TOPIC: HEAT

General Objective: The Learner should be able to;

- Quantity heat energy in terms of specific heat capacity and latent heat capacity.
- Understand the effect heat on solids and liquids.

SUB-TOPIC: QUANTITY OF HEAT

SPECIFIC OBJECTIVES

The Learner should be able to;

- Define heat.
- Define heat capacity and specific heat capacity.
- Describe an experiment to determine specific heat capacity by method of mixtures.
- Solving numerical problems.

HEAT CAPACITY AND CHANGE OF STATE

HEAT

It is that energy which flows from one body to another due to a temperature difference between them.

It is that form of energy whose loss or gain leads to a temperature change.

The SI unit of heat is a Joule (J)

HEAT CAPACITY

This is the quantity of heat required to raise the temperature of a given body by 1K.

Its unit is JK^{-1}.

$Q = C\Delta T$

$Q = C(T_f - T_i)$

$$C = \frac{Q}{(T_f - T_i)}$$

Example

A metal block with a heat capacity of 9000 JK^{-1} is heated from 10^0C to 50^0C. Calculate the quantity of heat absorbed. (360kJ)

Specific Heat Capacity

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

The SI unit is $Jkg^{-1}K^{-1}$

$Q = mc\Delta T$

$Q = mc(T_f - T_i)$

$$c = \frac{Q}{m(T_f - T_i)}$$

Examples

1. How much heat energy is given out when a piece of metal of mass 4kg and specific heat capacity 460 $Jkg^{-1}K^{-1}$ cools from 68^0C to 60^0C. (14720J)
2. Calculate the amount of heat required to raise the of 500g of salt from -5^0C to 15^0C. (S.H.C of the salt solution = 4000 $Jkg^{-1}K^{-1}$) (Ans: 40000J)

3. 10kg of paraffin initially at 20^0C is supplied with 220000J of heat. Given that the S.H.C of paraffin is 2200 $Jkg^{-1}K^{-1}$. Calculate the final temperature reached by paraffin. (30^0C)

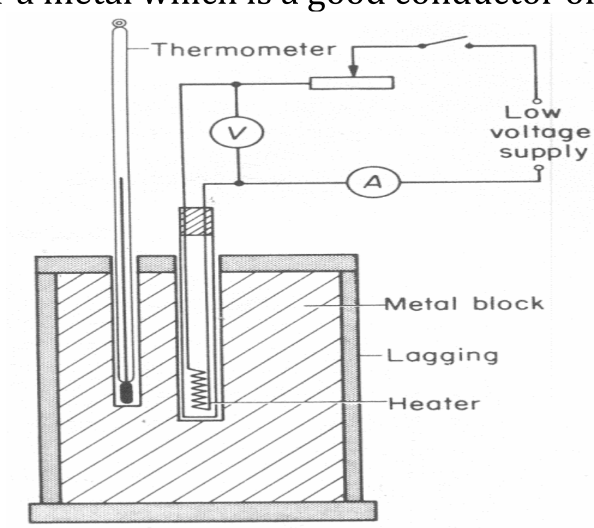
Quantity of Heat

When the temperature of a body changes, the quantity of heat transferred is given by:
Quantity of heat transferred = mass x specific heat capacity x temperature change

Let Q = quantity of heat transferred
m = mass of substance
c = specific heat capacity of the substance
T_i = initial temperature
T_f = final temperature
Then ,
$Q = mc(T_f - T_i)$

An experiment to measure the specific heat capacity of a metal by the electrical method.

This method is suitable for a metal which is a good conductor of heat.



A cylindrical block of metal is drilled with two holes one for an electric heater and the other a thermometer.
A little oil is used in the holes to ensure good thermal contact.
Heat losses are reduced by standing the block on a slab and lagging the block.

The heater circuit is connected and rheostat is adjusted to obtain suitable current.
Before switching on the current note the temperature of the block is noted. The current and voltmeter are switched on simultaneously and the stop clock is started.
The voltmeter and ammeter are readings when the temperature has risen by about 10degrees.
The current is switched off and the clock is stopped simultaneously.
The final temperature is read on the thermometer.

Energy received by block=energy supplied by heater.
$mc(T_f - T_i) = VIt$
Specific heat capacity of metal

$$c = \frac{VIt}{m(T_f - T_i)}$$

Precautions

(i) The metal block must be heavily lagged to prevent heat loss to the surroundings.
(ii) The two holes should be filled with a light oil to improve thermal contact with the heater and thermometer.

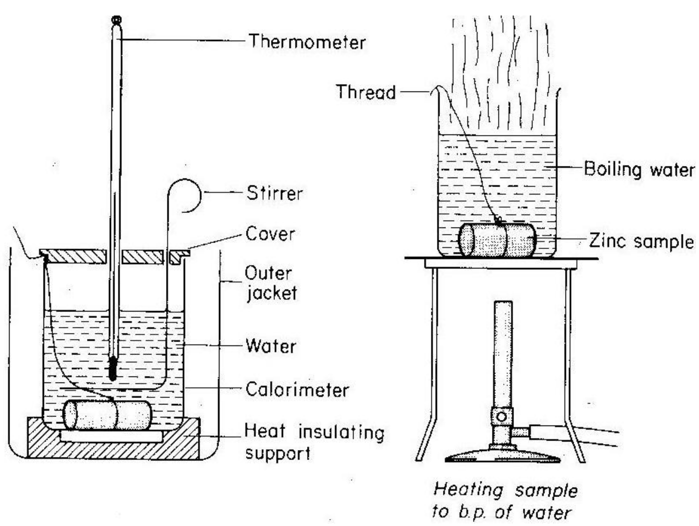
Examples

1. The following data was obtained from an experiment. Mass of copper metal block = 200g, initial temperature of the block = 22^0C, ammeter reading = 5A, voltmeter reading = 3.0V, final temperature of the block = 30^0C, time of heating 7 minutes. Use the data to calculate the specific heat capacity of copper. What does this value mean? (3937.5 $Jkg^{-1}K^{-1}$)

2. Calculate the heat energy required to raise the temperature of 2.5kg of aluminium from 20^0C to40^0C, if the specific heat capacity of aluminium is 900 $Jkg^{-1}K^{-1}$ (45000J)

3. An electric heater is used to heat 0.2kg of water for 200s. Find the p.d across the heater, if the current is 0.5A and the temperature of the water rises from 30^0C to 55^0C. (S.H.C of water is 4200 $Jkg^{-1}K^{-1}$) (Ans: 210V)

Experiment: to determine the specific heat capacity of a solids by method of mixtures



The solid is weighed to find its mass, m, and heated in boiling water for some time and temperature, θ_2 of the boiling water is noted.
Meanwhile a calorimeter, with the stirrer, is weighed to determine its mass, m_c
A suitable amount of water is poured into the calorimeter and the calorimeter is weighed again to find the mass of water, m_w, added.

The calorimeter with its contents is placed in its jacket.
The temperature, θ_1, of the water in the calorimeter is noted.
The temperature, θ_2, of the heated solid is noted, and the solid quickly transferred to the calorimeter, which is then covered.
While stirring, the temperature of the contents of the calorimeter is observed and its maximum value, θ_3, is noted.
Calculations:
Let c = specific heat capacity of the solid
c_c = specific heat capacity of the calorimeter material
Heat lost by solid = heat gained by water and calorimeter

$$mc(\theta_2 - \theta_3) = m_w c_w(\theta_3 - \theta_1) + m_c c_c(\theta_3 - \theta_1)$$

$$\therefore \quad c = \frac{(m_w c_w + m_c c_c)(\theta_3 - \theta_1)}{m(\theta_2 - \theta_3)}$$

NOTE:
The same above experiment is used to determine S.H.C of a liquid e.g water.

Precautions:
1. The calorimeter must be well lagged to limit heat losses to the surrounding.
2. The metal block must be transferred as quickly as possible from the hot water to the calorimeter to limit heat losses to the surrounding during the transfer.

Sources of heat loss during the above experiment include:
1. Heat is lost to the surroundings during the transfer of the metal block to the calorimeter.
2. Heat is lost to the stirrer, thermometer and calorimeter.

Example
A piece of copper of mass 50 g at 180^0C is placed in a copper calorimeter of mass 60 g containing 40 g of water at 15^0C. Ignoring losses, find the final steady temperature after stirring.
[specific heat capacity of copper = 400 $Jkg^{-1}K^{-1}$), that of water = 4200 $Jkg^{-1}K^{-1}$)]

Solution
Let θ = the final temperature
Heat given out by copper = heat gained by water and calorimeter

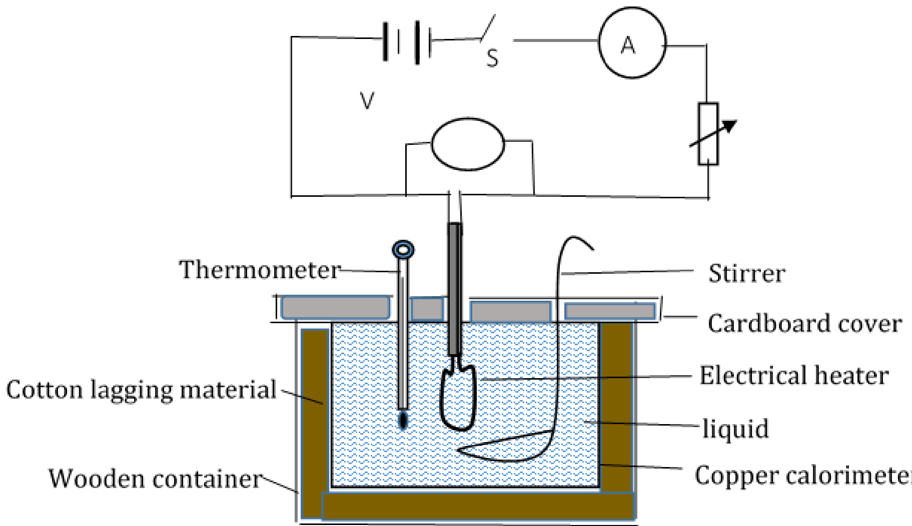
$$0.050 \times 400(180 - \theta) = 0.040 \times 4200(\theta - 15) + 0.060 \times 400(\theta - 15)$$

$$\therefore \quad 3600 - 20\theta = 168\theta - 2520 + 24\theta - 360$$

$$\therefore \quad 212\theta = 6480$$

$$\therefore \quad \theta = 30.6^0C$$

EXPERIMENT TO DETERMINE THE SPECIFIC HEAT CAPACITY OF A LIQUID BY ELECTRICAL METHOD



Procedure;

- The liquid of known mass (m) is poured into a clean and dry copper calorimeter with a stirrer of the same specific heat capacity as the colorimeter.
- The heater of known power (P) and the thermometer are put in the copper container containing the liquid.
- The initial temperature θ_1 of the liquid is measured and recorded.
- Switch, S is closed and a stop clock is simultaneously started. A variable resistor is used to maintain a steady current, I through the heater and a steady p.d, V across it. This steady current is passed through the heater to warm the liquid for a time, t seconds.
- The liquid gently stirred throughout the warming.
- The final stable temperature, θ_2 of the liquid, the ammeter reading, I and the voltmeter reading, V are read and recorded.

Calculate the specific heat capacity as follows:

Heat gained by liquid = Heat supplied by the heater.

$$mc\,(\theta_2 - \theta_1) = VIt$$

Specific heat capacity of the liquid ,

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

Assumptions made during the above experiment are;

- The amount of heat absorbed by the copper container, stirrer or thermometer is negligible.
- No heat is absorbed by liquid from the surroundings.

Examples;

1. An immersion heater of 60 W was used to heat a liquid of 1kg for $\frac{1}{2}$ a minute. Find the specific capacity of the liquid if the initial and final temperatures were 27^0C and 87^0C respectively.

   SOLUTION:

   Heat absorbed by water = Heat supplied by the heater

$mc(\theta_2 - \theta_1) = Pt$
$1 \times c(87 - 27) = 60 \times 30$
$c = 30\ Jkg^{-1}$.

2. Latifah wants to have a warm bath. She mixes 5 kg of hot water at 85^0C with 15 kg of cold water at 25^0C . Taking specific heat capacity of water to be 4200 $Jkg^{-1}K^{-1}$. Find the final temperature of the mixture.
SOLUTION:
Heat lost by hot water = Heat gained by cold water.
$m_1c(\theta_1 - \theta_f) = m_2c(\theta_f - \theta_2)$
$5 \times 4200(85 - \theta_f) = 15 \times 14200(\theta_f - 25)$
$\theta_f = 40^oC$

Revision exercise 16 pages 268 – 269 Longhorn book three.

REVISION QUESTIONS ON CALCULATIONS
Method of mixtures:

1. A metal block of mass 2 kg and at a temperature of 85^0C is put in a copper calorimeter of mass 30g containing 1800g of water at a temperature of 50^0C. If the final steady temperature of the three is 55^0C, find the specific heat capacity of the metal. (Take s.h.c of water = 4200$Jkg^{-1}K^{-1}$ and that of copper = 400 $Jkg^{-1}K^{-1}$)
(Ans:631 $Jkg^{-1}K^{-1}$)

2. To wash clothes of a certain fabric, water is required at a temperature of 50^0C. Find how much water at a temperature of 80^0C is needed to be added to 60kg of water at 10^0C to achieve this.

3. A body of mass 0.15kg is heated in boiling water at a temperature of 100^0C and is then quickly transferred to a copper calorimeter of mass 40g containing 50g of water at a temperature of 15^0C. After stirring, the final steady temperature was found to be 26.1^0C. Calculate the specific heat capacity of the body. (take s.h.c. of copper = 400 $Jkg^{-1}K^{-1}$, and of water = 4200 $Jkg^{-1}K^{-1}$)

4. Some hot water was added to 3 times its mass of water at 10^0C and the resulting mixture has a steady temperature of 20^0C. What was the temperature of the hot water?

5. A metal block of mass 5kg is heated to 110^0C and the put into 2kg of water. The final temperature is found to be 50^0C. What was the initial temperature of the water? (take s.h.c. of water = 4200 $Jkg^{-1}K^{-1}$and that of the metal = 840 $Jkg^{-1}K^{-1}$)

6. A cold water tap of a bath delivers water at 10^0C at a rate of 30kg min^{-1}. The hot water tap of the bath delivers water at 70^0C at a rate of 40kg min^{-1}. The two taps are

left to run for 2 minutes. Determine the final temperature of the water in the bath. Ignore heat losses.

7. A piece of aluminium of mass 2kg at 100^0C is fully immersed in in 400g of water in a calorimeter of negligible heat capacity. The final steady temperature of the water after stirring was 75^0C. Determine the initial temperature of the water. (s.h.c of aluminium = 900 Jkg $^{-1}$K^{-1}and for water = 4200 Jkg $^{-1}$K^{-1})

8. The same quantity of heat was supplied to 5.0 kg of sea water and 12.0 kg of methylated spirit. The temperature rise was 30^0C and 20^0C respectively. Find the ratio of the specific heat capacity of sea water to that of methylated spirit.

Involving electrical sources of heat:

1. An electric heater rated 1500 kW is used to heat water in an insulated container of negligible heat capacity for 10 minutes. The temperature of the water rises from 20^0C to 40^0C. Calculate the mass of water heated. (s.h.c of water = 4200 Jkg $^{-1}$K^{-1})

2. An electric kettle of negligible heat capacity rated at 2 kW is filled with 2 kg of water and heated from 20^0C to 98^0C. Assuming there are no heat losses to the surroundings, determine the time taken to heat the water. (s.h.c of water = 4200 Jkg $^{-1}$K^{-1})

3. A heating element is connected to a 240 V mains supply and a current of 1.3 A flows through it. If it takes this element 300 s to warm 2 kg of a certain liquid from 40^0C 60^0C, find the specific heat capacity of this liquid.

4. A liquid X of mass 0.5 kg and specific heat capacity 4000 Jkg $^{-1}$K^{-1}is put in an electric kettle connected to a 240 V mains supply and a current of 2.0 A. If the kettle is left on for three minutes, what will be the final temperature of this liquid if it was initially at 20^0C ?

5. An electric heater that is 90% efficient operates at 240 V at a current of 1.4 A. It takes this heater 4×10^3 s to raise the temperature of a liquid of specific heat capacity 3600 Jkg $^{-1}$K^{-1}by 33.6^0C. Find the mass of this liquid.

MECHANICAL ENERGY CONVERTED TO INTERNAL HEAT ENERGY.

1. During the process of striking a nail using a hammer, the temperatures of both nail and hammer head increase after some time. This is because energy is converted from potential energy to kinetic energy and finally to internal heat energy and sound.
2. When the brakes of any vehicle are applied, kinetic energy is converted to internal heat energy in the brake discs.

3. The water at the top of a water fall is usually cooler than that at its bottom. This is because potential energy is converted to kinetic energy that is eventually converted to internal heat energy and sound at the bottom of the water fall.
The temperature rise that occurs during conversion of mechanical energy to internal heat energy is usually small due to heat losses to the surroundings and sound.

Examples:

1. A class of Physics students decided to determine the specific heat capacity of water in a waterfall. They used a sensitive thermometer to find the difference in temperature of water at the top and the bottom of the waterfalls and obtained the following results: height of the waterfalls = 52 m, temperature of the water at the top = 21.54^0C, temperature of water at the bottom = 21.67^0C. Stating any assumptions made, calculate a value for the specific heat capacity of water.
2. A metal fell from a height of 100m. If the specific heat capacity of the metal is 350 $Jkg^{-1}K^{-1}$, calculate the final temperature of the body given that its temperature before falling was 26^0C. State any assumptions you have made when arriving to your answer.

Table of specific heat capacities of some solids and liquids:

Substance	**Specific heat capacity in $\mathbf{Jkg^{-1}K^{-1}}$.**
Aluminium	900
Brass	370
Copper	390
Cork	2000
Glass	670
Ice	2100
Iron	460
Lead	130
Silver and Tin	230
Water	4200
Mercury	140
Glycerol	2400
Paraffin oil	2130
Sulphuric acid	1380
Olive oil	2000

KEY FACTS ABOUT S.H.C:

1. Most metals have low specific heat capacities compared to liquids with the exception of mercury.
2. Good conductors of heat have low specific heat capacities while poor conductors of heat have large specific heat capacities.
3. Most of the oils that are used as lubricants have relatively large specific heat capacities to also provide a cooling effect, since friction causes heating.

THE IMPORTANCE OF THE HIGH SPECIFIC HEAT CAPACITY OF WATER:
4200J of heat required to increase the temperature of water by 1^0C is rather high and because of this, water is commonly used as a cooling agent in many cooling systems e.g. car radiators, heat engines, air conditioners.

SUB-TOPIC: LATENT HEAT

The Learner should be able to;

- Define specific latent heat of vaporization and melting between latent heat and change of state.
- Describe factors affecting rate of evaporation.
- Describe the effect of pressure on melting.
- Concept of latent heat.
- Factors affecting vaporization and melting.
- Cooling curves.
- Cooling by evaporation.
- The refrigerator.
- Experiments using methods of mixtures only.
- Discussion on vaporization and melting.
- Experimentation on specific latent heat.
- Treat latent as stored energy which is given out during condensation and solidification, and absorbed during evaporation and melting.
- Experimentally investigate the cooling curve of water and Naphthalene.
- Explain cooling by evaporation.
- Describe how a refrigerator works.
- Define specific latent heat (Vaporization and fusion)
- Experimentally determine the specific latent heat of
  - Vaporization for steam.
  - Fusion for ice.
- Solve numerical problems involving specific latent heat.
- Specific latent heat of;
  - Vaporization.
  - Fusion.
- Numerical problems.

Latent heat is the energy required by a substance to change its state at constant temperature.
The heat supplied goes in doing work against the intermolecular forces to increase the molecules' potential energy, but their kinetic energy remains the same. This is why there is no temperature change during change of state.

Latent heat is stored energy which is given out during condensation and solidification and absorbed during evaporation and melting.

Latent heat of Fusion (melting)
This is the quantity of energy required to change the substance from solid state to liquid state without change in temperature at a constant pressure.

Specific Latent heat of Fusion
This is the quantity of heat required to change 1kg of a substance from solid state to liquid state at constant temperature and pressure.

$$Q = ml_f$$

$$l_f = \frac{Q}{m}$$

Where l is a constant called specific latent heat of the substance.
Its SI unit is joule per kilogram (JKg^{-1}).

Experiment: To Determine the Specific Latent Heat of Fusion of Ice
A calorimeter, with stirrer, is weighed to determine its mass, m_c.
Some water is poured in the calorimeter and it is weighed again to find the mass, m_w, of the water added.
The calorimeter is warmed to a few degrees, say 10^0C, above room temperature and then fitted in its jacket.
The temperature, θ_1, of the water is noted and small pieces of dry ice are added while stirring until the temperature is as far below room temperature as it was above; the temperature, θ_2, is noted. **(Such procedure compensates for any heat transfer that would affect the accuracy of the result).**
The calorimeter is weighed once again to find the mass, m, of the ice that was added.

Heat
Calculation:
The ice melted and the resulting water warmed from 0^0C to θ_2 while the calorimeter and its contents cooled from θ_1 to θ_2.
Heat gained by ice is equal heat gained by water and calometer
Let l = specific latent heat of fusion of ice
c_w = specific heat capacity of water
c_c = specific heat capacity of the material of the calorimeter

Then, $ml + mc_w(\theta_2 - 0) = (m_w c_w + m_c c_c)(\theta_1 - \theta_2)$

$$\therefore \quad l = \frac{(m_w c_w + m_c c_c)(\theta_1 - \theta_2) - mc_w\theta_2}{m}$$

The significance of high value of specific latent heat of fusion of ice.

Ice is often used as a cooling agent e.g. ice cubes are added to juice to keep it cold. Ice a0^oC causes more cooling than water at the same temperature.

Examples

1. How much heat will change 10 g of ice at 0^0C to water 0^0C (take specific latent heat of fusion of ice to be 340,000Jkg^{-1})

$$Q = ml_v$$

$$Q = \frac{10 \times 340,000}{1000} = 3400J$$

2. What quantity of heat must be removed from 20 g of water at 0^0C to change it to ice at 0^0C.

$$Q = mlf$$
$$= \frac{20 \times 340,000}{1000} = 6800J.$$

3. How much heat is needed to change 5 g of ice at -5^0C to water at 20^0C?

$$Q = mc\theta + ml_f + mc\theta$$

$$= \frac{5 \times 2100(0--5)}{1000} + \frac{5 \times 340000}{1000} + \frac{5 \times (20-0)}{1000} = 1752.6J$$

4. An aluminum tray of mass 400 g containing 300 g of water is placed in a refrigerator, after 80 minutes, the tray is removed and it is found that 60 g of water remain unfrozen at 0^0C. If the initial temperature of tray and its content was 20^{o}C, determine the average amount of heat removed per minute by the refrigerator.

Specific capacity of aluminum = $1Jg^{-1}K^{-1}$

Specific capacity of water = 4 $Jg^{-1}K^{-1}$

Specific latent heat of fusion of ice = $340Jg^{-1}$

Heat removed by the fridge = Heat lost by water from 20^0C to 0^0C + Heat lost by water to ice + heat lost by tray.

$= M_wC_w (\theta_2 - \theta_1) + M_{ice} L_f + M_tC_1 (\theta_2 - \theta_1)$

$= 0.3 \times 4000 (20 - 0) + 0.24 \times 340,000 + 0.4 \times 1000 (20 - 0)$

$= 113600J$

Heat removed per minute $= \frac{113600}{80}$

$$= 1420Jmin^{-1}$$

Questions

1. (a) What is meant by specific heat capacity?

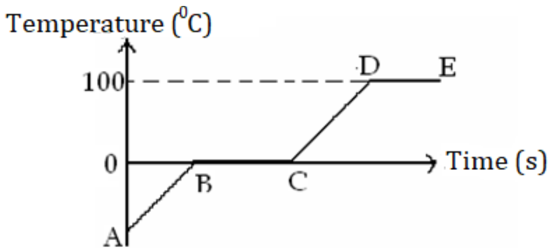
   (b) 2 kg of ice initially at -10^0C is heated until it changes to steam at 100^0C.

      (i) Sketch a graph to show how the temperature changes with time.

(ii) Calculate the thermal energy required at each section of the graph sketched in b(i) above.

Specific latent heat of fusion of ice is $= 3.36 \times 10^5 Jkg^{-1}$.
Specific latent heat of vapourization of water is = 2.26 x 10⁶ $2.26 \times 10^6 Jkg^{-1}$.
Specific heat capacity of water $= 42000\ Jkg^{-1}k^{-1}$
Specific heat capacity of ice is = $2100\ Jkg^{-1}k^{-1}$

GRAPH TO SHOW HOW TEMPERATURE CHANGES WITH TIME



(i) Thermal energy along AB,

$Q = m_{ice} l_f$
$= 2 \times 2.1 \times 10^{3} (0 - -5)$
$= 4.2 \times 10^4 J$

Thermal energy along BC

$Q = ml_f$

$= 2 \times 3.36 \times 10^5$

$= 6.72 \times 10^5 J$

Thermal energy along CD,

$= mc\theta$

$= 2 \times 4.2 \times 10^3 \times (100 - 0)$

$= 8.4 \times 105J$

Thermal energy along DE,

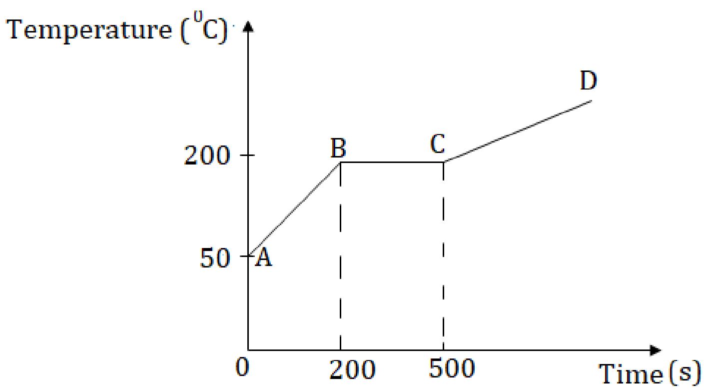
$= ml_v$

$= 2 \times 2.26 \times 10^{6}$

$= 4.52 \times 10^6 J$

Exercise; (leave space for the exercise)

1. State and define the 3 major methods of heat transfer.
2 (a) Distinguish between specific heat capacity and specific latent heat of a substance.
(b) Describe an experiment to determine the specific latent heat of fusion of ice.
3. The Graph showing a heating curve of a metal



Explain what happens to the metal.

(i) If the metal absorbs heat at the rate of $3000JK^{-1}$ and specific heat capacity is $400JKg^{-1}K^{-1}$, calculate mass of the metal.

(ii) Find the specific latent heat of the metal,

4. (a) Find the ways you would modify a liquid in glass thermometer so that it can register temperature more quickly.
   (b) Why is it usually not a good idea to have a thermometer with high heat capacity?
5. (a) Explain why the freezing compartment of a refrigerator is at the top.
   (b) A glass of orange squash contains 0.2 kg of water at temperature of 24^0C. What is the minimum amount of ice you would need to add in order that the temperature of the drink is 0^0C.

LATENT HEAT OF VAPORISATION

The **Latent Heat of Vaporisation** of a liquid is the amount of heat energy required to change the substance from liquid state to gaseous state at constant temperature and pressure.

SPECIFIC LATENT HEAT OF VAPORISATION

This is the quantity of heat required to change a unit mass of a substance from liquid to vapour at constant temperature.

$$Q = ml_v$$

Where l_v = specific latent heat of vaporisation and its unit is joule per kilogram (Jkg^{-1})

Example

1. Find the amount of heat required to convert 5kg of water at boiling point to steam (Take l_v of steam as $2.3 \times 10^6\ Jkg^{-1}$)

   Solution:

   $\mathbf{Q = Ml_v}$

   $Q = 5 \times 2.3 \times 10^6$

   $Q = 1.15 \times 10^7 J$

2. How much heat is needed to change 4 kg of water at 10^0C to steam at 100^0C?

   Solution

$Q = mc\theta + ml_v$
$Q = (4 \times 4200 \times 90) + (4 \times 2.3 \times 10^6)J$
$Q = 10,712,000\ J$

3. A 3 kW electrical kettle is left on for 2 minutes after the water starts boiling. What mass of water is boiled off in this time?

Solution

Latent heat absorbed by H_20 = Heat supplied by heater

$Ml_v = Pt$

$M \times 2.3 \times 10^6 = 3 \times 1000 \times 2 \times 60$

$\therefore M = 0.157\ kg = 157g$ of steam is boiled off.

4. Find the heat given out when 10 g of steam at 100^0C condenses and cools to water at 50^0C.

Solution

Heat given = heat required to convert steam to water at constant temperature + heat required to cool water from 100^0C to 50^0C

$Q = ml_v + mc(\theta_2 - \theta_1)$

$= \frac{10 \times 2300000}{1000} + \frac{10 \times 4200(100-50)}{1000}$

$= 25100J$

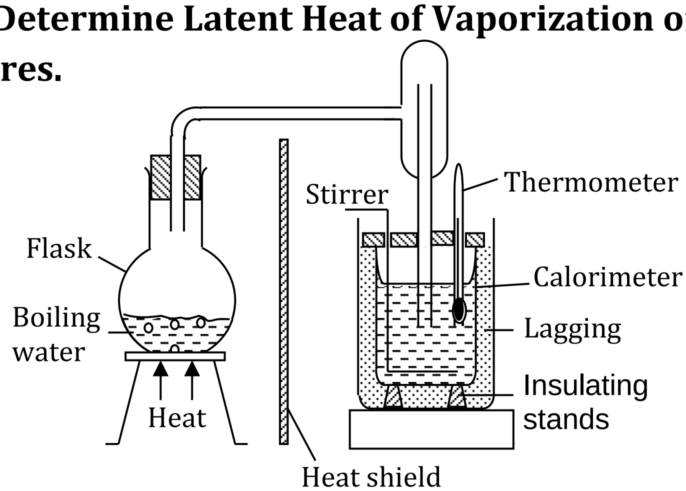
5. Calculate the heat required to convert 2kg of water at 100^0C to steam (specific latent heat of vaporization of water = $2.26 \times 10^6\ Jkg^{-1}$ **)** (Ans: $4.52x10^6$ J)

Note: Specific latent heat of vaporization of steam is about 2,260,000 Jkg^{-1} while specific heat capacity of water is 4200 $J\ kg^{-1}K^{-1}$.
Since the amount of heat in steam is about 5 times of heat in boiling water, steam burns are more fatal than burns due to boiling water.

Importance of high value of specific latent heat of vaporization

1. Because of this high value, steam is used as a heating agent e.g. cooking.
2. Can be used for sterilizing medical tools e.g. blades, forceps.
3. used in heat engines.

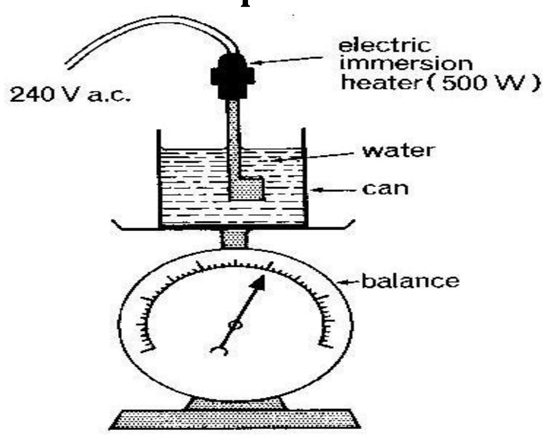
Experiment: To Determine Latent Heat of Vaporization of Water or steam by method of mixtures.



A calorimeter is weighed to find its mass, m_c.
Some water is poured in the calorimeter, which is weighed again to find the mass, m_w, of the water added.
The calorimeter with its contents is fitted into its jacket.
Water is boiled in a flask, as shown in the diagram, to generate steam for some time.
Then the temperature, θ_1, of the water in the calorimeter is noted and the steam is led into it.
After some minutes the calorimeter is disengaged and the new temperature, θ_2, of the water is recorded.
The calorimeter is weighed once again to find the mass, m, of the steam condensed.
Let l = specific latent heat of vaporisation of water
Then, $ml + mc_w(100 - \theta_2) = (m_w c_w + m_c c_c)(\theta_2 - \theta_1)$

$$\therefore \quad l = \frac{(m_w c_w + m_c c_c)(\theta_2 - \theta_1) - c_w(100 - \theta_2)}{m}$$

Determination of specific latent heat of vaporization of steam.



Procedure
A beaker of known mass is obtained
The mass of water in the beaker is weighed and recorded as m_1.
The heater is switched on to heat the water in the beaker.
While water is boiling, the position of the pointer of the stop clock is read.
After time t, the mass of water m_2, is weighed.
The mass of steam is calculated from

$$M = m_1 - m_2$$

The specific latent heat of vapourization is obtained from:
Latent heat absorbed by boiling water = heat supplied by heater

$$ml_v = pt$$

$$l_v = \frac{pt}{m}$$

Where l_v is the specific latent heat of vaporization.

Examples

1. Find the amount of heat required to convert 5kg of water at boiling point to steam (Take l_v of steam as $2.3 \times 10^6\ Jkg^{-1}$)

Quantity of heat $Q = ml_v$

$$= 5 \times 2.3 \times 10^6 J$$
$$= 11.5 \times 10^6 J$$
$$= 1.15 \times 10^5 J$$

2. How much heat is needed to change 4 kg of water at 10^0C to steam at 100^0C?

$Q = ml_v$

$Q = 4 \times 2.3 \times 10^6 J$

$Q = 9.2 \times 10^6 J$

3. A 3kW electrical kettle is left on for 2 minutes after the water starts boiling. What mass of water is boiled off in this time?

Latent heat absorbed by H_20 = Heat supplied by heater

$m \times 2.3 \times 10^6 = 3 \times 1000 \times 2 \times 60$

$m = 0.1565kg = 156.5g$

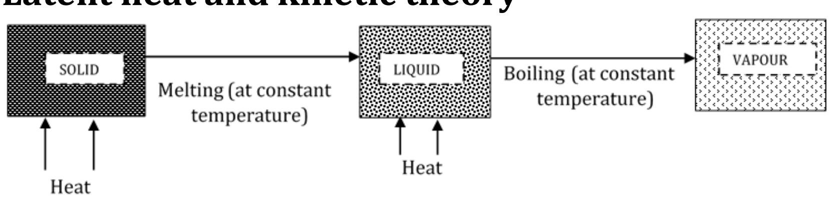
4. Find the heat given out when 10 g of steam at 100^0C condenses and cools to water at 50^0C.

Heat given = heat required to cool steam to water + heat required to cool water from 100^0C to 50^0C.

$$Q = ml_V + mc(\theta_2 - \theta_1)$$
$$= \frac{10 \times 2300000}{1000} + \frac{10 \times 4200(100 - 50)}{1000}$$
$$= 25100J$$

Since the amount of heat in steam is 5 times of heat in boiling water, therefore steam is more fatal than boiling water.

Latent heat and kinetic theory



(a) Latent heat of fusion.

During change of state from solid to liquid (melting at constant temperature), the heat supplied weakens the intermolecular forces of attraction, the molecular spacing increases, changing from static molecules of solid to fast moving molecules in liquid state.

The average K.E of molecules remains constant during melting because melting takes place at constant temperature. However, the average P.E of the molecules increases resulting into increase in the molecular spacing.

(b) **Latent heat of vaporization**;

During change of state from liquid to vapour, the molecules must overcome the intermolecular forces of attraction so that they gain freedom to move about independently. As a result, the heat supplied is used to overcome these forces resulting in gain in molecular potential energy but not their kinetic energy and also the work to expand against atmospheric pressure.

Why specific latent heat of vaporization of a substance is always greater than specific latent heat of fusion for the same substance.

Specific latent heat of vaporization is always greater than specific latent heat of fusion because for the molecules of a liquid to escape into the atmosphere, they require a lot of heat energy to overcome both the intermolecular force of attractions and to expand against the atmospheric pressure above the liquid surface. However, latent heat of fusion is required to weaken the intermolecular forces of attraction of the solid molecules for them to gain the free movement of the liquid state.

Importance of high value of specific latent heat of vapourization

1. Because of high value, steam is used as a heating agent e.g. cooking.
2. Can be used for sterilizing medical tools e.g. blades, forceps.

Exercise

Where necessary, use:

Specific capacity of copper = 400 J $kg^{-1}K^{-1}$

Specific capacity of water = 4200 J $kg^{-1}K^{-1}$

Specific latent heat of fusion of ice = 3.34×10^5J kg^{-1}

Specific latent heat of vaporisation of water = 2.26×10^6 J kg^{-1}

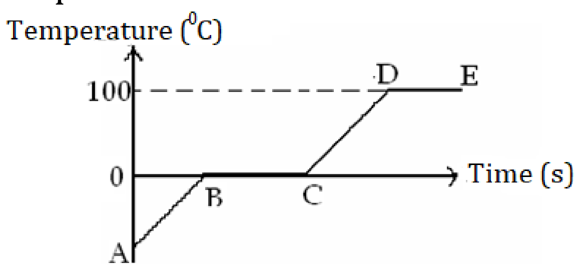
1. The specific heat capacity of a certain solution is 4000 J $kg^{-1}K^{-1}$. Calculate the quantity of heat required to raise the temperature of 800 g of the solution from -5^0C to 25^0C.
2. A 1000 W heater is used to warm 1 kg of a liquid from a temperature of 20^0C. If after 10 s its temperature is found to be 45^0C, what is the specific heat capacity of the liquid?
3. A heater was used to raise the temperature of 6 kg of water by 5 K. It was found that the same heater raised the temperature of 14 kg of a liquid L by 5 K in same time. Find the specific heat capacity of liquid L.
4. A copper block of mass 200 g is heated to a temperature of 140^0C and then dropped into a copper calorimeter of mass 100 g which contains 250 g of water at 25^0C. Neglecting heat losses, calculate the maximum temperature attained by the water.
5. A heater with power rating of 200W is placed in 500 g of ice at 0^0C. How long will it take to melt all the ice?
6. A copper calorimeter of mass 40 g contains 120 g of water at 15^0C. Dry steam at 100^oC is bubbled through the water in the calorimeter until the temperature of the water becomes 35^0C. Find the mass of steam condensed.
7. The cooling system of a refrigerator extracts 600 J per second of heat. How long will it take to convert 500 g of water at 15^0C into ice?

   Revision exercise 17 pages 290 – 291 Longhorn book 3

EFFECTS OF HEAT ON MATTER

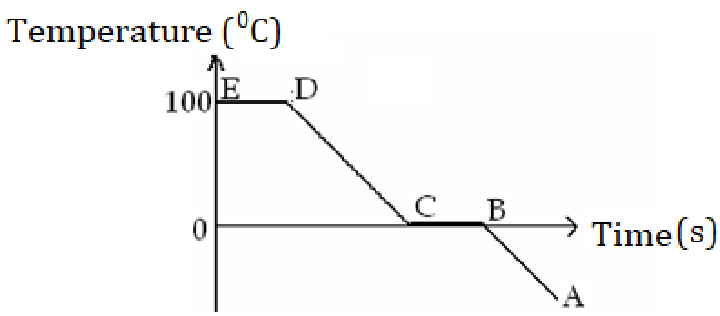
Melting point is the constant temperature at which a solid changes to a liquid.
When all the solid has melted and more heat is supplied the temperature of the liquid rises again, the heat gained by the liquid decreases the cohesion force in a liquid considerably and the speed of motion of the molecules increases steadily until the liquid changes into a gas.

Boiling point is the constant temperature at which a liquid changes to gas (vapour).
During boiling the temperature remains constant.
If water is heated, then its temperature varies with time as shown in the figure below.



Along AB the temperature of ice rises from A to B.
Along BC the temperature remains constant when the ice melts at 0^0C.
Along CD the temperature of melted ice rises from C to D.
Along DE the temperature remains constant at 100^0C.

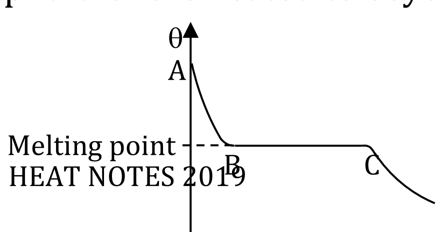
The reverse of the above process takes place when the water cools or when heat extracted from it.

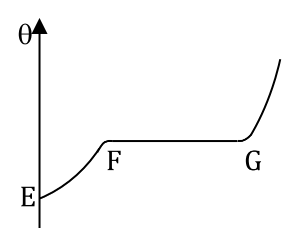


The temperature remains constant along ED at 100^0C when steam condenses. When all of it has condensed the temperature falls from D to C.
At 0^0C the temperature remains constant along CB as water changes to ice.
The temperature again falls along BA when all water has frozen.

COOLING CURVE OF A PURE SUBSTANCE

When liquid naphthalene is cooled while its temperature is noted with time the cooling curve obtained has the shape shown in (i) below. The curve in (ii) is one when solid naphthalene is heated to beyond melting.





In the region A to B liquid naphthalene is cooling. From B to C the substance is freezing and giving up latent heat. There is no change of temperature. At C all the naphthalene has solidified. So, after C the solid is cooling.

EFFECTS OF IMPURITIES ON BOILING (VAPORIZATION) AND MELTING POINTS

1. **Impurities**

   Impurities decrease or lower the melting point of a substance. Though pure water freezes at 0^0C, Salty water would remain as water at -1^0C. The extent to which melting point is lowered depends on the concentration of impurities dissolved into the liquid. For example when salt is added to ice, its melting point is reduces to a value as low as -10^0C.

Application

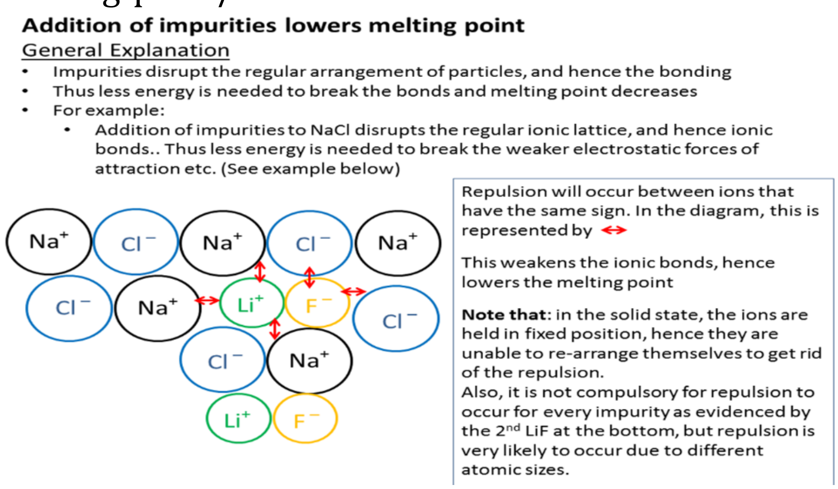
This method is used to

(a) Defreeze roads in cold countries during winter.

(b) Antifreeze material is added to the water in the car radiators to stop water from freezing.

Researched content (SKIP THIS)

https://anhourofchemaday.wordpress.com/tag/why-do-impurities-decrease-melting-point-but-increase-boiling-point/


Addition of impurities lowers melting point

General Explanation

- Impurities disrupt the regular arrangement of particles, and hence the bonding
- Thus less energy is needed to break the bonds and melting point decreases
- For example:
  - Addition of impurities to NaCl disrupts the regular ionic lattice, and hence ionic bonds.. Thus less energy is needed to break the weaker electrostatic forces of attraction etc. (See example below)

When a substance contains impurities the boiling point of substance is raised.

Note

When the substance is pure then its boiling point and melting point remains the same provided the pressure of the surrounding does not change.

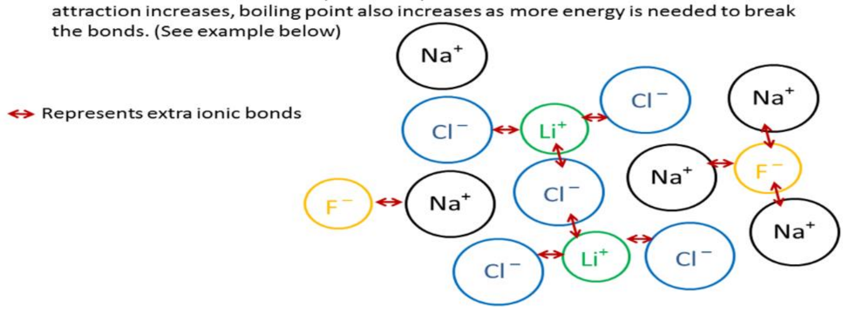
Researched content (SKIP THIS)

https://anhourofchemaday.wordpress.com/tag/why-do-impurities-decrease-melting-point-but-increase-boiling-point/

Addition of impurities increases boiling point

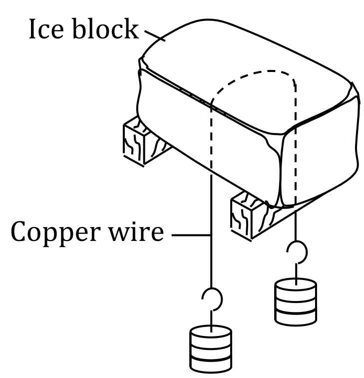
General Explanation

- In liquid state, particles are mobile thus would re-arrange themselves to achieve maximum attraction and hence stability.
- Thus more energy is needed to break the bonds and boiling point increases
- For example:
    - In the molten state, the Na^+, Cl^-, Li^+ and F^- ions are mobile, hence the positive ions would be attracted to the negative ions and vice versa. This increases the amount of electrostatic attraction as compared to a pure substance. Since electrostatic attraction increases, boiling point also increases as more energy is needed to break the bonds. (See example below)



2. Pressure on Melting (Ref: Longhorn book3 page 275)

Most substances contract when they solidify. However, a few, like water, expand on solidification. If a substance contracts on solidifying, then application of pressure encourages solidification, i.e pressure raises its melting point.
On the other hand, if a substance expands on solidifying, then application of pressure makes it easier for such a substance to remain liquid, i.e pressure lowers its melting point. This may be demonstrated by placing a block of ice on two wooden supports and passing over it a copper wire which is supporting weights at its ends as shown below



After about an hour the wire cuts through the ice but the block remains a single piece. The pressure the wire on the ice increases, the melting point of the ice decreases and so the ice melts. The resulting water goes above the wire, where there is no applied pressure. So, it freezes again.
The copper wire helps conduct the heat from the freezing water above to the lower side where its required for further melting of the ice under the wire.
The wire cuts right through the block of the ice and falls to the floor, leaving ice still in a solid block.

Since ice contracts on freezing, an increase in pressure would help in its contraction and hence we should expect a decrease in the melting point of ice as pressure on its surface is increased. The melting point of ice decrease with increase in pressure.

For substances like wax, gold, silver etc. which expand on melting, an increase in pressure would make its expansion difficult. These substances have to be heated more in order to melt. For such substances, the melting point increases with increase in pressure.

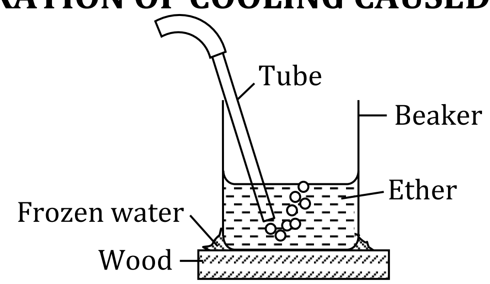
EVAPORATION
When a liquid is exposed to the atmosphere, some of the molecules gradually escape from its surface, causing the liquid to change to its vapour form. This process is known as evaporation.

Definition.
Evaporation is the process in which a liquid is converted to vapour at all temperatures.

Examples.
Both wet clothes spread out in the sun and those in the house eventually become dry but those in the house take a longer time.
Similarly, water in a shallow dish placed in open air gradually diminishes and ultimately disappears altogether.

EXPLANATION OF HOW EVAPORATION CAUSES COOLING.
During evaporation, Molecules move freely within a liquid and the energy is mainly kinetic. However, there is a small force of attraction between the molecules. The molecules are continually breaking through the surface of the liquid, but most of these are attracted back to the liquid by the cohesive forces.
The fast moving molecules which gain enough kinetic energy are able to escape from the attraction of other molecules and the average kinetic energy of the remaining molecules is reduced. As the temperature is the measure of the kinetic energy of the molecules, the temperature of the liquid falls during evaporation. Thus evaporation causes cooling.

DEMONSTRATION OF COOLING CAUSED BY EVAPORATION



A beaker, about one-third full of ether, is stood in a small pool of water on a flat piece of wood.
Air is bubbled through the ether for some time.
It is observed that the pool of water begins to freeze.

Explanation:
Bubbling causes rapid evaporation of the ether and vapour is quickly carried away as the bubbles rise to the surface and burst. The rate of evaporation increases.

The sudden change from liquid to the vapour requires latent heat of vaporisation which comes from the internal energy of the liquid itself. This causes the liquid to cool well below 0^0C. At the same time heat is being conducted from the thin pool of water underneath and water also cools to 0^0C. The water at 0^0C, begins to lose latent heat of fusion and finally freezes.

FACTORS AFFECTING EVAPORATION

(i) **Temperature**
Whenever the temperature of a liquid is raised more molecules are given enough energy to escape to the vapour phase. So, the rate of evaporation increases with rise in temperature.

(ii) **Exposed Surface Area**
The greater the surface area of the liquid the higher is the rate of evaporation, since more molecules are exposed to the atmosphere.

(iii) **Current of Air over the Liquid Surface (wind or drought)**
When an air current blows over the liquid, the liquid molecule in the gaseous state are carried away. This creates more space for more molecules to leave the liquid easily, increasing the rate of evaporation. This why wet clothes dry faster on a windy day.

(iv) **Nature of the liquid.**
The boiling point of a liquid depends upon the nature of the liquid, thus ether having a low boiling point will evaporate more easily than the same quantity of water under similar conditions.

(v) **Pressure.**
If the pressure acting on the surface of the liquid is decreased, more and more molecules can escape from its surface. Therefore, a decrease in pressure increases the rate of evaporation of a liquid. This is why in a vacuum the evaporation is extremely rapid.
Therefore, a vapour can be condensed by applying pressure and a liquid can be vaporized by reducing the pressure on it.

SIMILARITIES AND DIFFERENCES BETWEEN BOILING AND EVAPORATION
SIMILARITIES
Both are processes where a liquid changes to vapour.
For both latent heat of vaporisation is required.

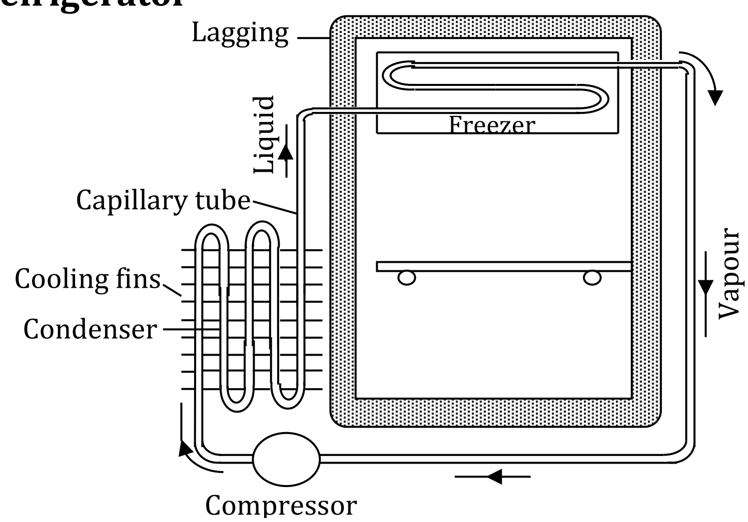
DIFFERENCES

BOILING	EVAPORATION
1.Takes place throughout the liquid	-Takes place only on the surface of the liquid
2. Takes place at a fixed temperature for a given liquid.	-Takes place at any temperature
3.Doesn’t cause cooling	-Cause cooling for the liquid

4. Evaporation is a slow and calm process.	-Boiling is a rapid and a noisy process.

APPLICATIONS OF COOLING EFFECT CAUSED BY EVAPORATION

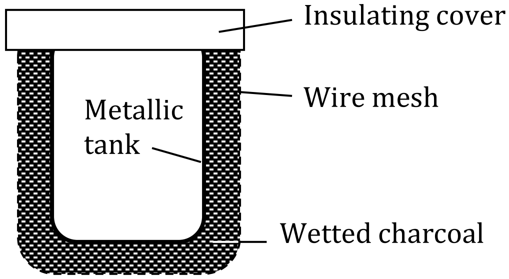
1. Water kept in earthen pitchers (clay and mud pots) is colder than the one in a metal container.
   The earthen pot is porous and water seeps through the pores and escapes.
   The required latent heat of vaporisation is being removed from the internal energy of water inside the pot. This causes the water to cool well below room temperature.
   If a wet cloth is wrapped around the pot, the rate of evaporation can be speeded up and more cooling effect produced.
2. If methylated spirit is sprayed on the hand, the hand feels cold. The spirit has a low boiling point and can change from liquid to vapour quite easily at room temperature. To change from liquid to vapour, the required latent heat of vaporisation is removed from the body. The hand loses heat and cools.
   Note: Such liquids are called volatile liquids.
3. Human beings sweat or perspire on a hot day or after severe exercise. Dogs pant, i.e. hung out their tongue, since their bodies are not porous. The sweating effect or panting is to keep the body cool.
4. When we perspire in a hot weather, we prefer to sit below and electric fan. Cooling effect is produced due to rapid evaporation.
5. In hot weather, the sprinkling of roads with water not only lays down dust particles from the road, bur also produces a cooling effect by evaporation.
6. If we expose ourselves to wind with wet clothes on a rainy day, we feel intense cold due to evaporation of water.
7. **The refrigerator**



The compressor circulates the refrigerant through the tubes. It sucks the fluid from the freezer and this lowers the pressure there, causing the fluid to evaporate. The evaporating fluid takes up heat from the surroundings, thus causing cooling.
At the same time the compressor pumps the fluid into the condenser. The capillary tube ahead constrains the fluid flow, causing pressure to build up in the condenser. This causes the fluid to condense there, giving up its latent heat to the surroundings.

The **cooling fins** help to take away the heat given up by the condensing fluid.
The cycle continues, each time heat being extracted from the freezer and being given up in the condenser. Between the freezer and the compressor, the fluid is in vapour form while between the condenser and freezer it is in liquid form.

The Charcoal Refrigerator



It consists of a metallic tank surrounded by wetted charcoal. The charcoal is kept in place by a wire mesh that surrounds the tank and an insulator covers the top of the tank.
Action:
Charcoal is porous and thus presents a lot of its surface to the surroundings. As water evaporates from the charcoal, it absorbs latent heat of vaporization from the metallic tank. So, heat flows from the inside of the tank to the outside.
The porosity of the charcoal quickens the evaporation. The performance of this refrigerator may be improved if it is placed in a draught.

SUBTOPIC: VAPOURS
SPECIFIC OBJECTIVES:
- Define saturated and unsaturated vapours, and SVP.
- Define boiling point.
- Explain effect of pressure on boiling point.
- Investigate boiling under reduced pressure.
- Explain the working of a pressure cooker.
- Explain the variation of boiling point with altitude.

MECHANISM OF EVAPORATION
A vapour is a substance, in gaseous state, that can be liquefied by compression.
Energetic molecules of a liquid do escape from the surface and join the gaseous state. On average the less energetic molecules remain behind. So the liquid cools as it evaporates – (Cooling by evaporation)

VAPOUR PRESSURE AND SATURATED VAPOUR PRESSURE.

VAPOUR PRESSURE
Suppose water is poured in a sauce pan and a sauce pan is covered with a tray. The water is then heated, until it boils. The space above begins to fill with vapour. The vapour molecules move about in all directions and exert pressure when they hit the walls of the

sauce pan and they also strike the surface of the liquid and may re-enter. At this point a state dynamic equilibrium is said be reached.

A **state of dynamic equilibrium** is when the rate at which molecules leave the surface of the liquid is equal to the rate at which they re-enter the liquid.

“Dynamic” means molecules are in continuous motion.

Definition
Vapour pressure is the pressure exerted by vapour molecules due to their constant motion.

Under these condition, the space above the liquid is said to saturated with vapour the pressure exerted is called saturated vapour pressure. (s.v.p).
For a given temperature, s.v.p is always the same.

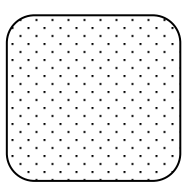
Definition
Saturated vapour pressure is the pressure exerted by a vapour which is in a state of dynamic equilibrium with its own liquid is called**.**

Before equilibrium is reached, the pressure is said to be unsaturated.

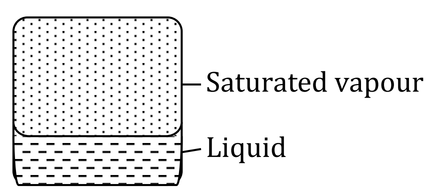
In case of unsaturated vapour, the pressure is referred to as **unsaturated vapour pressure.**

Unsaturated vapour is the vapour formed when molecules move about in a random motion and some of the return to the liquid after collision.

A saturated vapour is one which is in a state of dynamic equilibrium with its own liquid.



(i) Unsaturated vapour



(ii) Saturated vapour

CHARACTERISTICS OF A SATURATED VAPOUR

1. Pressure of a saturated vapour is independent of volume.
   When a saturated vapour is compressed, some vapour instead condenses to liquid reducing the vapour volume but leaving the vapour pressure the same. i.e the vapour portion decreases as that of the liquid increases. The other way round happens when a saturated vapour is expanded, still the pressure remaining the same.

2. Pressure of a saturated vapour increases with rise in temperature.

Humidity in the Atmosphere
This is the amount of water vapour actually present in the air.
When the air is saturated with water, its humidity is 100%.

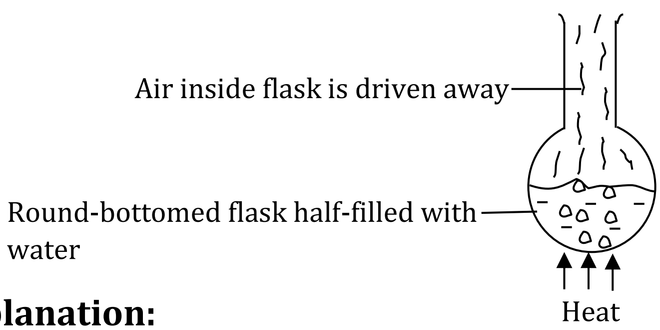
The dew point is the temperature at which air becomes saturated when cooled.

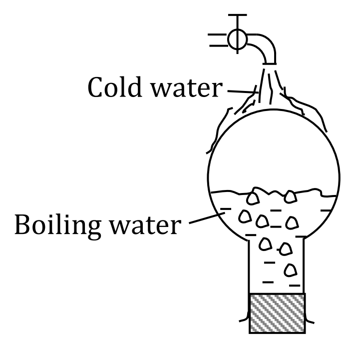
Relative humidity is the ratio of saturated vapour pressure of water if the air were at the dew point to the saturated vapour pressure of water at the present air temperature.

DEPENDENCE OF BOILING POINT ON EXTERNAL PRESSURE
(Effect of reduced pressure on boiling point of water)
A liquid boils at a temperature at which its saturated vapour pressure equals the external pressure. Since atmospheric pressure is lower at higher altitudes, it follows that the boiling point of a liquid is lower at higher altitudes. Raising the external pressure raises the boiling point of a liquid.

AN EXPERIMENT TO DEMONSTRATE REDUCTION IN PRESSURE LOWERS BOILING.
A round bottomed flask is half filled with water. The water is boiled until steam drives the air out of the flask.
The gas is turned off, the glass is fitted with a rubber stopper and a thermometer. The flask is clamped upside down.
When boiling has stopped, cold water is poured over the flask.

Observation.
The water boils again at a lower temperature.

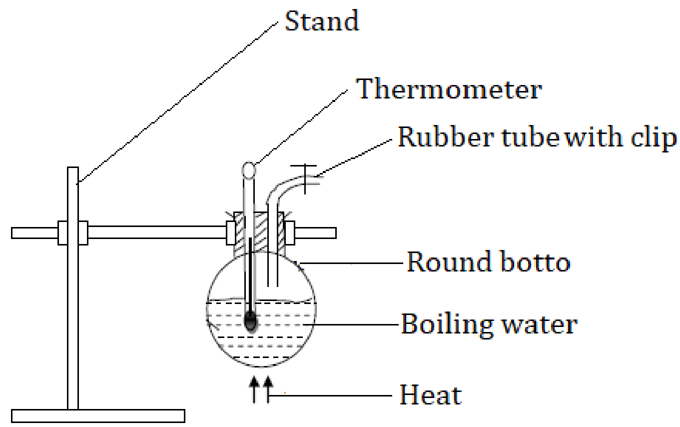




Explanation:
When the flask is cooled by water from the tap, the water vapour inside condenses leaving a partial vacuum above the water thus lowering the pressure inside. So water boils well below its boiling point.

Conclusion
Reduced pressure lowers the boiling point of water. Similarly, increased pressure raises the boiling point of water.

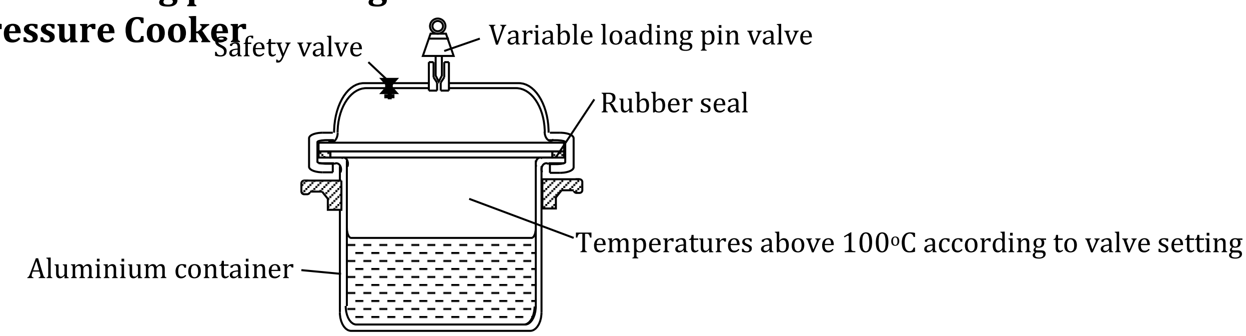
AN EXPERIMENT TO SHOW THE EFFECT OF INCREASE OF PRESSURE ON BOILING POINT OF WATER.



A round bottomed flask is filled with three quarters of water.
The round bottomed flask is closed with a two holed rubber cork is insert.
One hole is fitted with a thermometer and the other with a glass tube with a clip.
Water is heated in a round bottomed flask until it starts boiling under standard atmospheric pressure. The cliff is opened.
It is observed that the water boils at 100^0C.
The steam is trapped inside by the closing the cliff.
It is observed that there is an increase the reading of thermometer.
This shows that the boiling point increases with increase in pressure.
(For the video visit http://youtube.com/watch?v=AFARWpoaSJA)

Applications of boiling point changes.

1. The Pressure Cooker



This device works on the principle that at the boiling point of a liquid is raised when pressure is increased.
It is an aluminum container with a lid having a rubber sealing ring called a gasket.
The ring makes the gas cooker air tight.
There is much space left empty at the top so that steam pressure can build up in that space to twice the atmospheric pressure.
A pin valve is used is used to release some steam in order to maintain the required pressure and avoid an explosion when there is to much pressure inside the cooker.
Due to high pressure water boils at about 200^0C which makes food cook faster.
Food cooked in a pressure cooker with water boiling at a higher temperature than 100^0C takes less time to be ready.
https://www.youtube.com/watch?v=TWV3FbgPPXo

2. Cooking on mountains

Water boils at lower temperatures up a mountain e.g. at the top of Mt. Evarest which is 8850m above sea level, water boils at 73^0C. It is therefore not possible to cook food properly on high mountains, or even tea.
Mountains climbers therefore use pressure cookers to overcome this problem.

VARIATION OF BOILING WITH ALTITUDE
Page 297.
Increase in pressure leads to increase in the boiling point of a liquid, similarly, a decrease in pressure leads to a decrease in boiling point.
At sea level atmospheric pressure is high, water boils at 100^0C. At a higher altitude air is less dense and exerts less pressure which reduces the boiling point.
It is advisable to use a pressure cooker while cooking in areas of higher altitude, otherwise the food is not properly cooked.

Conclusion
Boiling takes place faster at higher altitude than at sea level
Cooking takes a longer time

(DO NOT COPY THIS ONE)
How about that egg we want to cook on top of a high mountain, say at 10,000 feet?
We now know that the water will boil at a lower temperature on top of the mountain at lets say, 185 degrees Fahrenheit. To hard-boil an egg at sea level takes say, five minutes at 212 degrees Fahrenheit.
Now, there is a very good law in chemistry that states "You cannot get something for nothing" (the left-hand value of an equation must equal the right-hand value). Time multiplied by temperature equals a hardboiled egg. That is to say, 212 times 5 equals a hardboiled egg.
If the temperature of the boiling water on the mountaintop is 185 degrees Fahrenheit, then the time taken to cook the egg will have to INCREASE to get our hardboiled egg. Our equation to equal a hardboiled egg cannot change. (185 times extended time equals hardboiled egg.) It is no different to cooking a piece of steak or cooking the potatoes. You can cook at a low temperature for a long time, or a high temperature for a short time.
It is time and temperature that does the cooking. It has nothing to do with whether the water is boiling. That is only a physical phenomenon that you can see. You have to measure for temperature and time, as these are the two factors that determine when the egg is hardboiled.

THE END.