CHAPTER TWELVE

LATENT HEAT

The latent of vaporization:

- This is the quantity of heat which is required to change the whole mass of a substance from the liquid to the vapour state, at its boiling point without a change in temperature.
- When water is heated, its temperature rises steadily until it reaches 100^0C which is its boiling point.
- It then starts to boil and once it starts boiling, its temperature remains constant at 100^0C.
- But at the same time, heat is being steadily absorbed by the water from the source of heating such as a heater or a burner.
- This heat which goes into the water but does not cause a change in its temperature, is the energy needed to convert the water from the liquid state into the vapour state and is called the latent heat of vapourization.
- But the amount of heat which is needed to convert a unit mass, (1kg) of a liquid into vapour as its boiling point (constant temperature), is called the specific latent heat of vapourization.
- For example, experiment shows that 2260000J is required to convert 1kg of water at its boiling point into steam at the same temperature, and this is what is referred to as the specific latent heat of steam.
- When the steam condenses to form water, this latent heat is given out.
- Because steam contains more or additional heat as compared to boiling water, a scald from steam does more harm than one from boiling water.
- The S.I unit of specific latent heat of vaporization is the joule per kilogram (J/kg).
- However kJ/kg or MJ/kg may be used instead.
- 1kJ = 1000J and 1MJ = 1000000J.
- For example, the specific latent heat of vaporization of water is 2260kJ/kg, or

2.26MJ/kg.
- The latent heat of vaporization = ml, where m = mass and l = the specific latent heat of vaporization.

(Q1) Calculate the amount of heat needed to change 5kg of a substance into the vapour state at its boiling point. [Take the specific latent heat of vaporization of the substance = 2J/kg].

N/B: Since the mass of the substance is given in kg and the latent heat of vaporization is given in J/kg, we therefore solve the question without doing any conversion.

Soln:

Mass = m = 5kg.
Specific latent heat of vaporization = l = 2J/kg.
The amount of heat needed is the latent heat of vaporization = $m \times l = 5 \times 2 = 10J$.

(Q2) The mass of a body is 1.5kg and its specific latent heat of vaporization is 2260J/g. Determine the amount of heat which will be needed to change this liquid into the vapour state at its boiling point.

N/B: Since the mass is given in kg and the specific latent heat is given in J/g, we must first convert the 1.5kg into grams.

Soln:

m = 1.5kg = 1500g.

L = 2260J/g.

The amount of heat needed = ml = 1500×2260

= 3390000J = 3390kJ.

(Q3) A liquid of mass 20kg is at a temperature of 10^0C, and has a boiling point of 50^0c. Determine the amount of heat which will be needed to evaporate the whole liquid. [The specific latent heat of vaporization of the liquid = 2J/kg, and the specific heat capacity of the liquid = $4J/kg^0C$].

Soln:

(a)- First the liquid will be heated from its initial temperature of 10^0C to its boiling point of 50^0c.

- The amount of heat needed in this case, is the heat capacity where m = 20kg and

c = specific heat capacity of the liquid = $4J/kg^0c$.

Amount of heat needed = m x c x $\Delta\theta$ = $20 \times 4 \times 40$ = 3200J.

(b)- At the boiling point, the temperature remains constant and the liquid changes into the vapour state.

- The amount of heat needed is the latent heat of vaporization = ml or $m \times l$,

where m = mass = 20kg and l = the specific latent heat of vaporization.

=> The amount of heat needed = ml = 20×2 = 40J.

The amount of heat needed to change the liquid from 10^0c into the vapour state

= 3200 + 40 = 3240J or 3.24kJ.

(Q4) 116360J of heat was needed in order to evaporate a certain amount of water, whose temperature was 20^0c. Calculate the mass of the water which was evaporated. [Boiling point of water = 100^0c, specific latent heat of steam = 2260J/g, the specific heat capacity of water = $4.2J/g^0c$].

Soln:

(a)Let m = the mass of water. The water first heats from 20^0c to its boiling point of 100^0C.

The amount of heat needed to do this = $m \times c \times \Delta\theta$

= $m \times 4.2 \times (100 - 20)$

= $m \times 4.2 \times 80$ = 336m.

(b) The amount of heat needed to convert the water at its boiling point into steam = ml = m $\times$ 2260 = 2260m.

(c)The total amount of heat needed to convert the water from 20^0C into vapour = 336m + 2260m = 2596m.

Since the amount of heat needed to convert the water from 20^0c into water vapour = 116360J, then 2596m = 116360,

=> m = $\frac{116360}{2596} = 45g.$

N/B: - Since both the specific heat capacity of water i.e. $4.2J/g^0C$ and the specific latent heat of steam i.e. 2260J/g are both given is grams, our answer must be in grams but not in kg.

- The amount of heat generated within an electrical heating device or a material heating device or a material is given by heat generated = IVt, where I = current in amperes, V = the P.d or the potential difference in volts and t = time in seconds.
- Also, the amount of heat generated is also given by heat generated = I^2Rt, where I = current in amperes, R = the resistance in ohm (Ω), and t = time in seconds.

(Q5) All the heat generated in a 5Ω resistor by a current of 2A flowing for 30 seconds, was used to evaporate 5g of a liquid at its boiling point. Calculate the specific latent heat of the liquid.

Soln:

The heat generated within the 5Ω resistor = I^2Rt, where I = 2A, R = 5Ω and t = 30 seconds.

=> The heat generated = $2^2 \times 5 \times 30$ = 600J.

- This was the amount of heat, which was used to evaporate the 5g of the liquid at its boiling point.

- Also since the liquid is already at its boiling point, only the latent heat of vaporization will be needed for this change to occur.

=> Amount of heat needed = ml = 5 $\times$ l = 5l, where l = the specific heat of vaporization.

Since the amount of heat needed = 600J, => 5l = 600,

=> l = $\frac{600}{5} = 120\text{J}/g$.

N/B: The latent heat of vaporization of a substance is the amount of heat needed, to convert the whole substance from the liquid state into the vapour state, at its boiling point.
-Latent heat of vaporization = ml, where m = mass of the substance and l = its specific heat of vaporization.

Example : If 4220 J of heat was used to evaporate 5kg of a liquid at its boiling point into the vapour state, determine the specific heat of vaporization of the liquid.

Soln:

Latent heat of vaporization = 4220J.

Mass = m = 5kg.

Specific heat of vaporization = l =?

Since latent heat of vaporization = ml, => 4220 = 5l => l = $\frac{4220}{5} = 884$.

=> The specific latent heat of vaporization of the liquid = 884J/kg.

(Q6) 50g of steam was condensed into liquid which was then allowed to cool from 100^0C to 30^0c. Determine the amount of heat given out. [Specific latent heat of steam = 2260J/g, the specific heat capacity of water = 4.2J/g^{0}C].

Soln:
(a)The steam first condenses into liquid and the heat given out = the latent heat of vaporization = ml = 50 × 2260 = 113000J.

(b)The condensed steam or the liquid then cools from 100^0c to 30^0C, and the heat given out = m × c $\times \Delta\theta$ = 50 × 4.2 × (100 – 30) = 50 × 4.2 × 70 = 14700J.

Amount of heat therefore given out = 113000 + 14700 = 128KJ.

(Q7) 0.05kg of steam which was contained in a can, was allowed to cool to a temperature of 20^0C. Calculate the amount of heat given out by the steam and the can. [specific latent heat of steam = 2260J/g, specific heat capacity of water = $4.2J/g^0C$, thermal heat capacity of the can = $4J/^0c$].

N/B: Since the mass is in kg, and the specific latent heat of vapourization as well as the specific heat capacity are associated with grams, then the mass in kilogram must be converted into grams.

Soln:

Mass of steam = 0.05kg = 0.05×1000 = 50g.

The temperature of steam = 100^0C.

Since the steam was contained within the can => the initial temperature of the can = 100^0C.

(a) The steam first condenses into water, and the heat given out is the latent heat of vaporization = ml = 50×2260 = 113000J.

(b) The heat given out by the condensed steam (water) cooling from 100^0C to 20^0C

$= m \times c \times \triangle\theta = 50 \times 4.2 \times (100 - 20)$
$= 50 \times 4.2 \times 80 = 16800J.$

(c) The heat given out by the can in cooling from 100^0c to 20^0c = thermal heat capacity $\triangle\theta = 4 \times (100 - 20) = 4 \times 80 = 320J$.

Therefore the total heat given out by the steam and the can = 113000 + 16800 + 320 = 130120J or 130kJ.

The latent heat fusion:

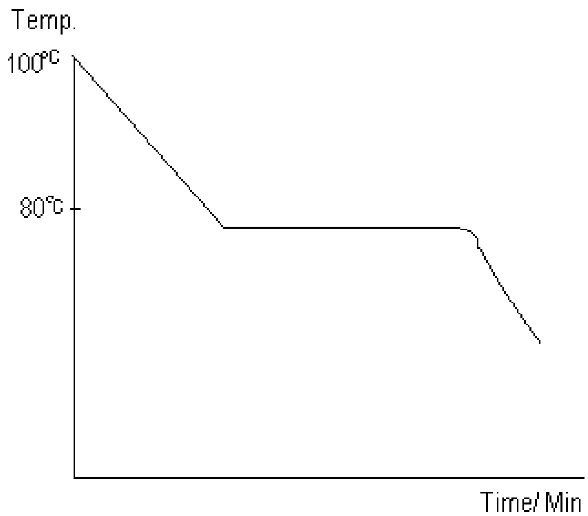
- Just as latent heat is taken in when water changes from the liquid state into the vapour state at a constant temperature, almost a similar thing happens when water changes into ice at a constant temperature.
- The latent heat of fusion is the amount of heat, which is needed to change a substance from the liquid state into the solid state, or from the solid state into the liquid state at a

constant temperature.
- The specific latent heat of fusion of a substance is the amount of heat, which is needed to convert a unit mass (1kg) of it, from either the solid into the liquid state, or from the liquid into the solid state, at a constant temperature (I.e. the freezing or the melting point).

- For example, latent heat of fusion is absorbed or needed in order to convert ice at 0^0C into water at the same temperature.
- Likewise when water at 0^0C freezes into ice, the same quantity of heat (i.e. the latent heat of fusion), is needed.
- Other substances apart from water also absorb latent heat of fusion when they melt.
- They also give out this latent heat when they solidify.
- The latent heat of fusion = ml, where m = the mass and l = the specific latent heat of fusion.
- Its unit is J/kg, kJ/kg or MJ/kg.

The determination of the melting point of a substance, from a cooling curve:

- The latent heat given out when a molten substance freezes into the solid state, can be investigated by using the following experiment with naphthalene.
- A test tube containing naphthalene is held vertically by a clamp and a stand.
- The naphthalene is then gently heated by a very small flame until it melts.
- A thermometer is inserted into the naphthalene, and the heating continued till the temperature gets to around 100^{0c}.
- The Bunsen flame is then removed and readings of the thermometer are taken at small interval as the tube and its contents cooling.
- It will be noticed that when the freezing point or what is the same as the melting point of the naphthalene is reached (i.e. 80^0C), the temperature remains constant until all the naphthalene has solidified, and after all the naphthalene has solidified, the temperature then begins to fall continuously.



- The temperature changes can be illustrated, by plotting a graph of temperature against time.
- The flat portion or the straight line portion of the graph represents the time during which the naphthalene was solidifying.
- At this stage, i.e. 80^0C, the temperature becomes constant even though heat is being lost or gained by the naphthalene.
-This heat being lost or gained which does not cause a change in temperature is what is referred to as the latent heat of fusion.
- And it only causes a change of state of the substance (i.e. either from the liquid into the solid state or from the solid into the liquid state), without causing an increase or decrease in temperature of the substance.
- The flat portion or the straight line portion of the curve gives us the melting point of the substance (naphthalene).

(Q1) A substance of mass 2kg is solid in state, even though it is at its melting point. Determine the amount of heat needed to melt it. [The specific latent heat fusion of the substance = 10J/kg].

Soln:

Since the substance is at its melting point, then the amount of heat needed to melt it = the latent heat of fusion = ml = 2×10 = 20J.

(Q2) The specific latent heat of fusion of ice is given as 336J/g.

(a) Explain what this statement means.
(b) Determine the amount of heat, which will be needed to melt 5g of ice into water.

Soln:

(a) This means that the amount of heat needed to convert 1kg of ice into water at a constant temperature of 0^0C, is 336J.
(b) Mass = m = 5g.

Specific latent heat of fusion = l = 336J.

Amount of heat needed = ml = 5 x 336 = 1680J = 1.68KJ.

(Q3) A material of mass 5kg and at a temperature of - 8^0 C ,was heated till its temperature became 22^0c. If its melting point is 2^0C, calculate the amount of heat absorbed by the substance. [Specific heat capacity of the substance = 11J/kg^{0}c, specific latent heat of fusion of the substance = 30J/kg].

Soln:

(a)First the substance gains heat and its temperature rises from - 8 to 2^0, and the Change in temperature = $\triangle\theta$ = 2 – (- 8) = 2 - - 8 = 2 + 8 = 10^0C.

The heat absorbed = m × c × $\triangle\theta$ = 5 × 11× 10 = 550J.

(b)At its melting point of 2^0C, the temperature remains constant as the substance changes from the solid into the liquid state.

- The heat absorbed = the specific heat of fusion =

ml = 5 × 30 = 150J.

(c) The substance was finally heated from its melting point of 2^0C to 22^0C and the heat absorbed = m × c × $\triangle\theta = 5 \times 11$ ×(22 – 2) = 55 × 20 = 1100J.

The amount of heat absorbed by the substance when warmed from - 8^0C to 22^0C = 1100 + 150 + 550 = 1800J.

N/B: - The specific latent heat of fusion is the heat used or involved when

(a) there is a change from the solid into the liquid state (melting).
(b) a change of state from the liquid into the solid state occurs (freezing/ solidification).

(Q4) 2g of ice whose temperature is -6^0C is to be converted into steam. Find the amount of heat which will be needed. [Specific heat capacity of ice = $2.1J/g^0C$, Specific latent heat of fusion of ice = 336J/g, specific heat capacity of water = $4.2j/g^0c$, specific latent heat of vaporization of steam = 2260J/g].

Soln:

(a) The ice will first absorb heat and its temperature will change from -6^0c to 0^0c (which is the freezing/ melting point of ice).

The amount of heat needed or absorbed = $m \times C \times \triangle\theta = 2 \times 2.1 \times (0 - (-6)) = 4.2 \times (0 + 6) = 4.2 \times 6 = 25.2J$.

(a) At the melting point, the temperature remains constant as the ice changes from the solid into the liquid state. The heat needed = the latent heat of fusion = ml, where l = specific latent heat of fusion of ice. => Heat needed = $2 \times 336 = 672J$.

(b) The water whose temperature is 0^0c, is now then heated to its boiling point of 100^0c. The amount of heat needed = $m \times c \times \triangle\theta$, where c = specific heat capacity of water.

=>Amount heat needed = $2 \times 4.2 \times (100 - 0) = 8.4 \times 100 = 840J$. $\triangle$

(d) The water at its boiling point of 100^0c, is then changed into steam and the heat needed to carry out this change = ml, where l = specific latent heat of vaporization of steam.=> The amount of heat needed = $2 \times 2260 = 4520$.

=> The total amount of heat needed = $4520 + 840 + 672 + 25.2 = 6057J$.

(Q5) Water of mass 2.0kg at a temperature of 30^0c is heated by a 5.0kw coil. Calculate the time taken by the water to boil. [Specific heat capacity of water = $4.2 \times 10^3 Jkg^{-1}k^{-1}$].

Soln:

The heat gained by the water = the heat supplied by the 5kw coil.

Water:

Mass = 2kg.

Initial temperature = 30^0c.

Final temperature = the boiling point of water = 100^0C.

Specific heat capacity = c = $4.2 \times 10^3 = 4.2 \times 1000$ = 4200J/kgk.

Heat gained by water = m$\times\ c \times \triangle\theta = 2 \times 4200 \times (100 - 30)$

$= 2 \times 4200 \times 70 = 588000$J.

For the 5.0KW coil:
Power = P = 5kW = 5000W.

Amount of heat supplied = 588000J.

But power = $\frac{heat\ supplied}{time}$

=> 5000 = $\frac{588000}{time}$

=> 5000 $\times$ time = 588000,

=> Time = $\frac{588000}{5000} = 118Sec.$

N/B: The power given in kW must be converted into W (watts), since kilowatt goes with kJ and watt goes with J.

(Q6) A refrigerator can convert 400g of water at 20^0c to ice at -10^0C in 3 hours. Determine the average rate of heat extraction from the water in JS^{-1}. [S.H.C of ice = $2100Jkg^{-1}k^{-1}$, specific latent heat of fusion of ice = 336000J/kg, S.H.C of water

= $4200Jkg^{-1}k^{-1}$].

N/B: (I) You must first determine the amount of heat needed to convert the 400g of water at 20^0C to ice at -10^0C.

II) Then divide your answer by the time given, after you have converted it into seconds.

Soln:

Mass of water = 400g = 0.4kg.

C = 4200$Jkg^{-1}k^{-1}$.

Initial temperature = 20^0C.

First the temperature of the water falls from 20^0C to 0^0c.

The amount of heat needed for this to occur = $m \times c \times \triangle\theta$ = $0.4 \times 4200 \times 20$ = 33600J.

(II)The amount of heat needed to convert this 0.4kg of water, whose temperature is now 0^0c, into ice at the same temperature = ml, where m = 0.4kg and l = specific latent heat of fusion of ice.

=> Amount of heat needed = 0.4×336000 = 134400J.

(III)The temperature of this ice then falls from 0^0c to -10^0c, and $\triangle\theta$ = 10^0C.

The amount of heat needed for this to occur = $m \times c \times \triangle\theta$ = $0.4 \times 2100 \times 10$ = 8400J.

The amount of heat needed to convert the water from 20^0C to ice at -10^0C = 33600 + 8400 + 134400 = 176400 = 176400J.

=> The amount of heat extracted = 176400J.

Total time taken for this extraction to occur = 3hrs = 3×3600 = 10800 seconds.

The rate of heat extraction = $\frac{176400}{10800} = 16JS^{-1}$.

(Q7) 0.5kg of water at 10^0C is completely converted into ice at 0^0c by extracting 188000J of heat from it. If the specific heat capacity of water is 4200$Jkg^{-1}C^{-1}$, determine the specific latent heat of fusion of ice.

Soln:

(a)First the 0.5kg of water is cooled from 10^0c to 0^0C.

The amount of heat needed for this to occur = m $\times$ c $\times$ $\triangle\theta$ = 0.5 $\times$ 4200 $\times$ (10 – 0) = 0.5 $\times$ 4200 $\times$ 10 = 21000J.

(b)When the temperature of the water gets to 0^0C, it must be converted into ice at the same temperature.

The amount of heat needed to do this conversion = ml, where m = mass and l = the specific latent heat of fusion of ice.

=> The amount of heat needed = ml = 0.5l.

=> Amount of heat needed to change the 0.5kg of water, at 10^0c into ice at 0^0c = 21000 + 0.5l.

Since the amount of heat extracted to do this change = 188000J,

=> 21000 + 0.5l = 188000,

=> 0.5l = 188000 – 21000,

=> 0.5l = 167000 => l = $\frac{167000}{0.5}$ = 334000.

=> The specific latent heat of fusion of ice = 334000Jkg^{-1}.

(Q8) 0.5kg of naphthalene contained in an aluminum can of mass 0.4 kg, was melted in a water bath and its temperature raised to a temperature of 100^0c. Calculate the total amount of heat given out, when the can and its content was allowed to cool to a room temperature of 20^0c. Neglect the heat losses by evaporation, during the heating process and give your answer to the nearest kilojoules. [For naphthalene, melting point = 80^0C, specific heat capacity = 2100J/kg^0C i.e. for both liquid and solid naphthalene, specific latent heat of fusion = 170000J/kg. For aluminum: specific heat capacity = 900J/kg^0C].

N/B: Since the naphthalene which was contained in the aluminum can was heated to 100^0C, then the final temperature of the can and the naphthalene = 100^0C.

The heat given out when the can and its content cools from 100^0c to 20^0c = heat given out when the naphthalene cools form 100^0C to 20^0c + the heat given out when the can cools from 100^0C to 20^0C.

For naphthalene:

Melting point = 80^0C.

Mass = 0.5kg.

Initial temperature = 100^0C.

Final temperature = 20^0C.

c = 2100J/kg.

l = 170000J/kg.

(a)First of all, the naphthalene cools from 100^0c to its melting point of 80^0C. The heat given out = m x c x $\Delta\theta$ = 0.5 x 2100 x (100 – 80) = 0.5 x 2100 x 20 = 21000J.

(b)At its melting point of 80^{0c}, the temperature remains constant while there is a change of state from the liquid into the solid state. The heat lost or required for this change = ml, where l = specific latent heat of fusion of naphthalene. Heat given out = 0.5 × 170,000J = 85000J

(c) The temperature of the naphthalene then falls from 80^0c to 20^0c, and the heat given out= 0.5 × 2100 × (80 – 20) = 0.5 × 2100 × 60 = 63000J.

The total heat the naphthalene alone will give out when its temperature falls from 100^0c to 20^0c = 21000 + 85000 + 63000 = 169000J.

For the can:

Mass = 0.4kg

Initial temperature = 100^0C.

Final temperature = 20^0C.

$\Delta\theta$ = 100 – 20 = 80^0c.

C = 900J/kg^{0}C.

Amount of heat given out by the can when it cools from 100^0c to 20^0c = m × c × $\Delta\theta$

$= 0.4 \times 900 \times 80 = 28800J$.

The total amount of heat given out when the can and its contents cools from 100^0c to 20^0c = Heat given out by the naphthalene + heat given out by the can = 169000 + 28800 = 197800J = 198kj.

(Q9) A copper can together with a stirrer of total heat capacity $60J/^0C$, contains 200g of water at 10^0c. Dry steam at 100^0C is passed into the water while it is stirred, until the whole system reached a temperature of 30^0c. Calculate the mass of steam condensed.

N/B: The heat lost by the steam in cooling from 100^0c to 30^0c = Heat gained by the water in warming from 10^0c to 30^0c + heat gained by the can/ stirrer in warming from 10^0c to 30^0c.

(a) <u>For steam:</u>

Initial temperature = 100^0c.

Final temperature = 30^0c.

$l = 2260J/g$.

mass = m = ?

$\triangle\theta = 100 - 30 = 70^0c$.

The amount of heat given out by the steam in changing into liquid, at a temperature of $100^0c = ml = m \times 2260 = 2260m$.

The amount of heat given out when this condensed steam's (water`s) temperature falls from 100^0c to $30^0c = m \times c \times \triangle\theta = m \times 4.2 \times 70 = 294m$.

The total amount of heat lost by the steam in cooling from 100^0c to 30^0c = 2260m + 294m = 2554m.

<u>For water:</u>

Mass = 200g.

Initial temperature = 10^0c.

Final temperature = 30^0c.

C = $4.2J/g^0c$.

Amount of heat gained by water = m $\times$ c $\times \triangle\theta$ = 200 $\times$ 4.2 $\times$ (30 – 10) = 200 $\times$ 4.2 $\times$ 20 = 16800J.

<u>For the copper/ stirrer</u>

Heat capacity = 60J/c.

Change in temperature = 30 – 10 = 20^0c.

Heat gained = Heat capacity $\times$ change in temperature.

= 60 $\times$ 20 = 1200J.

But since the amount of heat lost by the steam = amount heat gained by water + amount of heat gained by copper/ stirrer,

then 2554m = 16800 + 1200,

=> 2554m = 18000 => m = $\frac{18000}{2554}$ = 7g. Mass of steam condensed = 7g.

N/B: The heat energy supplied by a heating coil is also given by $\frac{V^2t}{R}$, where v = the p.d or the voltage, t = time in seconds and R = resistance.

(Q10) A heating coil of resistance 30ohms is used to heat 1.7kg of water at 20^0c kept in a vessel. The supply voltage is 240v and the heat capacity of the vessel is 200J/k. Calculate the time taken by the water to boil. [Specific heat capacity of water = $4200J/kg^0k$, specific latent heat of vaporization of water = 33600J/kg].

Soln:

<u>For heating coil:</u>

R = 30 ohms, v = 240V and t = time for which current (voltage) was passed.

This time = t = the time taken by the water to boil. Energy supplied by the heating coil = $\frac{V^2t}{R} = \frac{(240)^2t}{30}$

= 1920t => energy supplied = 1920t.

<u>For the vessel:</u>
Heat capacity = 200J/k.

Initial temperature = 20^0c.

Final temperature = the temperature of the boiling point of water = 100^0c.

Change in temperature = $\triangle\theta$ = 100 – 20^0 = 80^0c.

Energy absorbed by the vessel or gained by the vessel = heat capacity $\times$ change in temperature = 200 $\times$ 80 = 16000J.

=>The heat energy absorbed by the vessel which contains the water in warming from 20^0c to 100^0c (which is the boiling point of the water it contains or the highest temperature the water can be heated to) = 16000J.

<u>For the water:</u>

Mass = 1.7kg

c = specific heat capacity = 4200J/kg^{0}k.

l = specific latent heat of vaporization = 33600J/kg.

Initial temperature = 20^0c.

First the water will be heated from 20^0c to 100^0c.

Amount of heat absorbed by or gained by the water in warming from 20^0c to 100^0c

= m x c x (100 – 20)

= 1.7 x 4200 x 80 = 571200J.

At the boiling point, the water starts to boil i.e. changes into the vapour state.

The amount of heat absorbed or gained by the water for this change of state to occur = ml = 1.7 x 33600 = 57120J.

Total amount of heat absorbed by the water = 571200 + 57120 = 628320J.

But since the amount of heat lost or supplied by the heating coil = amount of heat gained by the vessel + amount of heat gained by the water,

then1920t = 16000 + 628320,

=>1920t = 644320,

=> t = $\frac{644320}{1920}$ = 336 seconds = 5.6minutes.

N/B: Because the water is within the vessel, then the temperature of the vessel at any given time will be the same as that of the water.

- For if the temperature of the vessel increases or decreases by a certain amount, then that of the water will correspondingly increases or decreases by the same amount.

(Q11) (a) 200g of a liquid at a temperature of 21^0c was heated to a temperature of 51^0c, by a current of 5A at 6v for 5 minutes. Neglecting the heat losses, calculate the specific heat capacity of the liquid.

(b) If the current was changed to 2.5A, and all the other factors remain the same, calculate the rise in temperature.

Soln:

(a) <u>For the liquid:</u>

Mass = m = 200g = 0.2kg.

Initial temperature = 21^0c.

Final temperature = 51^0c.

$\triangle\theta$ = 51 – 21 = 30^0c.

Specific heat capacity = c =?

Heat gained by water = m x c x $\triangle\theta$ = 0.2 x c x 30 = 6c.

<u>For the heating coil:</u>

Current = I = 5A.

Voltage (p.d) = 6V.

Time = t = 5 minutes = 5 x 60 = 300 seconds.

Heat energy supplied by the heating coil = IVt = 5 x 6 x 300 = 9000J.

But since heat supplied by the heating coil = heat gained by liquid, => 9000 = 6c => c = $\frac{9000}{6}$ = 1500, => the specific heat capacity of the liquid = 1500J/kg^{0}k.

(b) <u>For the heating coil:</u>

I = 2.5A.

V (p.d) = 6V.

t = 300 seconds.

Heat energy supplied by the heating coil = IVt = 2.5 x 6 x 300 = 4500J.

<u>For the liquid:</u>

Mass = m = 0.2kg.

Specific heat capacity = c = 1500J/kg.^{0}k

Rise in temperature = $\triangle\theta$

Heat gained = m x c x $\triangle\theta$

= 0.2 x 1500 x $\triangle\theta$ = 300 $\theta\triangle$

But since heat supplied by the heating coil = heat gained by the water,

=> 4500 = 300$\triangle\theta$, => $\triangle\theta$ = $\frac{4500}{300}$ = 15 .

, The rise in temperature = 15^{0}c.

N/B:$\triangle\theta$,= the rise or fall in temperature.

(Q12) (a) Calculate the mass of steam at 100^0c, which must be added to 300g of water whose temperature is 30^0c, in order to raise its temperature to 70^0C. [Specific heat capacity of water = 4200J/kg^{0}k, specific latent heat of vaporization of steam = 226000J/kg^{0}k].

(b) State any three assumptions made.

<u>For the steam:</u>

Let m = the mass of steam.

l = 226000J.

c = 4200J/kg.

First of all, the steam changes into water at 100^0c, and the heat given out = ml = m x 226000 = 226000m.

Final temperature of the mixture = 70^0c.

The condensed steam (water), then cools from 100^0c to 70^0c, and the heat given out

= m x c x $\triangle\theta$, = m x 4200 x (100 – 70) = m x 4200 X 30 = 126000m.

Total amount of heat given out by the steam in cooling from 100^0c to 70^0c = 226000m + 126000m = 352000m.

<u>For the water:</u>

Mass = 300g = 0.3kg.

Initial temperature = 30^0c.

Final temperature = 70^0c.

Heat gained by water in warming from 30^0c to 70^0c

= m x c x $\triangle\theta$ = 0.3 x 4200 x (70 – 30)

= 0.3 x 4200 x 40 = 50400J.

Since heat lost by steam = heat gained by water => 35200m = 50400, => m = 0.14,

=> mass of steam = 0.14kg.

(b)Assumptions made

(1) Values of specific latent heat of vaporization and specific heat capacity are accurate.

(2) The container and the stirrer took no heat.

(3) There is no heat lost through radiation, convection or conduction.

(Q13) A metal can which is efficiently lagged with expanded polystyrene, contains a mixture of ice and water at 0^0c. It is weighed and mixture stirred immediately. Steam is then allowed to come in. The steam supply is cut off when all the ice has melted, and a second weighing reveals a gain in mass of 15g. Calculate the mass of ice originally present. [S.H.C of water = 4200J/kg^{0}k, specific heat of fusion of ice = 336000Jkg, specific latent heat of vaporization of water = 2260000J/kg].

Soln:

<u>For steam:</u>

Mass of steam condensed = the gain in mass = 15g,

=> m = 15g = 0.015kg.

(a)The steam first changes into water at 100^0c, and the heat needed for this change or the heat lost by the steam = ml = 0.015 x 2260000 = 33900J.

(b)The temperature of this condensed steam (water) falls from 100^0c to 0^0c, and the heat lost in this case = m x c x$\triangle\theta$, = 0.015 x 4200 x (100 – 0) = 6300J.

Total heat lost by steam in cooling from 100^0c to 0^0c = 33900 + 6300 = 40200J.

This heat lost by the steam = the heat gained by ice and water.

But since the mass of water is not given, it is assumed that the amount of heat gained by the water is negligible, since there was no increase in its temperature.

=> Heat lost by steam = heat gained by the ice.

Since the ice just only melted, then the heat involved is the latent heat of fusion, = ml = m x 336000 = 336000m, where m = the mass of ice.=> Heat gained by ice = 336000m.

Since heat lost by the steam= heat gained by ice, then 40200 = 336000m,

=> m = $\frac{40200}{336000} = 0.12kg.$

Therefore the mass of ice originally present = 0.12 x 1000 = 120g or 0.12kg.

(Q14) A solid substance labeled A has a melting point of -2^0c. A quantity of this substance of mass 5kg and whose temperature is 5^0c is to be brought to a temperature of -10^0c

(a) Determine the amount of heat expected to be lost by the substance.
(b) If the whole process is to take place in 10 minutes, determine in seconds the rate at which heat will be lost by the substance. [Specific heat capacities of the substance in the solid and liquid forms are respectively 200J/kg and 215J/kg, the specific latent heat fusion of the substance = 40J/kg].

N/B: In this given case, the specific heat capacity of the substance in the liquid state differs from that of the substance in the solid state.

Soln:

(a)The substances in its solid state, first loses heat as its initial temperature of 5^0c drops to a temperature of -2^0c which is its melting point.

Amount of heat lost = m x c x $\triangle\theta$, where c = the specific heat capacity of the substance in the solid state.

Heat lost = m x c x$\triangle\theta$ = 5 x 200 x (5 – (-2)) = 5 x 200 x 7 = 7000J.

At its melting point of -2^0c, a change of state occurs and the amount of heat lost = ml, where l = the specific latent heat of fusion of the substance.

Heat lost = 5 x 40 = 200J.

The amount of heat lost by the substance in cooling from a temperature of -2^0c to the final one of -10^0c = m x c x $\triangle\theta$,, where c = the specific heat capacity of the substance when it is in the liquid state, since the substance is now in the liquid state.

Amount of heat lost = 5 x 215 x (-2 – (-10)) = 5 x 215 x 8 = 8600J.

The amount of heat expected to be lost by the substance = 7000 + 200 + 8600 = 15800J.

(b) Time to be taken for the heat lost = 10 minutes = 3600 x 10 = 36000 seconds (since there are 3600 seconds in a minute).

Amount of heat lost = 15800J.

Rate of heat lost = $\frac{15800}{36000}$ = 0.44J/s.

(Q15) A substance of mass 600g and whose melting point is 10^0c was heated from an initial temperature of 2^0c to a final one of 25^0c.(a) Determine the amount of heat gained by the substance.(b) If this required heat energy was supplied by an electrical element of resistance 15 ohms and voltage 220v, how many minutes was it necessary for heat to be provided? [Specific heat capacity of the substance in both the solid and the liquid states = 128J/kg, and the specific latent heat of fusion of the substance = 102J/kg].

N/B: - The specific heat capacity in this case is the same for the substance in both the liquid and the solid states.
- Since the melting point of the substance is 10^0c, then at an initial temperature of 2^0c, the substance will be in the solid state.

Soln:

(a) The temperature of the substance first increases from 2^0c to 10^0c.

Amount of heat absorbed by the substance = m x c x$\triangle\theta$ = 0.6 x 128 x 8 = 614J.

At its melting point of 10^0c, the substance changes from the solid into the liquid state,

and heat gained or absorbed = ml = 0.6 x 102 = 61J.

The temperature of the substance then increases from 10^0c to a final one of 25^0c, and

heat gained by the substance = m x c x$\triangle\theta$ = 0.6 X 128 X 15 = 115J.

Total amount of heat gained by the substance = 614 + 61 + 115 = 790J.

(b)Amount of heat supplied to the substance by the electrical heating element

= $\frac{V^2t}{R}$, $where\ t = time\ in\ seconds.$

Heat supplied = $\frac{220^2 \times t}{15}$ = 3227t.

But amount of heat supplied = the total heat gained by the substance, => 3227t = 790,=> t = $\frac{790}{3227} = 0.24\ seconds$ = 0.004 minutes.

(Q16) In an experiment to determine the specific latent heat of fusion of ice by the method of mixtures, the following measurements were made:

Mass of calorimeter and stirrer = 800g.

Mass of calorimeter, stirrer and water = 1500g.

Mass of calorimeter, stirrer, water and ice = 2100g.

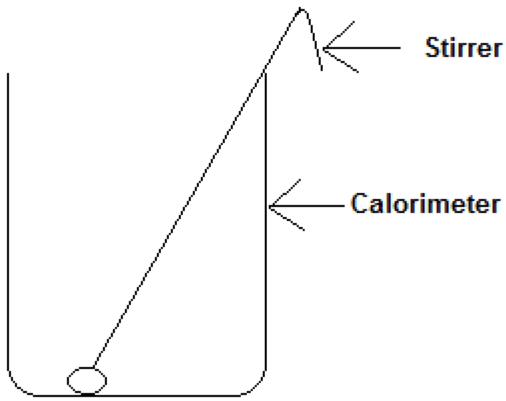
Initial temperature of water in the calorimeter = 15^{0c}.

Final steady temperature of the mixture = 5^0c. Calculate the specific latent heat of fusion of ice. [Specific heat capacity of calorimeter and stirrer = 400J/kg^{0}k, specific heat capacity of water = 4200J/kg^{0}k].

Soln:

N/B: Consider the analysis

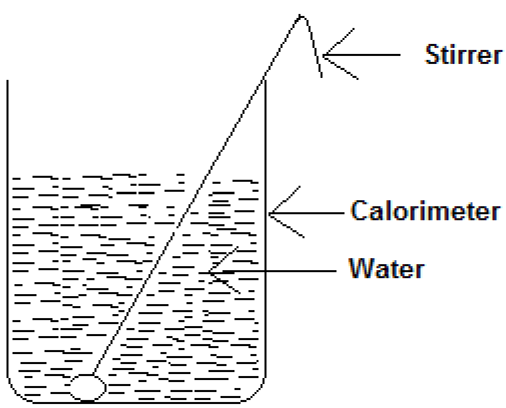
(a)



(1)

Mass of calorimeter and stirrer = 800g.

(b)



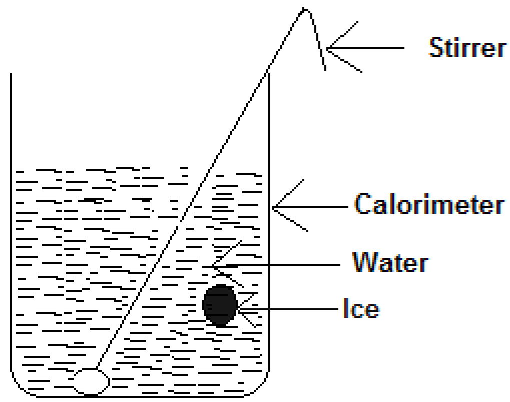
(2)

Mass of calorimeter, stirrer and water = 1500g,

=> Mass of water = (2) – (1)

= 1500g – 800g = 700g.

(c)



(3)

Mass of calorimeter, stirrer, water and ice = 2100g,

=> mass of ice = (3) – (2)

== 2100g – 1500g = 600g.

<u>For calorimeter/stirrer:</u>

Mass = m = 800 = 0.8kg.

Specific heat capacity = C = 400J/kg.

Initial temperature = 15^0c

Final temperature = 5^0C

Change in temperature= $\triangle\theta$ = 15 – 5 = 10

Heat lost by calorimeter and stirrer = m x c x $\triangle\theta$

= 0.8 x 400 x 10 = 3200J

<u>For Ice:</u>

Let L_F = the specific latent heat of fusion of ice.

Mass of ice = 600g = 0.6kg.

Initial temperature = 0^{0c}, final temperature = 5^0c

Heat gained by ice at 0^0c in order to melt into water = $mL_F = 0.6 \times L_F = 0.6L_F$.

Heat gained by melted ice (water), in warming from 0^{0c} to 5^0c = $m \times c \times \triangle\theta$

$= 0.6 \times 4200 \times (5 - 0)$

= 12600J.

Total heat gained by the Ice = $12600 + 0.6L_F$

<u>For water:</u>

Mass = 700g = 0.7kg

Specific heat capacity = $4200J/kg^0k$

Final temperature = 15^{0c}

Initial temperature = 5^{0c}

Since there is a drop in temperature => heat has been lost.

Heat lost by the calorimeter and stirrer + heat lost by water = heat gained by ice.

=> $3200 + 29400 = 0.6L_F + 12600$

=> $32600 = 0.6L_F + 12600$,

=> $32600 – 12600 = 0.6L_{F,}$

=> $20000 = 0.6L_F$ => $L_F = \frac{20000}{0.6}$,

=> $L_F = 33333J/kg^0C$

=> Specific latent heat of fusion of ice = $33333J/kg^0c$

<u>Determination of the specific latent heat of ice by direct heating:</u>

(1) A calorimeter is lagged using sheet expanded polystyrene.

(2) It is filled with ice, which has been dried previously on a cloth.

(3) The immersion heater is then inserted in the ice.

(4) The stop watch is started simultaneously as the current is switched on.

(5) As soon as the ice has just melted, the current is switched off and the time is noted.

(6) The jacket is them removed and the calorimeter weighed.

<u>Data:</u>

Mass of empty Calorimeter = M_1(g).

Current = I (A).

P.d across the heater = V (v).

Time = t (s).

Mass of calorimeter + melted ice = M_2

Mass of ice used = $M_2 - M_1 = M$

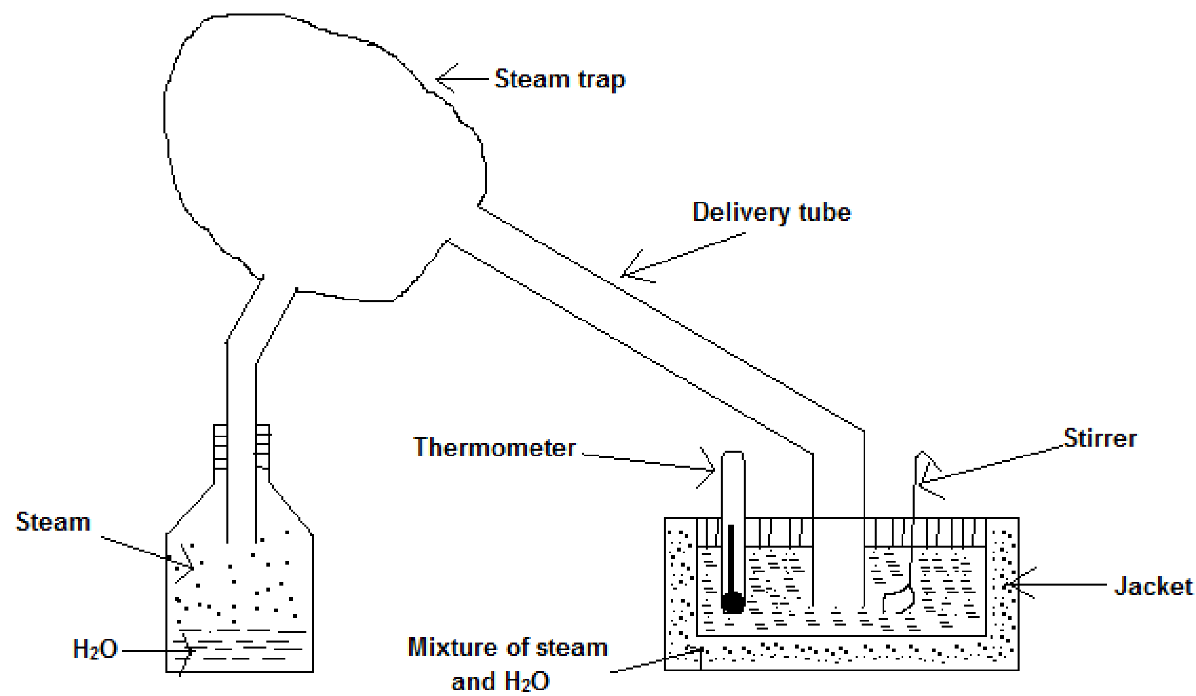
Energy supplied by the heater = Vit.

Let l = the specific latent heat of ice.

Then heat absorbed by the ice in melting at 0^{0c} = ml = energy supplied by the heater.

=>ml = Vit => l = $\frac{Vit}{M}$

Determination of the specific latent of vaporization of steam:



(1) A quantity of pure water is put inside a calorimeter, and the initial temperature of the water is measured.
(2) Steam at 100^{0c} is then added to the water through a steam trap, and the mixture is gently and continuously stirred, until the temperature becomes steady.
(3) This steady temperature is then noted.

Data:

Mass of calorimeter and stirrer = M_1

Mass of calorimeter, stirrer and water = M_2.

Initial temperature of water in the calorimeter = θ_1.

Final temperature of water in calorimeter = θ_2.

Mass of calorimeter, stirrer and water = M_3 at the end of the experiment.

Calculation:

Mass of water, $M_W = M_2 - M_1$.

Mass of steam added = $M_3 - M_2 = M_s$

Let L_V = the specific latent heat of vaporization of steam.

C_W = the specific heat capacity of water.

C_C = the specific heat capacity of calorimeter and stirrer.

Heat gained by calorimeter and stirrer = $M_1 C_C (\theta_2 - \theta_1)$.

Heat lost by steam in condensing to water or condensed steam at 100^{0c} = $M_S L_V$. Heat lost by water at 100^{0c} in cooling to θ_2 = $M_S C_W(100 - \theta_2)$.

Heat gained by water in warming from θ_1 to θ_2 = $M_W C_W (\theta_2 - \theta_1)$.

Neglecting heat losses, heat lost = heat gained.

=> $M_S L_V + M_S C_W(100 - \theta_2) = M_1 C_C(\theta_2 - \theta_1) + M_W C_W(\theta_2 - \theta_1)$

=> $L_V = \{M_1 C_C(\theta_2 - \theta_1) + M_W C_W(\theta_2 - \theta_1) - M_s C_W(100 - \theta_2)\} / M_S$

- Since all these parameters in this equation are known, L_V can be calculated.

Questions:

(Q1) Briefly explain how you will determine the specific heat capacity, of a piece of metal.

(Q2) A liquid of mass 2kg has a boiling point of 80^{0c}. Determine the number of joules of energy that will be needed,

(a) to convert it into the vapour state, at its boiling point.

Ans: 4010J.

(b) to heat it from a temperature of 20^{0c} until it changes into vapour.

Ans: 7610J.

[Specific latent heat of vaporization and specific heat capacities of the liquid are respectively 2005J/kg and $30J/kg^{0c}$].

(Q3) 80g of water vapour was converted into liquid water, which was then allowed to cool to a temperature of 20^{0c}. Calculate the amount of heat energy given out by the vapour and liquid. [Specific latent heat of steam = 2260J/g, specific heat capacity of water = $4.2J/g^{0}c$].

Ans: 207680J or 0.2077mJ.

(Q4) Water in the vapour form and of mass 0.02kg, was cooled to room temperature of 30^{0c}. Determine the amount of heat released into the surrounding air. [Specific heat capacity of water = $4.2J/g^{0}c$, specific latent heat of steam = 2260J/g].

Ans: 51080J or 51J.

(Q5) 0.04kg of ice whose temperature is -20^{0c}, is to be converted into water. If the temperature of the water is expected to be 30^{0c}, determine the amount of heat which will be needed for this conversion. [Specific latent heat of fusion of ice = 336J/g, specific heat capacity of water = $4.2J/g^{0}c$ and specific heat capacity of ice = $2.1J/g^{0}c$]

Ans: 20160J or 20.2kJ.

(Q6) The melting point of a substance is given as 40^{0c}. 600g of it was heated from an initial temperature of $15^{0}c$ to a final temperature of 90^{0c}. Determine the amount of heat needed to carry out this process. [Specific heat capacity of the substance in both the solid and the liquid form = 80J/kg^{0}c, specific latent heat of fusion of the substance = 45J/kg].

Ans: 3627J.

(Q7) 50kg of a substance was placed in an aluminum container of mass 2kg. If the initial temperature of the substance was 20^{0c},

(a) determine the amount of heat which was needed to raise the temperature of the aluminum container and its content to a temperature of 80^{0c}.

Ans: 741kJ.

(c) Assuming that the boiling point of the substance is 90^{0c}, determine the additional heat which was needed to vaporise the substance.

[Specific heat capacity of the substance = 211J/kg, specific latent heat of vaporization of the substance = 340JJ/kg^{0c}, and the specific heat capacity of aluminum = 900J/kg^{0c}].

Ans: 123kJ.

(Q8) You are given 2kg of ice at an initial temperature of $-5^{0}c$. Determine the amount of heat that will be needed in order to convert it into steam. [Specific heat capacity of ice = 2.2×10^{3}J/kg^{0}c, specific heat capacity of water = 4.18×10^{3}J/kg^{0c}, specific heat of fusion of ice = 3.34×10^{5}J/kg, specific latent heat of vaporization of water = 2.26×10^{6}J/kg].

Ans: 6046kJ or 6.046mJ.

(Q9) A certain amount of steam at 100^{0c} was added to 450g of water, whose temperature was 50^{0c}. Given that the final temperature of the mixture was 80^{0c}, determine the amount of steam which was added in kg.[Specific heat capacity of water = 4200J/kg^{0}k, specific latent heat of vaporization of steam = 226000kJ/kg.]

Ans: 0.18kg

(Q10) A physics tutor took 400g of a substance whose melting point is 20^{0c}, and heated it from its initial temperature of 5^{0c} to a final one of 45^{0c}.

(a) Determine the amount of heat gained by the substance.
Ans: 1742J.

(b) If this amount of heat was provided by a 6V electrical heating element, and the time required for the heating was 25 seconds, find the current.
Ans: 11.6A.

[Assume that the specific heat capacity of the substance in the solid state = 102J/kg, and that of the substance in the liquid state = 104J/kg and the specific latent heat of fusion of the substance = 225J/kg].

(Q11) An element has a melting point of 10^{0c} and a boiling point of 80^{0c}. Determine the quantity of heat which will be required to convert 22kg of the element, whose temperature is 2^{0c} into the vapour state.

[S.H.C of the element = 420J for both the liquid and the solid state, the specific latent heat of vaporization of the element = 123J/ kg, and the specific heat of fusion of the element = 140J/kg].
Ans: 727kJ.