Quantity of heat:

Calorimetry : The branch of physics in which we study about the measurement of quantity of heat is called calorimetry. The device which is used to measure the quantity of heat Caloriemeter

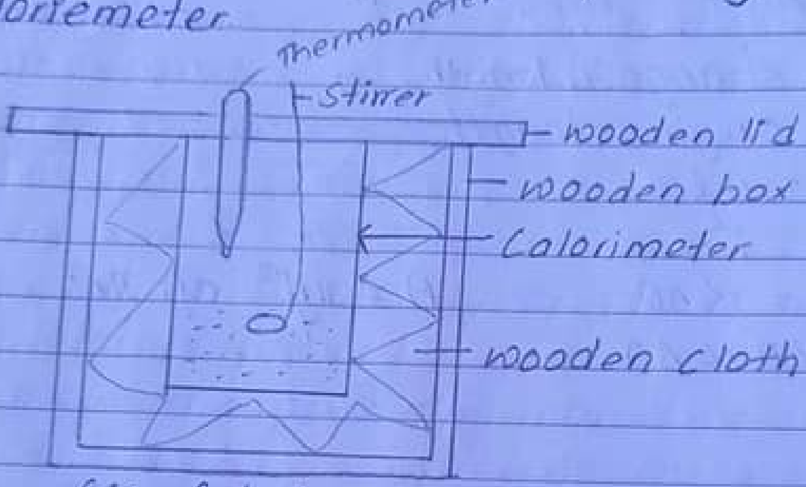

fig = Caloriemeter

A simple construction of Caloriemeter is shown in figure. It consist of a cylindrical vessel. Generally made up of copper with a stirrer made by the same copper. It is kept inside the wodden box by wrapping it with woolen cloth so that it is totally insulated from the surrounding. Thermometer is used to record the temperature of Caloriemeter & its content.

The experimental object are kept inside the Caloriemeter in contact ~~to~~ to each other, there will be exchange of heat betn Caloriemeter & objects and finally, they will be in thermal equilibrium.

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Principle of Calorimetry:
The heat loss by hot body is numerically equal to the heat gain by cold body i.e. heat loss = heat gain.

Provided that there is no loss of heat to the surrounding.

Specific heat capacity
From experiment, it has been found that the amount of heat energy 'Q' contain in a body is

(i) directly proportional to the mass (m) of the body i.e. $Q \propto m$ ... (i)

(ii) directly proportional to the change in temperature $(\theta_2 - \theta_1)$ of the body ~~th~~ i.e. $Q \propto (\theta_2 - \theta_1)$ ... (ii) where θ_2 & θ_1 are final & initial temperature.

Now combining above two relation we get,

$Q \propto m(\theta_2 - \theta_1)$

$Q = ms(\theta_2 - \theta_1)$ ... (iii) where s is the proportionality constant called specific heat capacity whose value depends upon the nature of material taken.

From eqn (iii)

$S = \frac{Q}{m(\theta_2 - \theta_1)}$ If $m = 1$ unit & $\theta_2 - \theta_1 = 1$ unit ($1°C$ or $1K$) then $s = Q$.

Thus, specific heat capacity is defined as amount of heat energy required to change the temperature of unit mass of the body through unit °c.

Unit of s
It's SI unit is $J kg K^{-1}$ & CGS unit $Cal/g°c$.

Specific heat capacity of water is 4200 $J/kg K$ or 1 $Cal g°C$.

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Thermal capacity or heat capacity

→ It is defined as the amount of heat energy required to change the temperature of given mass of the body through unit °C.

If Q is the amount of heat energy required to change the temperature of the body of mass(m) through $\Delta\theta$ then we have,

$Q = ms\Delta\theta$

If $\Delta\theta = 1°C$ or 1 K then,

$Q = ms$

Hence, thermal capacity of a body is numerically equal to the product of mass & specific heat capacity. SI unit of thermal capacity is J/K & its CGS unit is Cal /°C.

Water equivalent

The water equivalent of a substance is defined as the mass of water gains or loses the same amount of heat as gained or loss by the substance for the same rise or fall in temperature. It is denoted by w.

Let us consider a substance of mass (m), & specific capacity (s). Let θ_2 & θ_1 be the final & initial temperature respectively then the quantity of heat Q is given by, $Q = ms(\theta_2 - \theta_1)$ ...(i)

If w is the water equivalent of the substance than $Q = ws_w(\theta_2 - \theta_1)$ ...(ii)

where S_w is the specific heat capacity of the water,

Now from eqn (i) & (ii)

$ws_w(\theta_2 - \theta_1) = ms(\theta_2 - \theta_1)$

$$ws_w = ms$$

or, $$w = \frac{ms}{s_w}$$

In CGS system $s_w = 1$ cal/g°C

$$w = ms$$

Hence water equivalent of a substance in CGS system is numerically equal to thermal capacity.

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

The specific heat capacity of solid can be determine by using the method of mixture. It is based on the principle of Calorimetry i.e heat loss = heat gain.

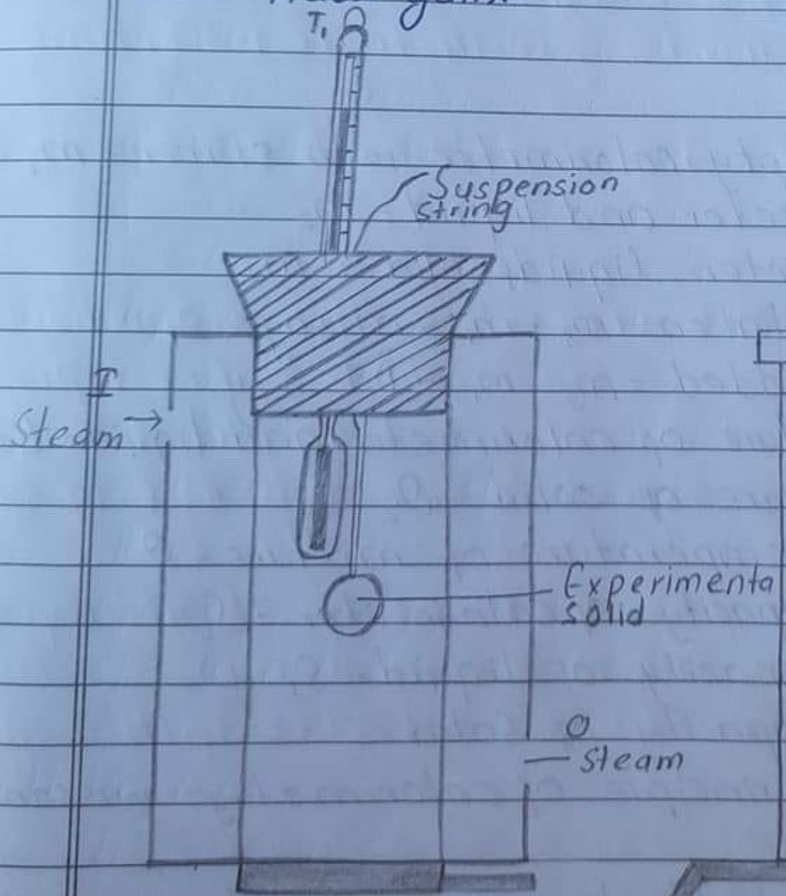
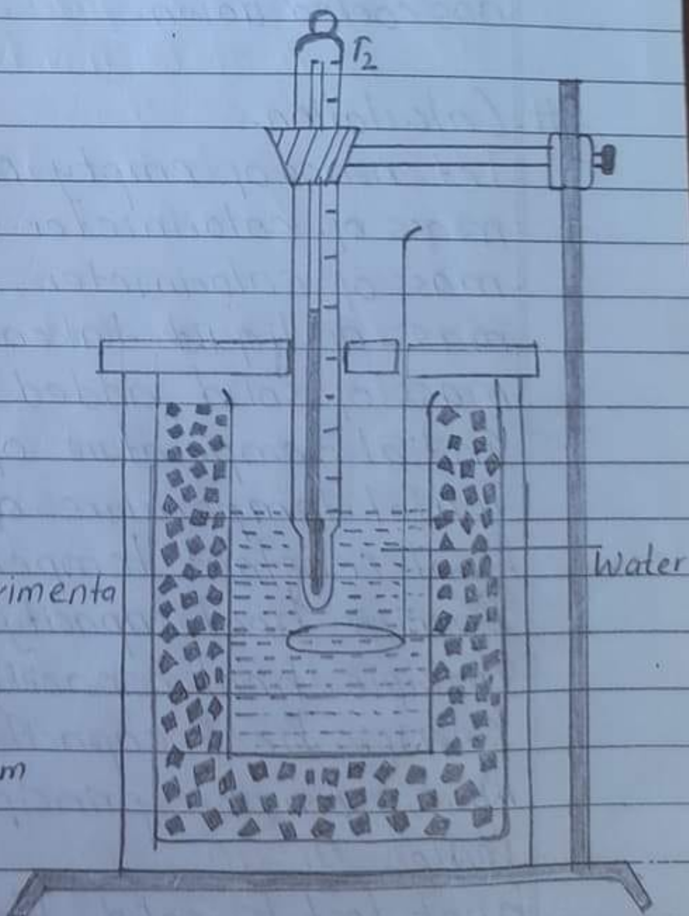


fig:- Steam chamber



fig(ii) Calorimeter

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Method: A neat, clean dry and empty caloriemeter along with stirrer is taken and weighed it. About $\frac{3}{4}$th of the caloriemeter is filled with liquid and the whole mass is measured again. The caloriemeter with the liquid is kept inside the wooden box. and their initial temperature is noted.

The solid whose specific heat capacity is to be determined is heated to a ~~to~~ known high temperature and is quickly transferred into the liquid inside the calorimeter. The lid is closed and the mixture is stirred well. The final constant temperature of the mixture is noted. The whole mass of the mixture is weighed again after the mixture has cooled down.

Calculation.

Let, mass of empty calorimeter with stirrer = m_1
mass of calorimeter and liquid = m_2
mass of calorimeter, liquid & solid = m_3
mass of liquid taken = $m_2 - m_1 = m$ say
mass of solid added = $m_3 - m_1 = M$ say
Initial temperature of calorimeter and liquid = θ_1
Initial temperature of solid = θ_2
Final constant temperature of mixture = θ
Specific heat capacity of calorimeter = S_c
Specific heat capacity of liquid = S_l
Specific heat capacity of Solid = S
Now, from the principle of calorimetry, we can write,
heat lost by solid = Heat gained by calorimeter + Heat gained by liquid.

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i.e. $Ms(\theta_2-\theta_0) = m_1 s_c(\theta-\theta_1) + m s_l(\theta-\theta_1)$

or, $Ms(\theta_2-\theta) = (m_1 s_c + m s_l)(\theta-\theta_1)$

or, $s = \frac{(m_1 s_c + m s_l)}{M} \frac{(\theta-\theta_1)}{(\theta_2-\theta)}$

Thus, by knowing the value of all the physical quantities of RHS. s can be determined.

Newton's law of cooling

It states that "The rate of cooling of hot liquid is directly proportional to the difference in temperature between the liquid and that of its surroundings, provided the difference in temperature between the liquid and surroundings should be small and heat loss due to to radiation should be minimum."

Let us consider a hot liquid of temperature θ and temperature of the surrounding θ_0. If the liquid losses small amount of heat (dQ) in small time (dt) then it's rate of heat loss is $-\frac{dQ}{dt}$, where negative sign indicates the decrease in heat within body with increase in time.

According to the above statement we can write

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

or, $-\frac{dQ}{dt} = k(\theta - \theta_0)$ where k is the proportionality constant, whose value depends

or, $\frac{dQ}{dt} = -k(\theta - \theta_0)$ ...(i) on nature of liquids & surface area expose to the surrounding ~~or~~

If m & s be the mass and specific heat capacity of liquid then we have, $Q = ms\theta$ ...(ii)

differentiating eqn (ii) on both side with respect to t, we get,

$$\frac{dQ}{dt} = ms\frac{d\theta}{dt} \quad \text{...(iii)}$$

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Now, equating eqⁿ (iii) & (i), we get,

$ms\frac{d\theta}{dt} = -k(\theta-\theta_0)$ or, $\frac{d\theta}{(\theta-\theta_0)} = \frac{-k\,dt}{ms}$

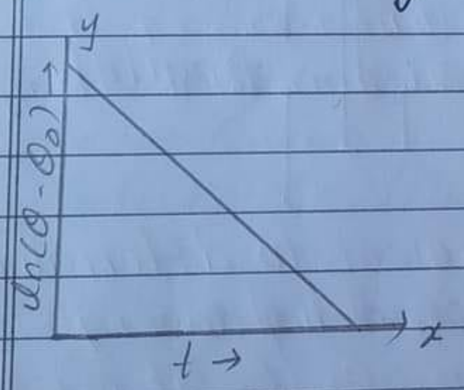
On integration we get,

~~$\int ms\frac{d\theta}{dt} = \int -k(\theta-\theta_0)$~~

$\int\frac{d\theta}{(\theta-\theta_0)} = \int\frac{-k}{ms}dt$

or, $\ln(\theta-\theta_0) = \frac{-k}{ms}t + c$ {where is c is the integration Constant}

This eqⁿ is in the form of $y = mx + c$, which is the eqⁿ of straight line. If we plot a graph between $\ln(\theta-\theta_0)$ and t, we get the following straight line which verifies newton's law of cooling



LIMITATIONS Of Newton's law of cooling.

(i) This law cannot be applied for large difference of temperature between the liquid and that of surrounding.

(ii) This law is strictly valid only for liquid and not for solid and gas.

Determination of specific heat capacity of liquid by the method of cooling.

It is based on the principle that when the two liquids are cooled under identical condition, their rates of cooling are same.

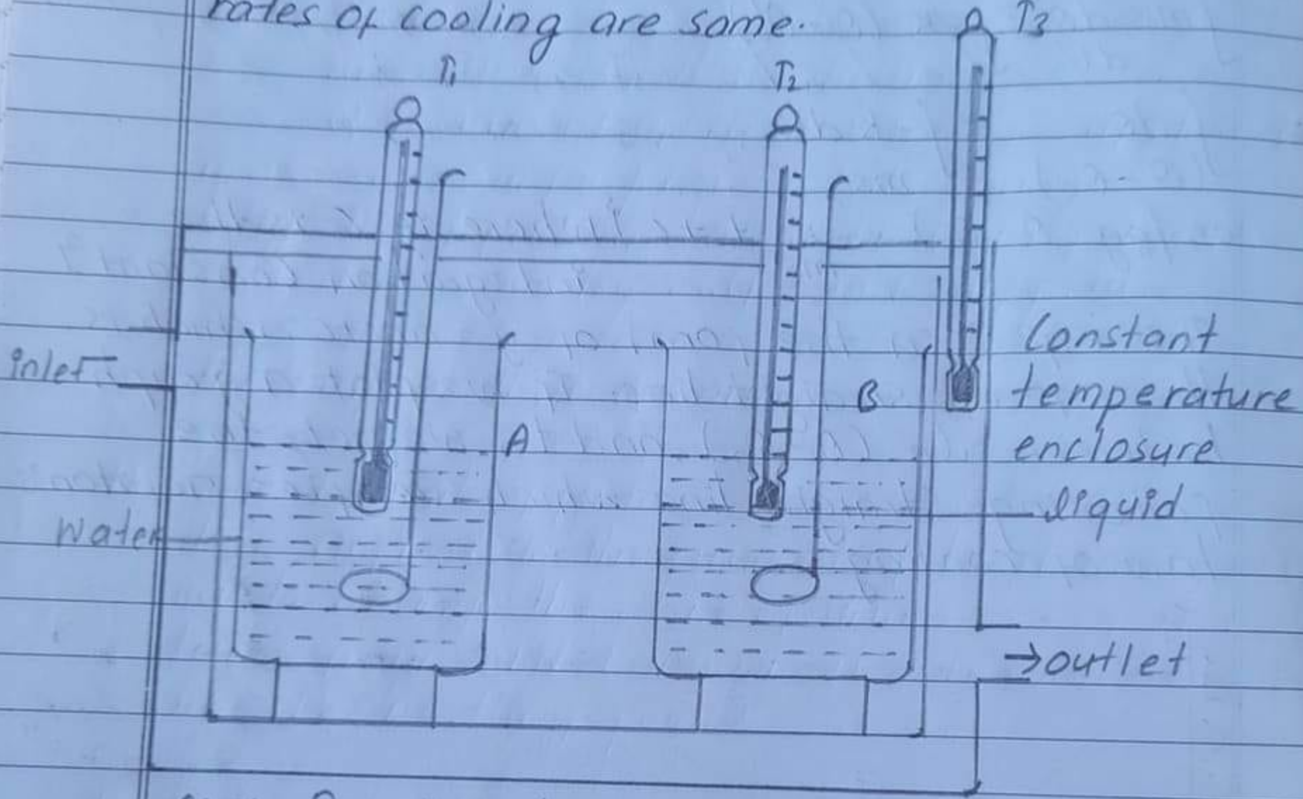


fig:- Experimental arrangement to determine Specific heat capacity of a liquid.

Let us take two identical Caloriemeter A & B of masses m_1 and m_2 respectively, made of the same material. let S_c be the specific heat capacity of material of the Caloriemeter. Suppose m_1 contains water of mass M_1 and specific heat capacity S_w. Similarly ~~A~~ m_2 contains experimental liquid of mass M_2 and Specific heat capacity S. Two calorimeters are kept inside the constant temperature enclosure and their initial temperature

θ_1 is noted. Two caloriemeters are identical and they are left for cooling in the similar surroundings. Let t_1 and t_2 be the time taken by the water & experimental liquid respectively to cooled down from initial temperature θ_1 to the final temperature θ_2.
Now,
Heat loss by water and caloriemeter $A = M_2 S_w (\theta_1 - \theta_2) + m_2 S_c (\theta_1 - \theta_2)$
$\therefore$ Rate of cooling of water & caloriemeter A

$$= \frac{(M_2 S_w + m_2 S_c)(\theta_1 - \theta_2)}{t_1}$$

Similarly, rate of cooling of liquid and caloriemeter B.

$$= \frac{(M_2 S + m_2 S_c)(\theta_1 - \theta_2)}{t_2}$$

From the law of cooling, the rate of cooling of water Caloriemeter A = rate of cooling of liquid & calorie meter B. i.e.

or, $$\frac{(M_2 S_w + m_2 S_c)(\theta_1 - \theta_2)}{t_1} = \frac{(M_2 S + m_2 S_c)(\theta_1 - \theta_2)}{t_2}$$

or, $$(M_2 S + m_2 S_c) = (M_2 S_w + m_2 S_c)\frac{t_2}{t_1}$$

or, $$M_2 S = (M_2 S_w + m_2 S_c)\frac{t_2}{t_1} - m_2 S_c$$

or, $$S = \left(\frac{M_2 S_w}{M_2} + \frac{m_2 S_c}{M_2}\right)\frac{t_2}{t_1} - \frac{m_2 S_c}{M_2}$$

Latent heat

The amount of heat energy required to change the state of unit mass of substance from solid to liquid or liquid to vapour without any change

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in temperature is called latent heat or heat of transformation. It is denoted by capital(L).

Relation for Latent heat.

Let, L = Latent heat

m = mass of the substance

Q = amount of heat energy supplied to mass m ~~from~~ for phase/state change.

By the definition, Latent heat (L) = $\frac{Q}{m}$. It's SI unit is Joule/kg, CGS unit cal/g.

This emplies that $Q = mL$

Latent heat of fusion

It is defined as the amount of heat energy required to change the state of unit mass of the substance from solid to liquid at constant temperature (i.e it's melting point)

Latent heat of fusion of ice

It is defined as the amount of heat energy required to change the unit mass of ice at 0°C into water at 0°C. It is 80 cal/g or 336000 J/kg

Latent heat of vaporization

It is defined as the amount of heat energy required to change the state of unit mass of substance from liquid to vapour at constant temperature. (i.e boiling point)

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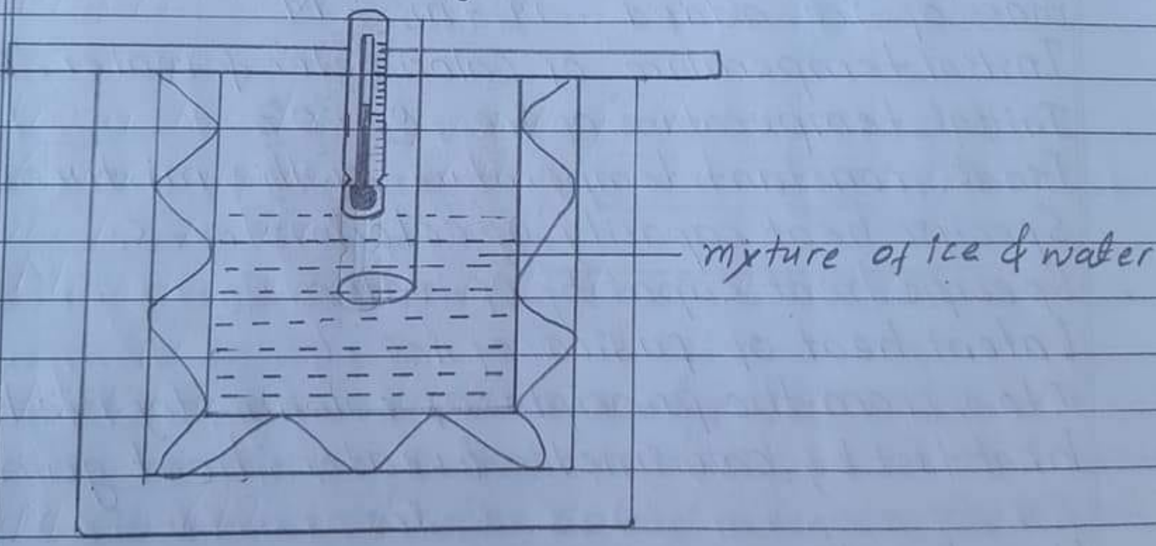
Latent heat of vaporization of water ~~an~~ or latent heat of steam.

→ It is defined as the amount of heat energy required to change the unit mass of water at 100°c into steam at 100°c. It is 540 cal/g or 2268000 J/kg.

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

→ The latent heat of fusion of ice can be determined by using the method of mixture. It is based on the principle of caloriemetry i.e. heat loss = heat gain.



Method: First of all, neat, clean ~~and~~ dry and empty caloriemeter along with stirrer is taken & weigh it. About half of the caloriemeter is fill with water & the whole mass is weighed again. The caloriemeter with water is kept inside the wooden box and their initial temperature is noted from the thermometer. A few pieces of

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ice are first dried by woolen clothe or blotting paper and then added to the water inside the calorimeter. The lid is closed and the mixture is stirred well and the final constant temperature of the mixture is noted. The whole mass of the mixture is weighed again.

Calculation:-

Let, mass of empty calorimeter along with stirrer $= m_1$

mass of caloriemeter & water $= m_2$

mass of calorimeter, water & ice $= m_3$

mass of water taken $= m_2 - m_1 = m$

mass of ice added $= m_3 - m_2 = M$

Initial temperature of calorimeter & water $= \theta_1$

Initial temperature of ice $= \theta_2 = 0°c$

Final constant temperature of the mixture $= \theta$

Specific heat capacity of calorimeter $= S_c$

Specific heat capacity of water $= S_w$

Latent heat of fusion of ice $= L$

Now, from the principle of calorimetry we have,

heat lost by calorimeter & water = heat gained by ice

Heat lost by calorimeter + heat lost by water = heat gained by ice to melt + heat gained by water (formed from ice) to the final constant temp.

i.e. $m_1 S_c (\theta_1 - \theta) + m S_w (\theta_1 - \theta) = ML + M S_w (\theta - \theta_2)$

or $ML = (m_1 S_c + m S_w)(\theta_1 - \theta) - M S_w (\theta - \theta_2)$

or $L = \left(\frac{m_1 S_c}{M} + \frac{m S_w}{M}\right)(\theta_1 - \theta) - S_w (\theta - \theta_2)$

Hence L is determined.

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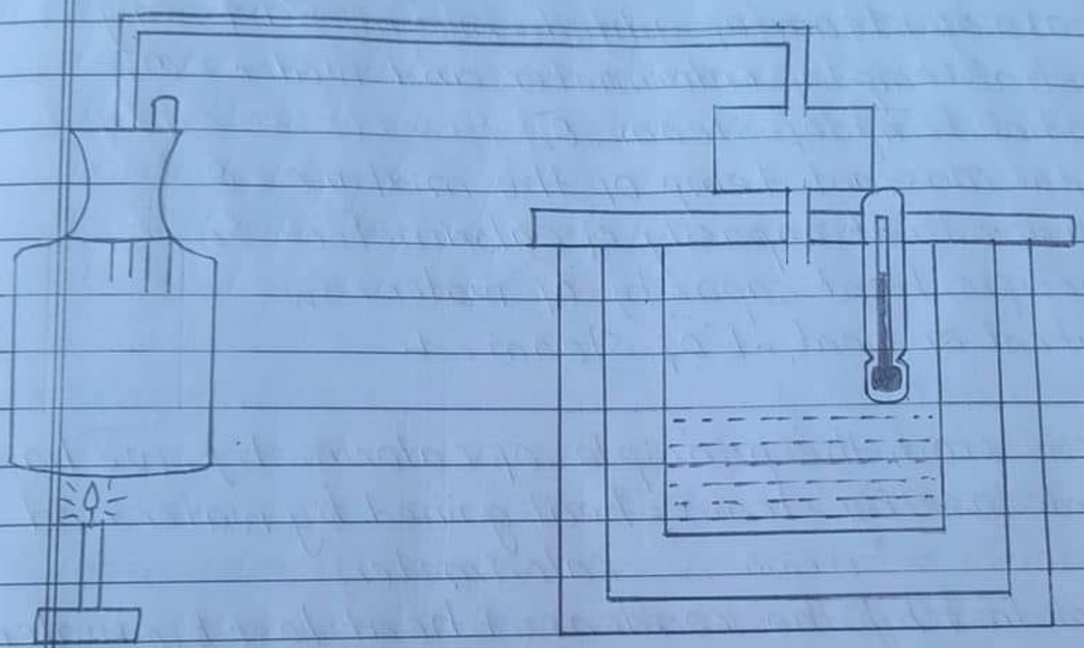
Determination of latent heat of steam by the method of mixture.

The latent heat of steam can be determined by using the method of mixture. It is based on the principle of calorimetry i.e. heat loss = heat gain.



Method: First of all, a neat, clean, dry and empty calorimeter along with stirrer is taken and weighed it. About half of the calrorimeter is filled with water and weighed ~~it~~ again. The calorimeter with water is kept inside the wooden box and their initial temperature is noted.

In the next side, the steam is produced on the boiler and that steam is supplied to the water inside the calorimeter with the help of delivery tube as shown in figure. The mixture is stirred well and final constant temperature of

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the mixture is noted. The whole mass of the mixture is weighed again.

* ~~hat~~. Calculation

Let mass of empty calorimeter with stirrer = m_1

mass of calorimeter and water = m_2

mass of calorimeter, water and steam = m_3

mass of water taken = $m_2 - m_1$ = m(say)

mass of steam of added = $m_3 - m_2$ = M say

Initial temp. of calorimeter and water = θ_1

Initial temp. of steam = θ_2

Final constant temp of the mixture = θ

Specific heat capacity of calorimeter = S_c

Specific heat capacity of water = S_w

Latent ~~of~~ heat ~~of~~ of steam = L

Now, from the principle of calorimetry, we have,

Heat lost by steam = heat gained by water and calorimeter.

Heat lost by steam the condense + heat lost by water (form from steam) to reach the final temp.

= Heat gained by calorimeter + heat gained by water.

i.e. $ML + MS_w(\theta_2 - \theta) = m_1 S_c(\theta - \theta_1) + mS_w(\theta - \theta_1)$

or, $ML = (m_1 S_c + mS_w)(\theta - \theta_1) - MS_w(\theta_2 - \theta)$

or, $L = \left(\frac{m_1 S_c}{M} + \frac{mS_w}{M}\right)(\theta - \theta_1) - S_w(\theta_2 - \theta)$

Hence L ~~b~~ can be determined.

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Melting and freezing:

The change of state from solid to liquid is called melting while the change of state from liquid to solid is called freezing. During melting and freezing of the substance, temperature remains same.

* Supercooling:- The phenomenon in which the liquid can be cooled below it's freezing point without changing it into its solid state is called supercooling.

This is possible by adding impurity atoms in the given liquid.

* Regelation:-

The process of melting of ice under the application of pressure and it's solidification after the removal of pressure is called ~~is~~ Regelation. For eg:- if we press two pieces of ice together then we get single piece of ice after the removal of external pressure.

Difference betn evaporation and boiling.

	Evaporation	Boiling
1.	It is slow and silent process of conversion of liquid into vapour.	It is rapid and noisy process of conversion of liquid into vapour.
2.	It takes place from the surface of the liquid.	It takes place throughout the liquid.

(3) It takes place at all the temperature.	It takes place at the boiling point of liquid.
(4) Cooling effect is observed.	Cooling effect is not observed.

How much heat is required to convert 10 g ice at -10°c into steam at 100°c?
($S_i = 0.5$ cal/g°c, $S_w = 1$ cal/g°c, $L_i = 80$ cal/g, L_s 540 cal/g

Soln:-

$m = 10g$

$S_i = 0.5$ cal/g°c

$S_w = 1$ cal/g°c

$L_i = 80$ cal/g

$L_s = 540$ cal/g

$Q = ?$

The amount of heat energy required to change ice at -10°c to ice at 0°c is

$Q_1 = mS_i(0-(-10))$

$= 10 \times 0.5 \times 10$

$= 50$ cal

The amount of heat energy required to change ice at 0°c to water at 0°c is

$Q_2 = mL$

$= 10 \times 80$

$= 800$ cal.

The amount of heat energy required to change the water at 0°c to water at 100°c

$Q_3 = mS_w(100-0)$

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$= 10 \times 1 \times 200$

$= 2000$ cal.

The amount of heat energy required to change the water at 100°C to steam at 100°C

$Q_4 = mLs$

$= 10 \times 540$

$= 5400$ cal.

$Q = Q_1 + Q_2 + Q_3 + Q_4$

$= 50 + 800 + 1000 + 5400$

$= 7250$ cal.

$= 30450$ J

$t = 15$ min.

Triple point: The point in phase diagram ~~wh~~ representing a particular pressure & temperature at which the solid, liquid and gaseous state of the substance can co-exist is called triple point.

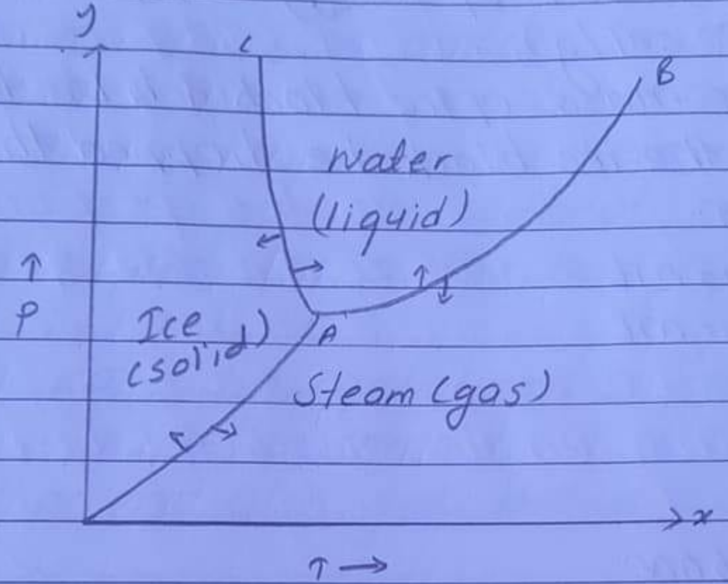

fig:- phase diagram of water (P-T)

Here, AB = Vaporization Curve (Hoar-frost line)

AC = Fusion curve (Ice-line)

OA = Sublimation curve (Steam-line)

A = Triple point

4·58 mm of Hg

0.0075°C

Triple point is the point of intersection of the Hoar-frost line, ice line & steam line.

It is taken as standard in modern thermometry because it always occurs at particular

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pressure & temperature.

The triple point of water is at 4.58 mm Hg of pressure & 0.0075 °c temperature.

From what ~~weight~~ height a block of ice be dropped in order that it may completely melt. It is assumed that 20% of energy of fall is retained by ice ($L = 80$ cal/g)

→ let m be the mass of ice block & h be the height from which the ice block be dropped then, by the question.

20% of $mgh = mL$

or, $\frac{20}{100} \times m \times gh = mL$

or, $h = \frac{5L}{g}$

$= \frac{5 \times 336000}{10}$

$= 168000$ m