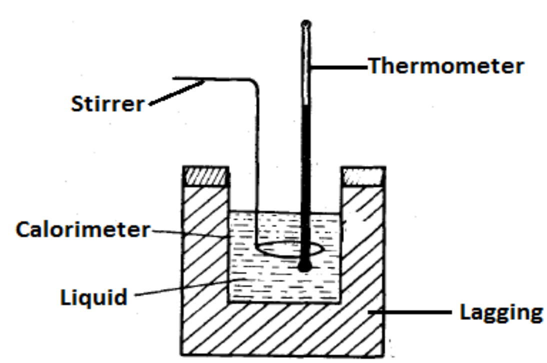
Note:

In the above experiment, practically, heat losses to the surroundings take place and this means that more heat must be supplied hence the value of specific heat capacity is greater than the actual value.

(b) For Liquids

(i) Methods of mixtures





- The mass m and specific heat capacity c of the solid are recorded.
- Liquid of mass m_1 and specific heat capacity c_1 is poured in a Calorimeter of mass m_2 and specific heat capacity c_2.

- The initial temperature θ_1 of the liquid is measured and recorded.
- The solid is heated to temperature θ_2 using steam.
- The solid is quickly transferred into the liquid.
- The mixture is stirred and the final steady temperature θ of the liquid in a calorimeter is recorded.
- Assuming no heat losses to the surroundings;

$$\begin{pmatrix} Heat\ lost\ by\ the \\ solid \end{pmatrix} = \begin{pmatrix} Heat\ gained\ by \\ liquid \end{pmatrix} + \begin{pmatrix} Heat\ gained\ by\ the \\ Calorimeter \end{pmatrix}$$

$$mc(\theta_2 - \theta) = m_1c_1(\theta - \theta_1\ ) + m_2c_2(\theta - \theta_1\ )$$

$$c_1 = \frac{mc(\theta_2 - \theta) - m_2c_2(\theta - \theta_1\ )}{m_1(\theta - \theta_1\ )}$$

Example

When a block of metal of mass 0.11kg and specific heat capacity 400 $Jkg^{-1}K^{-1}$ is heated to 100°C and quickly transferred to a calorimeter containing 0.20kg of a liquid at 10oC, the resulting temperature is 18°C. On repeating the experiment with 0.40kg of liquid in the same container and at the same initial temperature of 10°C, the resulting temperature is 14.5°C

Calculate

(a) the specific heat capacity of the liquid

(b) The mass of the container (Specific heat capacity of the calorimeter is 400 $Jkg^{-1}K^{-1}$)

Solution

1st experiment

$$\begin{pmatrix} Heat\ lost\ by\ the \\ solid \end{pmatrix} = \begin{pmatrix} Heat\ gained\ by \\ liquid \end{pmatrix} + \begin{pmatrix} Heat\ gained\ by\ the \\ Calorimeter \end{pmatrix}$$

$$m_sc_s(\ \theta_s - \theta_f) = m_lc_l(\theta_f - \theta_l) + m_cc_c(\theta_f - \theta_c)$$

$$0.11 \times 400 \times (100 - 18) = 0.2 \times c_l \times (18 - 10) + m_c \times 400 \times (18 - 10)$$

$3608 = 1.6c_l + 3200m_c$ ……………………..(i)

2nd experiment

$$m_sc_s(\ \theta_s - \theta_f) = m_lc_l(\theta_f - \theta_l) + m_cc_c(\theta_f - \theta_c)$$

$$0.11 \times 400 \times (100 - 14.5) = 0.4 \times c_l \times (14.5 - 10) + m_c \times 400 \times (14.5 - 10)$$

$3762 = 1.8c_l + 1800m_c$…………………………….(ii)

Solving (I) and (ii) simultaneously gives

$c_l = 1925Jkg^{-1}K^{-1}$

Therefore, specific heat capacity of the liquid is $1925Jkg^{-1}K^{-1}$

(b) From $3608 = 1.6c_l + 3200m_c$

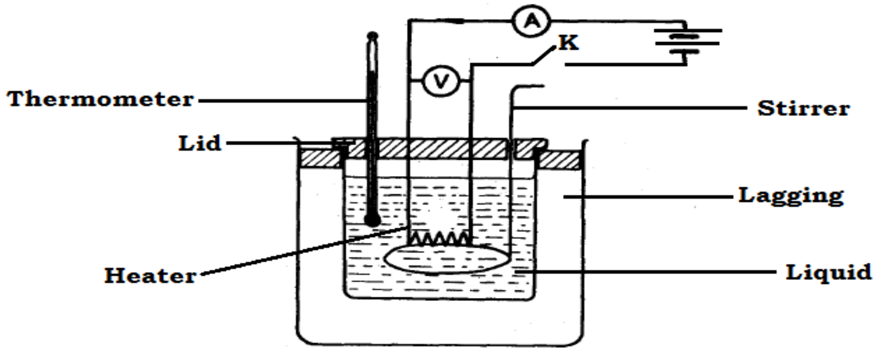
$$\Rightarrow m_c = \frac{3608 - 1.6c_l}{3200}$$

$= \frac{3608 - 1.6 \times 1925}{3200}$

= 0.165kg

Therefore, the mass of the container is 0.165kg

(ii) Electrical method



- Liquid of mass m is poured in a beaker.
- The initial temperature θ_1 of the liquid is measured and recorded.
- Switch K is closed and the stop clock is started simultaneously.
- The ammeter reading I and voltmeter reading V are recorded.
- The liquid is stirred and the final steady temperature θ_2 after time t is recorded.
- If no heat losses to the surroundings;
  Electrical energy supplied = Heat energy absorbed by the liquid.

$$IVt = mc_l(\theta_2 - \theta_1)$$

$$c_l = \frac{VIt}{m(\theta_2 - \theta_1)}$$

Where c_l is the specific heat capacity of the liquid.

Exercise.

1. A current of 2.5A passing through a heating coil immersed in 180g of paraffin of specific heat capacity $2Jg^{-1}K^{-1}$ contained in 100g calorimeter of specific heat capacity $0.4Jg^{-1}K^{-1}$ raises the temperature by 100°C in 100S. Find the reading of the voltmeter connected across the heating coil.

2. An electric kettle rated 1000W, 240V is used on 220V mains to boil 0.52kg of water. If the heat capacity of the kettle is $400JK^{-1}$ and the initial temperature of water is 20oC, how long will the water take to boil?

3. Hot water at 85°C and cold water at 10°C are run into a bath at a rate of $3.0\text{x}10^{-2}m^3min^{-1}$ and V respectively. At the point of filling the bath the temperature of the mixture of water was 40^0C. Calculate the time taken to fill the bath if its capacity is $1.5m^3$

4. An electrical heater rated 48W, 12V, is placed in a well-insulated metal of mass 1.0kg at a temperature of 18°C. When the power is switched on for 5minutes, the temperature of the metal rises to 34°C. Find the specific heat of the metal.