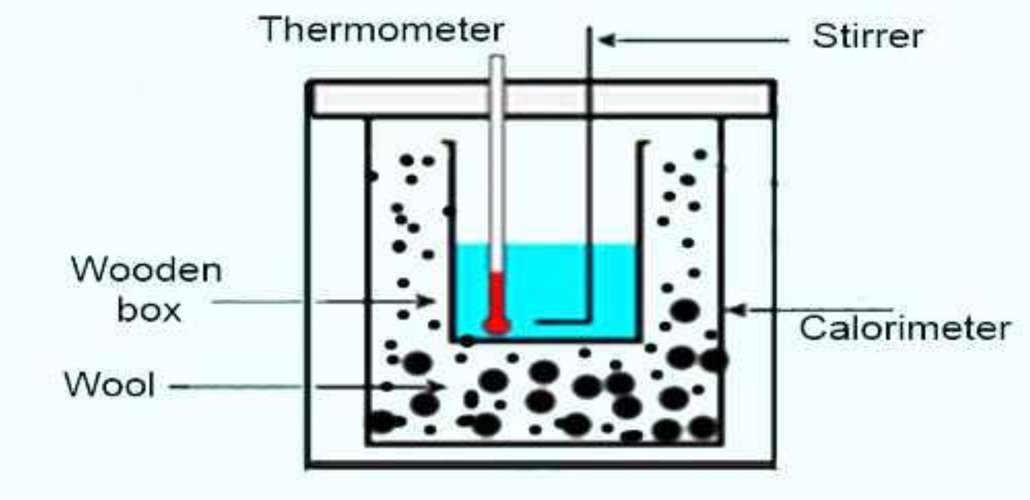
Quantity of Heat

Calorimetry:

The branch of physics that studies the quantitative measurement of amount of heat energy transform from one body to another body which are kept in thermal contact is called calorimetry.

The device which is used to measure the amount of heat energy is known as calorimeter. It consists a copper vessel provided with copper stirrer. The vessel is kept into a wooden box. The gap between wood and vessel is filled with insulating material.



Heat equation:

Experimentally, it is observed that the amount of heat energy (Q) required to change the temperature of any body by $\Delta\theta$ is:

1. Directly proportional to the mass of that body

   i.e $Q \propto m$ (1)

2. And, directly proportional to the change in temperature of the body

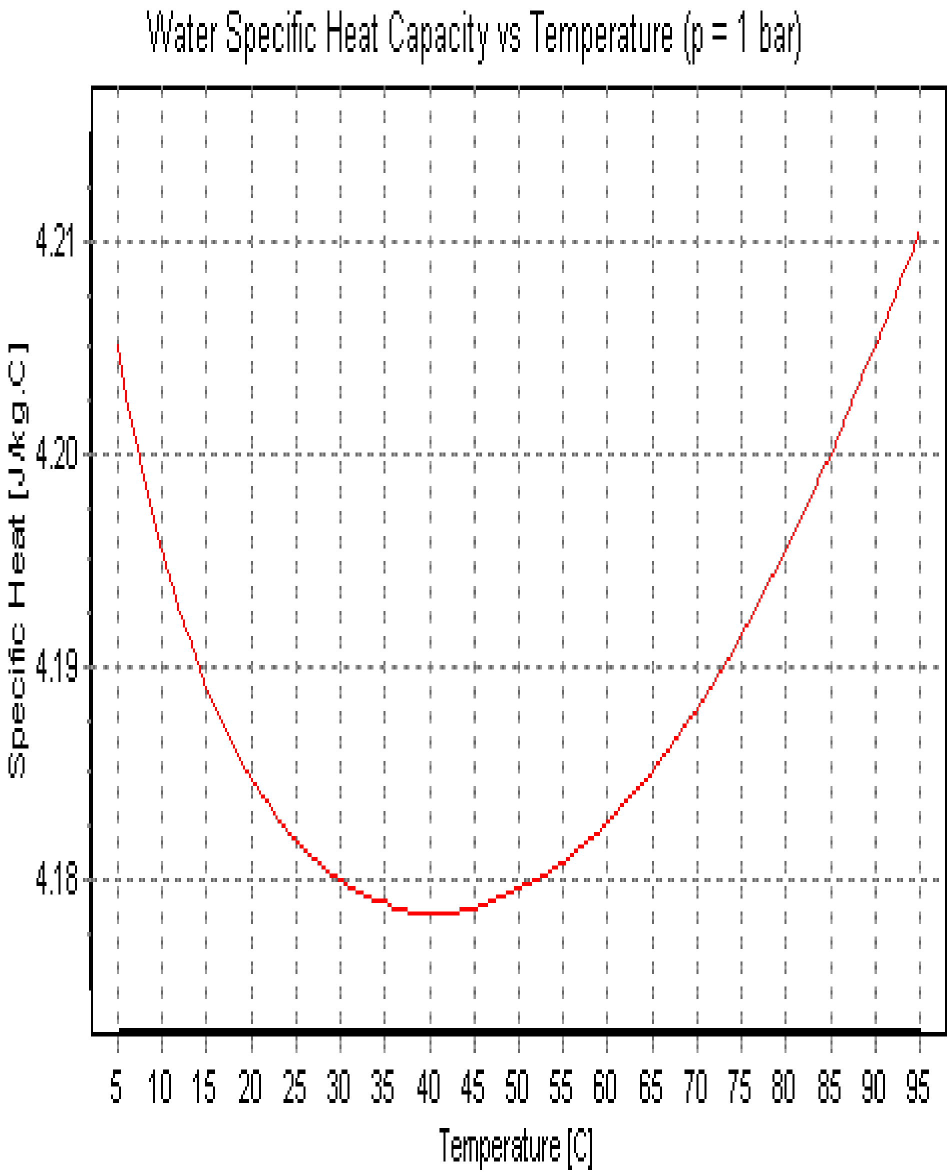
   i.e $Q \propto \Delta\theta$ (2)

combining equation (1) and (2)

$$Q \propto m\Delta\theta$$

$$Q = ms\Delta\theta \qquad (3)$$

Where s is proportionality constant know as specific heat capacity and its value depends on temperature.



Specific heat capacity:

It is define as the amount of heat energy required to change/ raise the temperature of unit mass substance by 1°C or 1 K.

Its SI unit is $Jkg^{-1}K^{-1}$ $and\ CGS\ unit\ is\ \ calgm^{-1}{}^{\circ}C^{-1}$

Note:

1. Specific heat capacity is maximum for Hydrogen i.e. $3.5calgm^{-1}{}^{\circ}C^{-1}$ and minimum for Radon and Actinium i.e. $0.022calgm^{-1}{}^{\circ}C^{-1}$.
2. Specific heat capacity is least for Solid, more for Liquid and maximum for Gas.
3. Specific heat capacity is infinite(∞) during Isothermal process or during change of state.
4. Specific heat capacity is zero(0) during Adiabatic process.
5. Negative specific heat capacity is exist for unstable system .like wise Gravitating body(sun,star),Black hole etc have negative specific heat capacity.

Heat capacity or Thermal capacity:

It is defined as the amount of heat energy required to raise the temperature of body of any mass by 1 ℃ or 1K. It is denoted by ‘C’.

We have from heat equation

$$Q = ms\Delta\theta$$

In case of heat capacity $\Delta\theta$=1 ℃

Q= ms

i.e. C= ms

Its SI unit is J/K and CGS unit is cal/ ℃

Water equivalent(W):

It is defined as the mass of water that absorbs or looses the same amount of heat energy as by the body for the same change in temperature.

Suppose a body of mass ‘m’ and specific heat capacity ‘S’ absorbs ‘Q’ amount of heat for the change in temperature $\Delta\theta$

Then from heat equation

$$Q = mS\,\Delta\theta \qquad (1)$$

If ‘W’ be the water equivalent of that body, then by definition,

$$Q = WS_W\,\Delta\theta \qquad (2)$$

From (1) and (2)

$$mS\,\Delta\theta = WS_W\,\Delta\theta$$

WS_W = mS (3)

In CGS unit $S_W = 1 cal gm^{-1} {}^\circ C^{-1}$

$\therefore W = mS$ (4)

Principle of calorimetry:

When two bodies of different temperature are kept in a thermal contact, the hot body losses the heat energy where as the cold body absorbs/gain the heat energy to maintain the thermal equilibrium state.

If there is no exchange of heat energy between the bodies and surrounding, the total heat lost by hot body is always equals to the heat gain by cold body . This is called the principle of calorimetry.

According to the principle of calorimetry

Total heat lost by hot body= total heat gain by cold body

Note:

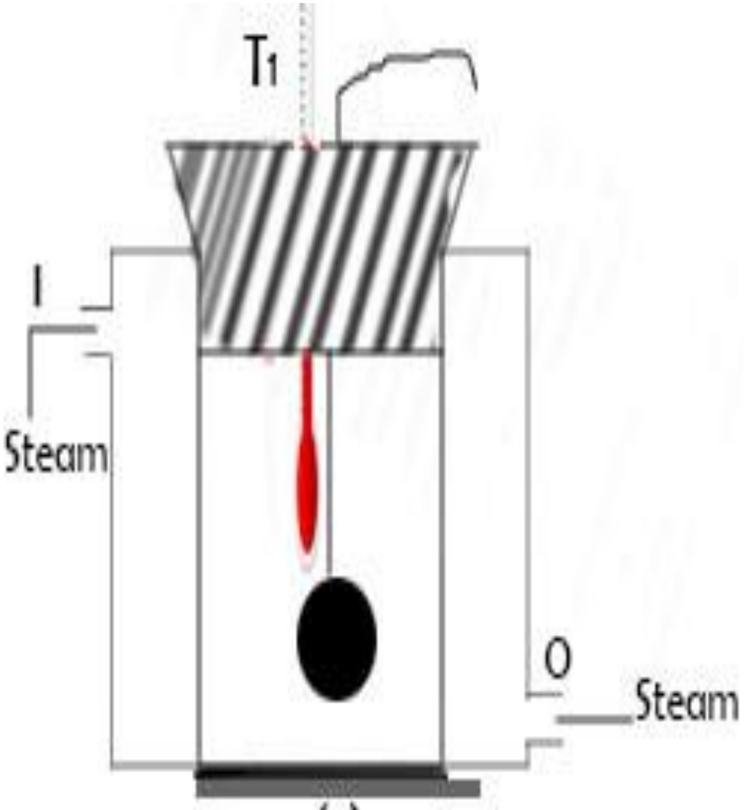
$S_W = 4200 Jkg^{-1}K^{-1}$, in SI unit

$S_W = 1 calgm^{-1}{}^\circ C^{-1}$, CGS unit

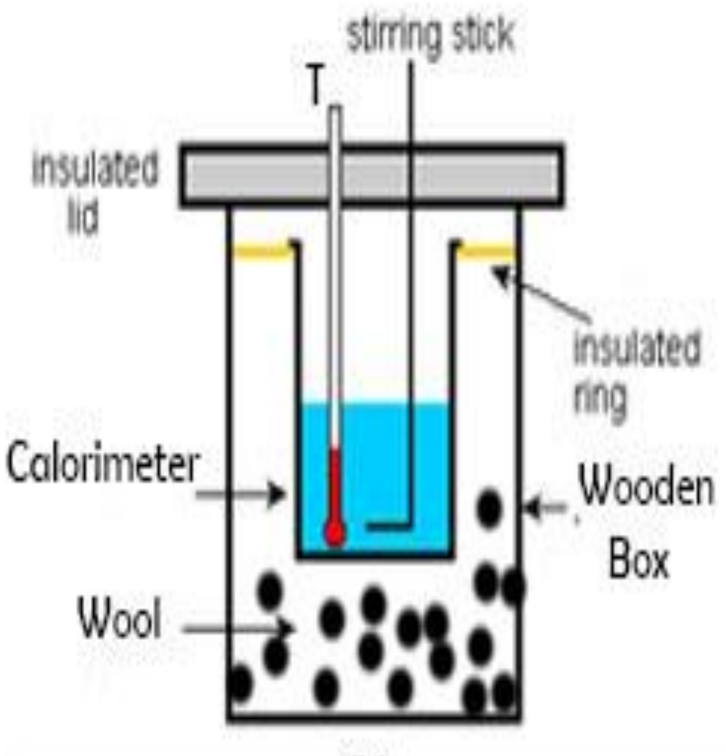
$S_{ice} = 2100 Jkg^{-1}K^{-1}$, in SI unit

$S_{ice} = 0.5 calgm^{-1}{}^\circ C^{-1}$, CGS unit

Determination of specific heat capacity of solid by the method of mixture:



(a)



(b)

The experimental arrangement for the measurement of specific heat capacity of solid by the method of mixture is shown in figure above.

Initially, a clean, dry calorimeter with stirrer is taken and is weighted. About two/third of it's volume is filled with water and further weighted to know the mass of water. The calorimeter and it's content is placed inside the wooden box and initial temperature of water and calorimeter is noted with the help of thermometer T_1.

Again, a solid whose specific heat capacity is to be determined is taken and weighted. Now, solid is heated inside a steam chamber continuously by passing steam until the thermometer T_2 records the constant temperature. That constant temperature will be initial temperature of solid. The hot solid is then dropped into calorimeter and the mixture is stirred gently and final temperature of the mixture is noted.

Let,

Mass of calorimeter and stirrer =M_C

Specific heat capacity of calorimeter=S_C

Mass of water = M_W

Specific heat capacity of water=S_W

Initial temperature of water and calorimeter=θ_1

Mass of solid=M_S

Specific heat capacity of solid=S_S=?

Initial temperature of solid = θ_2

Final temperature of mixture = θ

Now,

Heat lost by solid= $M_S S_S$ $(\theta_2 - \theta)$

And heat gained by water and calorimeter=$M_W S_W$ $(\theta - \theta_1)$+$M_C S_C$ $(\theta - \theta_1)$

Therefore, From the principle of calorimetry

Heat loss=Heat gain

$$M_S S_S(\theta_2 - \theta)=M_W S_W\ (\theta - \theta_1)+M_C S_C\ (\theta - \theta_1)$$

$$S_S = \frac{M_W S_W\ (\theta - \theta_1)+M_C M_C(\theta - \theta_1)}{M_S(\theta_2 - \theta)}$$

Newton’s law of cooling:

It state that “the rate of loss of heat by hot liquid when exposed in air/ surrounding is directly proportional to the temperature difference between liquid and the surrounding. This law holds good for small temperature difference.

Suppose any hot liquid of temperature θ losses ‘dQ’ amount of heat energy in time ‘dt’ to the surrounding of temperature ‘θ_o’ then,

according to the Newton’s law of cooling

$$\frac{dQ}{dt} \propto (\theta - \theta_0)$$

$$\frac{dQ}{dt} = -K(\theta - \theta_0) \qquad (1)$$

Where K is proportionality constant whose value depends on the nature of the liquid and surface area of the liquid that exposed to the surrounding.

And negative sign indicates that the rate of heat lost decreases as time increases

Suppose, a hot liquid of mass 'm' and specific heat capacity 'S' losses 'dQ' amount of heat in time 'dt' such that temperature of the liquid falls by 'dθ'

Therefore, from heat equation

$$dQ = mSd\theta$$

On differentiating

$$\frac{dQ}{dt} = mS\frac{d\theta}{dt} \qquad (2)$$

Now, from 1 and 2

$$mS\frac{d\theta}{dt} = -K(\theta - \theta_0)$$

$$\frac{d\theta}{dt} = \frac{-K}{mS}(\theta - \theta_0) \qquad (3)$$

$$\frac{d\theta}{(\theta - \theta_0)} = \frac{-K}{mS}\,\mathrm{dt}$$

On integrating,

$$\log_e(\theta - \theta_0) = \frac{-K}{mS}\,t + C \qquad (4)$$

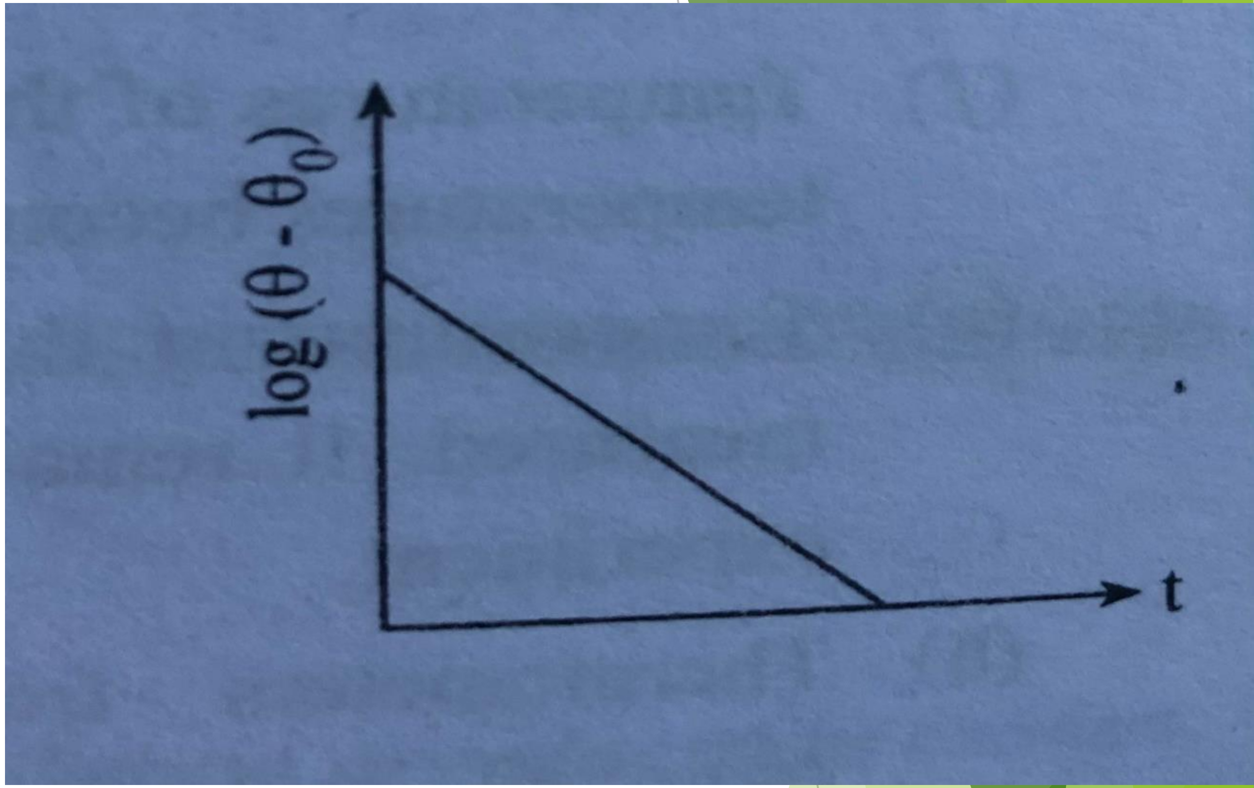
where C is integrating constant.

This equation (4) is similar to the equation

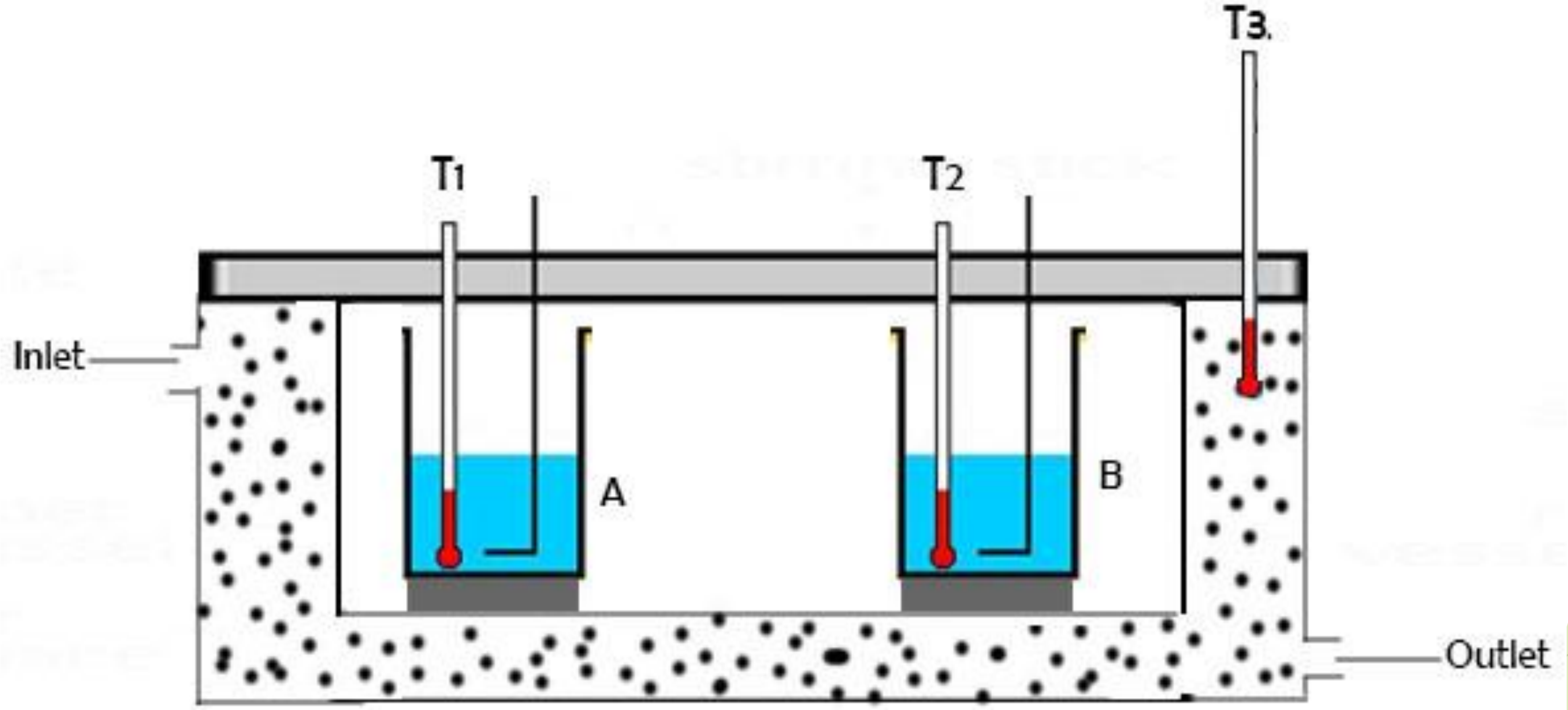
$y = mx + c$ where, $y = \log_e(\theta - \theta_0)$,

$m = \frac{-K}{ms}$, $x = t$ and $c = C$.

So equation(4) represents the equation of straight line. Hence Newton's law of cooling is verified theoretically.



Determination of specific heat capacity of liquid by cooling method:

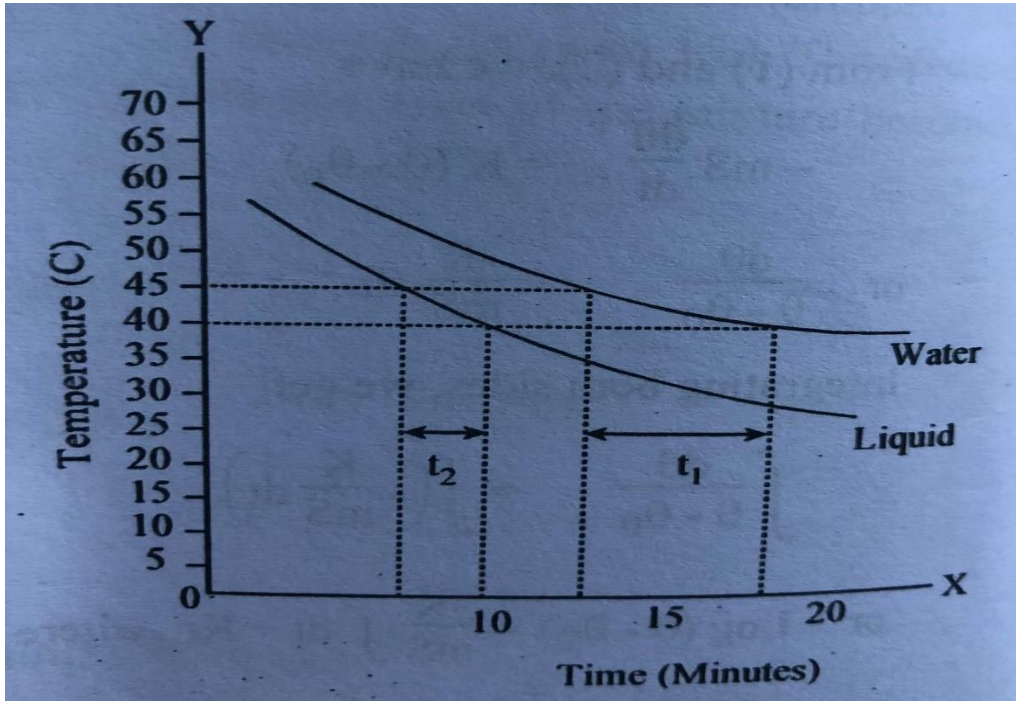


The experimental arrangement for the measurement of specific heat capacity of liquid by cooling method is as shown in figure.

This experiment is based on the principle that “If different liquids are cooled under same condition, their rate of cooling are always same”. And knowing the sp. heat capacity of one liquid, sp. heat capacity of another liquid can be easily determined.

Initially, two identical calorimeters C_1 and C_2 of the same material are taken and are weighed. Some amount of water in a beaker and equal volume of unknown liquid whose specific heat capacity is to be determined is taken in another beaker and are heated up to 70^0C. Now, hot water is poured into the calorimeter C_1 and liquid into calorimeter C_2. Then both calorimeters are placed inside the cooling apparatus whose temperature is maintained constant by the continuous flow of cold water.

After sometime, temperature of both water and liquid are noted in regular interval of time. Then a graph is plotted by taking time along X-axis and temperature along Y-axis for both water and liquid. And, from graph, time taken by water and liquid to cool through same range of temperature is noted. Finally, both calorimeters are weighed to know the mass of water and liquid.



- let,
- Mass of calorimeter $C_1 = M_{C_1}$
- Mass of calorimeter $C_2 = M_{C_2}$
- Sp.heat capacity of calorimeter $C_1 and\ C_2 = S_c$
- Mass water=M_W
- Mass of liquid=M_l
- Sp.heat capacity of water=S_W
- Sp.heat capacity of liquid=S_l=?

From graph,

Time taken by water and calorimeter C_1 to cool from θ_1 to θ_2 $=t_1$

Time taken by liquid and calorimeter C_2 to cool from θ_1 to θ_2 $=t_2$

Now, rate of heat loss by water and calorimeter C_1

$$\left(\frac{dQ}{dt}\right)_1 = \frac{M_W S_W(\theta_1-\theta_2)+M_{C_1} S_C(\theta_1-\theta_2)}{t_1}$$

And the rate of heat loss by liquid and calorimeter C_2

$$\left(\frac{dQ}{dt}\right)_2 = \frac{M_l S_l(\theta_1-\theta_2)+M_{C_2} S_C(\theta_1-\theta_2)}{t_2}$$

According to Newton’s law of cooling,

$$\left(\frac{dQ}{dt}\right)_1 = \left(\frac{dQ}{dt}\right)_2$$

$$\frac{M_W S_W(\theta_1-\theta_2)+M_{C_1} S_C(\theta_1-\theta_2)}{t_1} = \frac{M_l S_l(\theta_1-\theta_2)+M_{C_2} S_C(\theta_1-\theta_2)}{t_2}$$

$$\frac{t_2}{t_1}\left[M_W S_W + M_{C_1} S_C\right] = M_l S_l + M_{C_2} S_C$$

$$\therefore S_l = \frac{\left\{\frac{t_2}{t_1}\left[M_W S_W + M_{C_1} S_C\right] - M_{C_2} S_C\right\}}{M_l}$$

Change of state

Melting point

It is the temperature at which matter changes its state from solid to liquid at constant pressure. Melting point of ice at 760mm of Hg is 0^0C.

Freezing point

It is the temperature at which liquid just begin to freeze. Or ‘It is the temperature at which matter changes its state from liquid to solid at constant pressure. Freezing point of pure water at 760760mm of Hg is 0^0C.

Note**:** The melting point and freezing point are same for crystalline substance but not for amorphous non-crystalline substance.

Boiling point

It is the temperature at which matter changes its state from liquid to gas at constant pressure. boiling point of water at 760mm of Hg is 100^0C.

Latent heat and Specific latent heat

Heat energy required to change the state of a substance is called latent heat.

Heat energy required to change the state of a unit mass of a substance is called specific latent heat.

They are of two types:

1. Latent heat of fusion

It is defined as the amount of heat energy absorbed or loss by the substance to change it’s state either from solid to liquid or liquid to solid at constant temperature.

2. Latent heat of vaporization

It is defined as the amount of heat energy absorbed or loss by the substance to change it’s state either from liquid to gas and vice-versa at constant temperature.

Specific latent heat of fusion

It is defined as the amount of heat energy required to change the state of unit mass substance from solid to liquid at constant temperature.

Experimentally, it is observed that the amount of heat energy required to change the state of matter from solid to liquid at its melting point depends on the mass of the substance.

i.e. $Q \propto \text{m}$

$Q = L_f \text{m}$

$\therefore Q = \text{m}\ L_f$

Where, L_f is proportionality constant known as specific latent heat of fusion. Its SI unit is J/kg and CGS unit is Cal/gm.

Latent heat of fusion of ice is 80 Cal/gm or 3.36×10^5 J/kg.

Specific latent heat of vaporization

It is defined as the amount of heat energy required to change the state of unit mass substance from liquid to gas at constant temperature.

Experimentally, it is observed that the amount of heat energy required to change the state of matter from liquid to gas at its boiling point depends on the mass of the substance.

i.e. $Q \propto m$

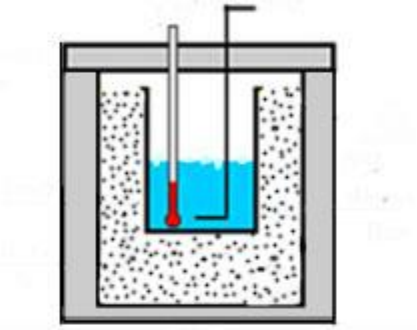
$Q = L_v m$

$\therefore Q = m L_v$

Where, L_v is proportionality constant known as specific latent heat of vaporization . Its SI unit is J/kg and CGS unit is Cal/gm.

Latent heat of vaporization of ice is 540 Cal/gm or 2.26×10^6 J/kg.

Determination of latent heat of fusion of ice by the method of mixture



The experimental setup for the measurement of latent heat of fusion of ice by the method of mixture is shown in figure above.

Initially, a clean dry calorimeter with stirrer is taken and weighted. About two-third of its volume is filled by water and further weighted to know the mass of water. The calorimeter and it's content is placed inside the wooden box and initial temperature of water and calorimeter is noted with the help of thermometer 'T'.

Some pieces of ice at melting state are taken and the water present on the surface of ice is soaked by using blotting paper and then placed inside the calorimeter. The mixture is stirred gently until all ice melts and then final temperature of mixture is noted. The mixture is again weighted to know the mass of ice.

Let,

Mass of calorimeter and stirrer =M_C

Specific heat capacity of calorimeter=S_C

Mass of water = M_W

Specific heat capacity of water=S_w

Initial temperature of water and calorimeter=θ_1

Final temperature of mixture = θ

Mass of ice=M_i

Initial temperature of ice = θ_2= 0^0C

Latent heat of fusion of ice= L_f= ?

Now,

Heat lost by water and calorimeter=$M_W S_W (\theta_1 - \theta) + M_C S_C (\theta_1 - \theta)$

Heat gained by ice

=Heat gained by ice at 0^0C to water at 0^0C + Heat gained by water at 0^0C to water at θ^0C

$=M_i L_f + M_i S_w (\theta - 0^0C)$

$=M_i L_f + M_i S_w \theta$

Therefore, From the principle of calorimetry

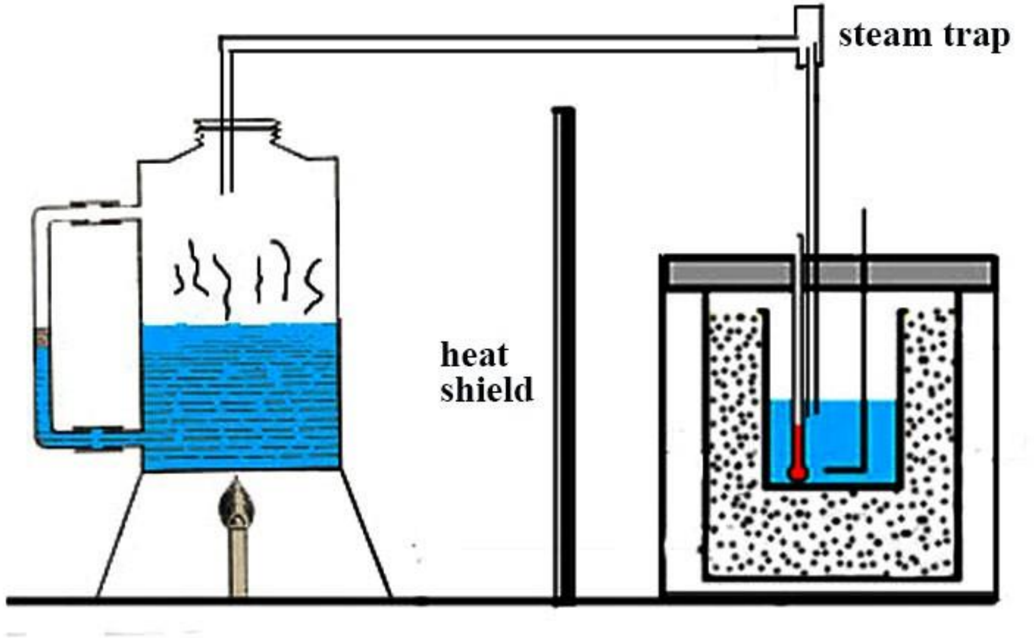
Heat loss=Heat gain

$$M_W S_W\ (\ \theta_1 -\ \theta) + M_C S_C\ (\ \theta_1 -\ \theta) = M_i L_f + \ M_i S_w$$

$$L_f = \frac{(M_W S_W\ + M_C M_C)(\ \theta_1 - \ \theta)}{M_i}\ - S_W\ \theta$$

Thus, by getting the value of M_W, S_W, M_C, S_C, θ, θ_1 and M_i, we can easily determine latent heat of fusion by the method of mixture.

Determination of latent heat of vaporization of water by the method of mixture



The experimental setup for the measurement of latent heat of vaporization of water by the method of mixture is shown in figure above.

Initially, a clean dry calorimeter with stirrer is taken and weighed. About two-third of its volume is filled by water and further weighted to know the mass of water. The calorimeter and it’s content is placed inside the wooden box and initial temperature of water and calorimeter is noted with the help of thermometer ‘T’.

Now, the steam is passed into the water from boiler/steamer for some time and the flow of steam is cut off. Then, the final temperature of mixture is noted. Again the mixture is weighed to know the mass of the steam.

Let,

Mass of calorimeter and stirrer $=M_C$

Specific heat capacity of calorimeter$=S_C$

Mass of water $= M_W$

Specific heat capacity of water$=S_w$

Initial temperature of water and calorimeter$=\theta_1$

Final temperature of mixture $= \theta$

Mass of steam$=M_S$

Initial temperature of steam $= \theta_2= 100^0C$

Latent heat of vaporization of water$= L_V= ?$

Now,

Heat gained by water and calorimeter=$M_W S_W$ (θ- θ_1)+$M_C S_C$ (θ- θ_1)

Heat lost by steam= $M_S L_V$+ $M_S S_w$ (100^0C-θ)

Therefore, From the principle of calorimetry

Heat loss=Heat gain

$$M_S L_V + M_S S_W (100 - \theta) = M_W S_W (\theta - \theta_1) + M_C S_C (\theta - \theta_1)$$

$$L_V = \frac{M_W S_W + M_C M_C (\theta - \theta_1)}{M_S} - S_W (100 - \theta)$$

Thus, by getting the value of M_W, S_W, M_C, S_C, θ, θ_1 and M_S, we can easily determine latent heat of vaporization of water by the method of mixture.