HEAT MEASUREMENT

Terminologies used:

i) <u>Heat capacity, C</u>:

This is the amount of heat required to raise the temperature of a body by 1K or 1^0C.

$$Heat\ capacity = \frac{Amount\ of\ heat}{Change\ in\ temperature}$$

$$C = \frac{H}{\Delta\theta}$$

The SI unit of heat capacity is joules per Kelvin (J/K or JK^{-1})

Also, $Heat\ capacity = mass \times specific\ heat\ capacity$

$$\boldsymbol{Heat\ capacity = mc}$$

ii) <u>Specific heat capacity, c</u>:

This is the amount of heat required to raise the temperature of 1kg mass of a substance by 1K or 1^0C.

$$Specific\ heat\ capacity = \frac{Amount\ of\ heat}{Mass \times \Delta\theta}$$

$$c = \frac{H}{m \times \Delta\theta}$$

The SI unit of specific heat capacity is Joules per kilogram per Kelvin (J/kgK or $Jkg^{-1}K^{-1}$).

Quantity of heat, $\mathbf{H = mc\Delta\theta}$

Where $\mathbf{\Delta\theta}$ – change in temperature.
c – Specific heat capacity
m – Mass of substance.

Note: $\Delta\boldsymbol{\theta} = \boldsymbol{\theta_2 - \theta_1}$

N.B: The specific heat capacity is different for different substances and the table below shows values of specific heat capacities of some common substances.

Substance	**Specific heat capacity ($Jkg^{-1}K^{-1}$)**
Water	4200
Ice	2100
Aluminium	900
Copper	400

NOTE:

Water has the highest specific heat capacity of $4200Jkg^{-1}K^{-1}$. <u>The high specific heat capacity of water makes water a very good liquid for cooling machines.</u>

Question:

"The specific heat capacity of water is $4200Jkg^{-1}K^{-1}$" What is meant by the statement?

This means that 1kg mass of water requires 4200J of heat to raise its temperature by 1K.

Heat calculations

The following should be noted:
Always mass must be in Kilograms (kg)
In questions with the phrase "**the temperature rises by**" or "**the temperature rose by**", the temperature value given is the change in temperature $\Delta\theta$

Examples:

1. How much heat is required to raise the temperature of 5kg of iron from 30^{O}C to 40^{O}C if the specific heat capacity of iron is 440Jkg^{-1}K^{-1}?
   $H = mc\Delta\theta$
   $H = 5 \times 440 \times (40 - 30)$
   $H = 2200 \times 10$
   $\boldsymbol{H = 22000\text{J}}$

2. When a block of iron of mass 2kg absorbs 19kJ of heat its temperature rises by 10^{O}C. Find the specific heat capacity of iron.
   $H = mc\Delta\theta$
   $19000 = 2 \times c \times 10$
   $c = \frac{19000}{20}$
   $\boldsymbol{c = 950\text{J}kg^{-1}K^{-1}}$

3. How much heat is given out when an iron metal of mass 2 kg and specific heat capacity 460 $J\ kg^{-1}\ K^{-1}$ cools from 300℃ to 200℃.
   $H = mc\Delta\theta$
   $H = 2 \times 460 \times (300 - 200)$
   $H = 920 \times 100$
$\boldsymbol{H = 92000\text{J}}$

4. Calculate the specific heat capacity of gold if 108 J of heat raises the temperature of a 9g mass from 0℃ to 100℃.
   $m = \frac{9}{1000} = 0.009kg$
   $H = mc\Delta\theta$
   $108 = 0.009 \times c \times (100 - 0)$
   $108 = 0.9c$
   $c = \frac{108}{0.9}$
   $\boldsymbol{c = 120\text{J}kg^{-1}K^{-1}}$

5. 5KJ of heat is supplied to a metal whose specific heat capacity is 400 $Jkg^{-1}K^{-1}$, if the temperature of the metal rises by 5K. Find the mass of the metal.
   $H = mc\Delta\theta$
   $5000 = m \times 400 \times 5$
   $5000 = 2000m$
   $\boldsymbol{m = 2.5\text{kg}}$

6. 1200J of heat is supplied to 100g of water at 20°C. Calculate the final temperature of water if its specific heat capacity is 4200$Jkg^{-1}K^{-1}$

$$m = \frac{100}{1000} = 0.1kg$$

$$H = mc\Delta\theta$$

$$1200 = 0.1 \times 4200 \times (\theta_2 - 20)$$

$$1200 = 420\theta_2 - 8400$$

$$1200 + 8400 = 420\theta_2$$

$$\theta_2 = \frac{9600}{420}$$

$$\boldsymbol{\theta_2 = 22.9°}$$

CALORIMETRY:

This is the measurement of flow of heat.

The instrument used in calorimetry is called <u>calorimeter</u>.

<u>Calorimeter</u>:

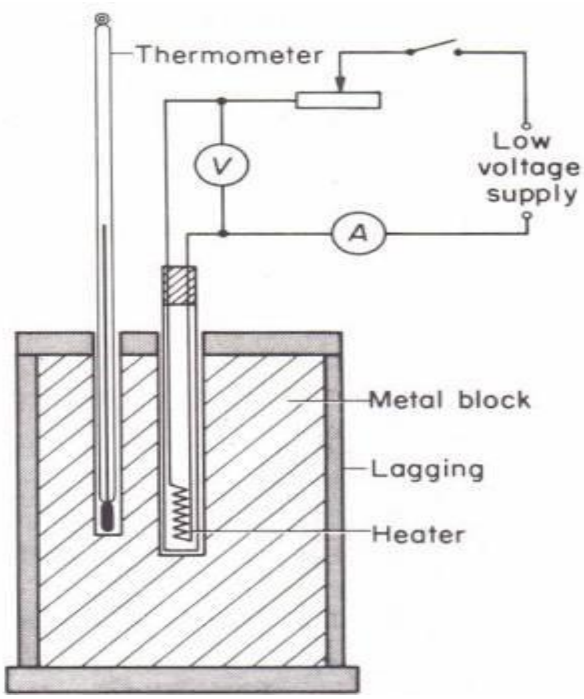
- It is made up of copper.
- It is lagged with an insulator and placed in a jacket with a plastic cover which has two holes for a thermometer and a stirrer.

<u>METHODS OF MEASURING SPECIFIC HEAT CAPACITY</u>:

There are two common methods namely;

- Electrical method.
- Method of mixtures.

<u>Experiment to determine Specific heat capacity of a solid by electrical method.</u>



- A metal block of mass, m whose S.H.C is to be determined is drilled with two holes, one for thermometer and the other for heater. Both the heater and thermometer must be in good contact with the block.
- The initial temperature, θ_1 of the block is recorded from the thermometer before closing the switch.
- The heater is then switched on by closing switch, K until the temperature of block changes to θ_2, in a given time, t.
- The ammeter and voltmeter readings I and V respectively are noted and recorded.

Assuming there are no heat losses,

$$\textit{Electrical heat supplied by heater} = \textit{Heat gained by metal block}$$

$$IVt = mc\Delta\theta \quad \text{But } \Delta\theta = \theta_2 - \theta_1$$

$$c = \frac{IVt}{mc(\theta_2 - \theta_1)}$$

But also power, $P = IV$

$$c = \frac{Pt}{mc(\theta_2 - \theta_1)} \text{ where c is specific heat capacity}$$

Example:

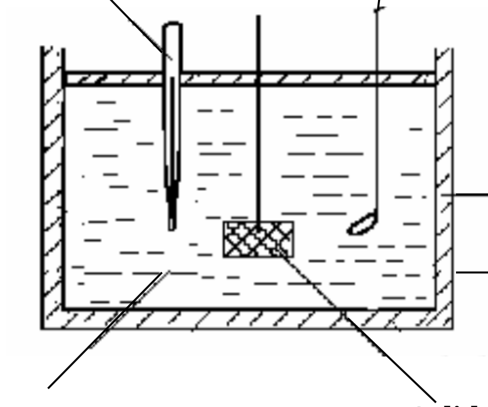
1. 98,000J of electrical heat are needed to raise the temperature of 2kg of a substance from 51^{o}C to 65^{o}C. Calculate the specific heat capacity of a substance.

$$\text{Electrical heat supplied} = \text{Heat gained by substance}$$
$$IVt = mc\Delta\theta$$
$$IVt = mc(\theta_2 - \theta_1)$$
$$98000 = 2 \times c \times (65 - 51)$$
$$c = \frac{98000}{28}$$
$$c = 3500Jkg^{-1}K^{-1}$$

2. A heater rated 2KW is used for heating the solid of mass 6kg, if its temperature rises from 30℃ to 40℃. In 12s, find the S.H.C of the solid.

$$P = 2\text{ kW} = 2x1000\text{ W},\ m = 6\text{ kg}$$
$$\text{Electrical heat supplied} = \text{Heat gained by substance}$$
$$IVt = mc\Delta\theta$$
$$Pt = mc(\theta_2 - \theta_1)$$
$$2000 \times 12 = 6 \times c \times (40 - 30)$$
$$c = \frac{24000}{60}$$
$$c = 400Jkg^{-1}K^{-1}$$

Experiment to determine Specific heat capacity of a solid by method of mixtures.



- A solid of mass, m_s whose specific heat capacity, c_s is required is heated to a temperature, θ_1.
- A solid is then transferred quickly to a calorimeter of mass, m_c and specific heat capacity c_c containing water of mass, m_w both at a temperature, θ_2.
- The mixture is well stirred until a steady final maximum temperature, θ_3 is reached.

Assuming there is no heat loss during the experiment,

$$\textbf{Heat lost by solid} = \textbf{Heat gained by water} + \textbf{Heat gained by calorimeter}$$

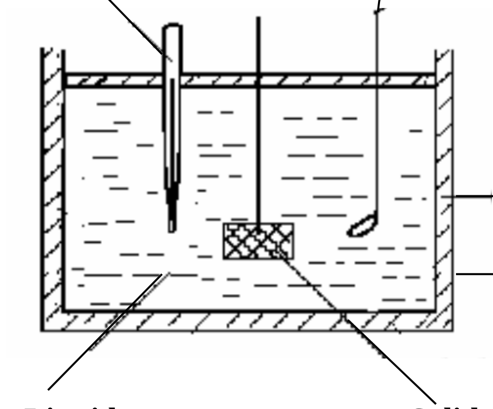
$$\mathbf{m_s c_s \Delta\theta = m_w c_w \Delta\theta + m_c c_c \Delta\theta}$$

$$\mathbf{m_s c_s (\theta_1 - \theta_3) = m_w c_w (\theta_3 - \theta_2) + m_c c_c (\theta_3 - \theta_2)}$$

$$\mathbf{c_s = \frac{m_w c_w (\theta_3 - \theta_2) + m_c c_c (\theta_3 - \theta_2)}{m_s (\theta_1 - \theta_3)}}$$

- Hence specific heat capacity, c_s of a solid can be calculated

Experiment to determine Specific heat capacity of a liquid by method of mixtures.



- A solid of mass, m_s and specific heat capacity,c_s is heated to a temperature,θ_1.
- A solid is then transferred quickly to a calorimeter of mass, m_c and specific heat capacity c_c containing a liquid of mass, m_l whose specific heat capacity c_l is required both at a temperature, θ_2.
- The mixture is well stirred until a steady final maximum temperature, θ_3 is reached.

Assuming there is no heat loss during the experiment,

$$\textbf{Heat lost by solid} = \textbf{Heat gained by liquid} + \textbf{Heat gained by calorimeter}$$
$$\boldsymbol{m_s c_s \Delta\theta = m_l c_l \Delta\theta + m_c c_c \Delta\theta}$$
$$\boldsymbol{m_s c_s(\theta_1 - \theta_3) = m_l c_l(\theta_3 - \theta_2) + m_c c_c(\theta_3 - \theta_2)}$$
$$\boldsymbol{c_l = \frac{m_s c_s(\theta_1 - \theta_3) - m_c c_c(\theta_3 - \theta_2)}{m_l(\theta_3 - \theta_2)}}$$

- Hence specific heat capacity,c_l of a liquid can be calculated.

Examples:

1. A piece of metal of mass 0.5kg is heated to 100^{o}C and then placed in 0.4kg of water at 10^{o}C, if the final temperature of the mixture is 30^{o}C. Calculate the specific heat capacity of the metal. (Neglect heat absorbed by container with water and S.H.C of water is 4200Jkg^{-1}K^{-1})

$$\textit{Heat lost by the metallic solid} = \textit{Heat gained by water}$$
$$\mathbf{m_s c_s \Delta\theta = m_w c_w \Delta\theta}$$
$$\mathbf{0.5 \times c_s \times (100 - 30) = 0.4 \times 4200 \times (30 - 10)}$$
$$\boldsymbol{35c_s = 33600}$$
$$\boldsymbol{c_s = \frac{33600}{35}}$$
$$\boldsymbol{c_s = 960Jkg^{-1}K^{-1}}$$

2. The temperature of a piece of copper of mass 250g is raised to 100℃ and it is then transferred to a well- lagged aluminum can of mass 10.0g containing 120g of methylated spirit at 10.0℃. Calculate the final steady temperature after the spirit has been well stirred. Neglect the heat capacity of the stirrer and any losses from evaporation. (S.H.C of copper, aluminum and spirit respectively = 400 $J\ kg^{-1}\ K^{-1}$, = 900 $J\ kg^{-1}\ K^{-1}$, = 2400 $J\ kg^{-1}\ K^{-1}$)

$$\theta_1 = 100^0C, \theta_2 = 10^0C, \theta_3 = ?$$
$$\text{Heat lost by copper piece} = \text{Heat gained by spirit} + \text{Heat gained by aluminium } can$$
$$m_C c_C \Delta\theta = m_S c_S \Delta\theta + m_A c_A \Delta\theta$$
$$m_C c_C(\theta_1 - \theta_3) = m_S c_S(\theta_3 - \theta_2) + m_A c_A(\theta_3 - \theta_2)$$
$$\frac{250}{1000} \times 400 \times (100 - \theta_3) = \frac{120}{1000} \times 2400 \times (\theta_3 - 10) + \frac{10}{1000} \times 900 \times (\theta_3 - 10)$$
$$100 \times (100 - \theta_3) = 288(\theta_3 - 10) + 9(\theta_3 - 10)$$
$$10000 - 100\theta_3 = 288\theta_3 - 2880 + 9\theta_3 - 90$$
$$288\theta_3 + 9\theta_3 + 100\theta_3 = 10000 + 2880 + 90$$
$$397\theta_3 = 12970$$
$$\theta_3 = \frac{12970}{397}$$
$$\theta_3 = 32.7°C$$

3. A metal of mass 0.2kg at 100℃ is dropped into 0.08kg of water at 13℃ contained in calorimeter of mass 0.12kg and S.H.C 400$Jkg^{-1}K^{-1}$. The final temperature reached is 35℃. Determine the S.H.C of the metal

$$m_M = 0.2kg, \theta_1 = 100℃,$$
$$m_W = 0.08kg, \theta_2 = 15℃, \quad c_W = 4200Jkg^{-1}K^{-1}$$
$$m_C = 0.12kg \quad c_C = 400Jkg^{-1}$$
$$\theta_3 = 35℃$$

$$Heat\ lost\ by\ metal = Heat\ gained\ by\ water + Heat\ gained\ by\ calorimeter$$
$$m_M c_M \Delta\theta = m_W c_W \Delta\theta + m_C c_C \Delta\theta$$
$$m_M c_M(\theta_1 - \theta_3) = m_W c_W(\theta_3 - \theta_2) + m_C c_C(\theta_3 - \theta_2)$$
$$0.2 \times c_M \times (100 - 35) = 0.08 \times 4200 \times (35 - 15) + 0.12 \times 400(35 - 15)$$
$$13c_M = 6720 + 960$$
$$c_M = \frac{7680}{13}$$
$$c_M = 590.78Jkg^{-1}K^{-1}$$

4. A liquid of mass 200g in a calorimeter of heat capacity 500 $Jkg^{-1}K^{-1}$ and mass 1kg is heated such that its temperature changes from 25℃ to 50℃. Find the S.H.C of the liquid if the heat supplied was 14,000J.

$$\textbf{Heat supplied} = \textbf{heat gained by liquid} + \textbf{heat gained by calorimeter}$$
$$H = m_l c_l \Delta\theta + m_c c_c \Delta\theta$$
$$H = m_l c_l(\theta_2 - \theta_1) + m_c c_c(\theta_2 - \theta_1)$$
$$14000 = \frac{200}{1000} \times c_l \times (50 - 25) + 1 \times 500 \times (50 - 25)$$
$$14000 = 5c_l + 12500$$
$$1500 = 5c_l$$
$$c_l = \frac{1500}{5}$$
$$c_l = 300Jkg^{-1}K^{-1}$$

5. 450g of water at 60°C is to be cooled to 35°C by addition of cold water at 20°C. Calculate the mass of cold water added. (S.H.C of water is 4200 $Jkg^{-1}K^{-1}$)

$$\textbf{Heat lost by hot water} = \textbf{Heat gained by cold water}$$
$$m_{hw} c_{hw} \Delta\theta = m_{cw} c_{cw} \Delta\theta$$
$$\frac{450}{1000} \times 4200 \times (60 - 35) = m_{cw} \times 4200 \times (35 - 20)$$
$$47250 = 63000 m_{cw}$$
$$m_{cw} = \frac{47250}{63000}$$
$$m_{cw} = 0.75kg$$

6. Hot water of mass 0.4kg at 100℃ is poured into calorimeter of mass 0.3kg and S.H.C of 400$Jkg^{-1}K^{-1}$ and contains 0.2kg of a liquid at 10℃. The final temperature of mixture is 40℃ determines the S.H.C of a liquid. (S.H.C of water is 4200 $Jkg^{-1}K^{-1}$)

$$m_w = 0.4kg, \theta_1 = 100℃$$
$$m_l = 0.2kg, \theta_2 = 10℃$$
$$m_c = 0.3kg, c_c = 400Jkg^{-1}K^{-1}$$
$$\theta_3 = 40℃$$
$$\textbf{Heat lost by hot water} = \textbf{Heat gained by liquid} + \textbf{Heat gained by calorimeter}$$
$$m_w c_w \Delta\theta = m_l c_l \Delta\theta + m_C c_C \Delta\theta$$
$$m_w c_w(\theta_1 - \theta_3) = m_l c_l(\theta_3 - \theta_2) + m_C c_C(\theta_3 - \theta_2)$$
$$0.4 \times 4200 \times (100 - 40) = 0.2 \times c_l \times (40 - 10) + 0.3 \times 400 \times (40 - 10)$$
$$100800 = 6c_l + 3600$$
$$6c_l = 97200$$
$$c_l = \frac{97200}{6}$$
$$c_l = 16200Jkg^{-1}K^{-1}$$

NOTE: Since mass is proportional to volume, then mass of liquid is equal to its volume for a unit substance.

7. A copper metal of mass 250g is heated to 145°C and then placed in a copper calorimeter of mass 250g which contains 250cm^3 of water at 20°C. Calculate the maximum temperature attained by water [specific heat capacity of water is 4200Jkg^{-1}K^{-1} and specific heat capacity of copper is 400Jkg^{-1}K^{-1}]

$$m_{CM} = 250g, \theta_1 = 145℃, c_{CM} = 400Jkg^{-1}K^{-1}$$
$$m_W = 250cm^3 = 250g, \theta_2 = 20℃$$
$$m_C = 250g, c_C = 400Jkg^{-1}K^{-1}$$
$$\theta_3 = ?$$

$$Heat\ los\ by\ copper\ metal = Heat\ gained\ by\ water + Heat\ gained\ by\ calorimeter$$
$$\mathrm{m_{CM}c_{CM}\Delta\theta = m_Wc_W\Delta\theta + m_Cc_C\Delta\theta}$$
$$\mathrm{m_{CM}c_{CM}}(\theta_1 - \theta_3) = \mathrm{m_Wc_W}(\theta_3 - \theta_2) + \mathrm{m_Cc_C}(\theta_3 - \theta_2)$$
$$\frac{250}{1000} \times 400 \times (145 - \theta_3) = \frac{250}{1000} \times 4200 \times (\theta_3 - 20) + \frac{250}{1000} \times 400 \times (\theta_3 - 20)$$
$$100(145 - \theta_3) = 1050(\theta_3 - 20) + 100 \times (\theta_3 - 20)$$
$$14500 - 100\theta_3 = 1050\theta_3 - 2100 + 100\theta_3 - 2000$$
$$1050\theta_3 + 100\theta_3 + 100\theta_3 = 14500 + 2100 + 2000$$
$$1250\theta_3 = 37500$$
$$\theta_3 = \frac{37500}{1250}$$
$$\theta_3 = 30°C$$

PRECAUTIONS TAKEN WHEN USING METHOD OF MIXTURES

- The solid/specimens should be transferred as quickly as possible to the calorimeter to avoid heat losses.
- The calorimeter must be insulated.
- Stirring must be done to ensure uniform distribution of heat.
- The calorimeter must be polished inside to avoid heat loss by radiation.

EXERCISE

1) A piece of copper of mass 100g is heated to 100℃ and is then transferred to a well lagged copper can of mass 50g containing 200g of water at 10℃. Neglecting heat loss, calculate the final steady temperature of water after it has been well stirred. Take S.H.C of copper and water to be 400Jkg^{-1}K^{-1} and 4200Jkg^{-1}K^{-1} respectively. **Ans; [14**℃]

2) A heating coil is placed in thermal flask containing 0.6kg of water for 600s. The temperature of water rises by 25℃ during this time. Water is replaced by 0.4kg of another liquid. And the same temperature rise occurs in 180s. Calculate the S.H.C of the liquid given that S.H.C of water is 4200Jkg^{-1}K^{-1}. State any assumption. **Ans; [1890Jkg^{-1}K^{-1}]**

3) Copper calorimeter of mass 120g contains 100g of paraffin at 15℃. If 45g of aluminum at 100℃ is transferred to the liquid and the final temperature is 27℃. Calculate the S.H.C of paraffin [S.H.C of aluminum and copper are 1000 Jkg^{-1}K^{-1} and 400 Jkg^{-1}K^{-1} respectively**].**

Ans; [2.4 x10^{3}Jkg^{-1}K^{-1}

4) A liquid of mass 250g is heated to 80℃ and then quickly transferred to a calorimeter of heat capacity 380JK^{-1} containing 400g of water at 30℃. If the maximum temperature recorded is 55℃ and specific heat capacity of water is 4200Jkg^{-1}K^{-1}. Calculate the S.H.C of the liquid.

Ans; [8240Jkg^{-1}K^{-1}]

5) 500g of water is put in a calorimeter of heat capacity 0.38JK^{-1} and heated to 60℃. It takes 2minute for the water to cool from 60℃ to 55℃. When the water is replaced with 600g of a certain liquid, it takes 1½ minutes for the liquid to cool from 60℃ to 55℃. Calculate the S.H.C of the liquid.

Ans; [2624.8kgJ^{-1}K^{-1}]

6) 400g of a liquid at a temperature 70℃ is mixed with another liquid of mass 200g at a temperature of 25℃. Find the final temperature of the mixture, if the S.H.C of the liquid is 4200 $J\,kg^{-1}\,K^{-1}$. **Ans; [55**℃]

7) 60 kg of hot water at 82℃ was added to 300 kg of cold water at 10℃. Calculate the final temperature of the mixture (S.H.C of water =4200 $J\,kg^{-1}\,K^{-1}$) **Ans; [=22**℃]

8) Calculate the final steady temperature obtained when 0.8 kg of glycerine at 25℃ is put into a copper calorimeter of mass 0.5 kg at 0℃ (S.H.C of copper =400 $J\,kg^{-1}\,K^{-1}$, $S.H.C\ of\ glycerine =$ 250 $J\,kg^{-1}K^{-1}$). **Ans; [12.5**℃]

9) A block of metal of mass 0.01 kg at a temperature of 100℃ was dropped in a container of water at 20℃. The final temperature was 40℃. Calculate the S.H.C of the metal ,if S.H.C of water 4200 $J\,kg^{-1}\,K^{-1}$. **Ans; [7000 Jkg^{-1} K^{-1}]**

10) A copper block of mass 250g is heated to a temperature of 145℃ and then dropped into a copper calorimeter of mass 250g which contains 2500m^3 of water at 20℃. Calculate the final temperature of water. (S.H.C of copper = 400Jkg^{-1} ℃$^{-1}$, S.H.C of water = 4200 $J\,kg^{-1}$ ℃$^{-1}$).

Ans; [30℃]

11) The temperature of heat which raises the temperature of 0.1 kg of water from 25℃ to 60℃ is used to heat a metal rod of mass 1.7 kg and S.H.C of the rod was 20℃. Calculate the final temperature of the rod. **Ans; [48.8**℃]

LATENT HEAT (HIDDEN HEAT)

This is the amount of heat required to change the state of substance without change in temperature.

There are two types of latent heat namely:

- Latent heat of fusion
- Latent heat of vaporization

KINETIC THEORY EXPLANATION OF LATENT HEAT

Question: Explain why during change of state, the temperature of a substance remains constant

- According to kinetic theory, when a substance is changing state, there is no change in temperature because all the heat supplied is only used to break the intermolecular forces between the molecules and increase the molecular spacing of the substance.

Latent heat of fusion:

This is the amount of heat required to change a substance from solid state to liquid state at constant temperature.

Specific latent heat of fusion (L_f):

This is the amount of heat required to change 1kg mass of substance from solid state to liquid state at constant temperature.

$$\boldsymbol{Heat\ required = mass \times specific\ latent\ heat\ of\ fusion}$$

$$\boldsymbol{H = mL_f}$$

The SI unit of specific latent heat of fusion is $\mathbf{Jkg^{-1}}$

Examples:

1. The specific latent heat of fusion of ice is 340,000 Jkg^{-1}. What do you understand by this statement?
   It means that 1kg of ice needs 34,000J of heat energy to change to a liquid.

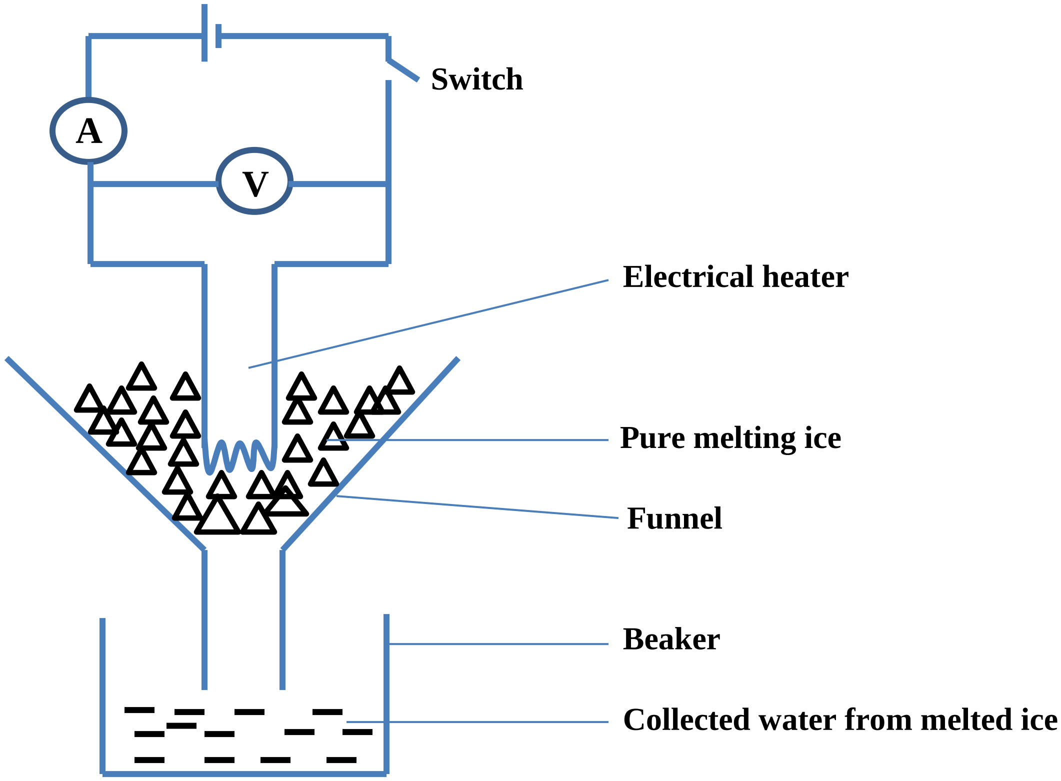
2. How much heat is needed to melt 10g of ice at 0^oC? [Specific latent heat of fusion of ice = $3.36 \times 10^5 Jkg^{-1}$]

$$\boldsymbol{H = mL_f}$$

$$\boldsymbol{H = \frac{10}{1000} \times 3.36 \times 10^5}$$

$$\boldsymbol{H = 3.36 \times 10^3 J}$$

Experiment to determine specific latent heat of fusion of ice by electrical method.



- An electrical heater is placed in a funnel.
- Small pieces of ice are packed around the heater.
- The heater is then switched on for a known time, t.
- The ammeter and voltmeter readings I and V respectively are noted and recorded.
- The mass, m of collected water from melted ice is measured and recorded
- Assuming there are no heat losses in the experiment,

$$\textbf{Heat supplied by the heater} = \textbf{Heat gained by ice to melt}$$

$$IVt = mL_f$$

$$L_f = \frac{IVt}{m}$$

$$\text{But also power}, P = IV$$

$$\text{Therefore}, L_f = \frac{Pt}{m}$$

- Hence specific latent heat of fusion of ice L_f can be calculated.

Examples;

1. A 3kW electrical heater is left for 2 minutes in a container packed with ice at 0^{O}C. If 100g of ice melted into water, calculate the specific latent of fusion of Ice.

$$P = 3kW = 3 \times 1000 = 3000W, \quad t = 2minutes = 2 \times 60 = 120s$$

$$m = 100g = \frac{100}{1000} = 0.1kg$$

$$IVt = mL_f$$

$$But\ P = IV, \quad L_f = \frac{Pt}{m}$$

$$L_f = \frac{3000 \times 120}{0.1}$$

$$L_f = 3600{,}000Jkg^{-1}$$

<u>Note</u>:

If the ice is not at its melting point0°C, the heat supplied first increases/raises its temperature to 0°C.

Therefore **,**

$$Heat\ supplied = Heat\ to\ raise\ temperature\ of\ ice\ to\ 0°C + Heat\ to\ melt\ the\ ice$$
$$H = mc\Delta\theta + mL_f$$

2. How much heat is needed to melt 10g of ice at -10^{O}C to water at 0^{O}C? [Specific latent heat of fusion of ice = 3.36 x 10^{5}kg and specific heat capacity of ice = 2100Jkg^{-1}K^{-1}]

$$Heat = Heat\ that\ raises\ temperature\ of\ ice\ from -10°C\ to\ 0°C + Heat\ to\ melt\ ice$$

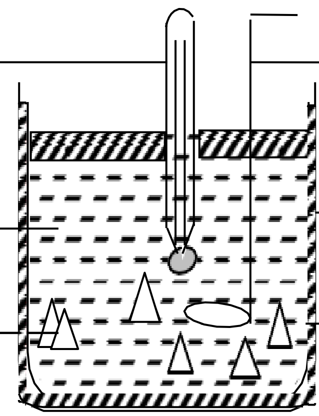
$$H = m_i c_i \Delta\theta + m_i L_f$$

$$H = \frac{10}{1000} \times 2100 \times \left(0 - (-10)\right) + \frac{10}{1000} \times 3.36 \times 10^5$$

$$H = 210 + 3360$$

$$H = 3570J$$

Experiment to determine specific latent heat of fusion of ice by method of mixtures.



- Hot water of mass, m_w and specific heat capacity, c_c is poured in a calorimeter of mass, m_c and specific heat capacity, c_c.
- The initial temperature $\theta_1$of the hot water and calorimeter is then recorded from the thermometer.
- Small pieces of pure melting ice at 0°C are placed in a calorimeter.
- Stir the mixture gently until all the ice melts.
- The final steady temperature, θ_2 of the mixture is recorded from the thermometer.
- Weigh the calorimeter and its contents and determine the mass, m_i of melted ice from

$$\boldsymbol{m_i = (m_w + m_c + m_i) - (m_w + m_c)}$$

- Assuming there are no heat losses

$$\boldsymbol{Heat\ gained\ by\ ice\ and\ cold\ water\ from\ melting\ ice = Heat\ lost\ by\ hot\ water\ and\ calorimeter.}$$

$$\boldsymbol{m_iL_f + m_ic_w\Delta\theta = m_{hw}c_{hw}\Delta\theta + m_cc_c\Delta\theta}$$

$$\boldsymbol{m_iL_f + m_ic_w(\theta_2 - 0) = m_{hw}c_{hw}(\theta_1 - \theta_2) + m_cc_c(\theta_1 - \theta_2)}$$

$$\boldsymbol{L_f = \frac{m_{hw}c_{hw}(\theta_1 - \theta_2) + m_cc_c(\theta_1 - \theta_2) - m_ic_w\theta_2}{m_i}}$$

Latent heat of vaporization:
This is the amount of heat required to change a substance from liquid state to gaseous state at constant temperature.

Specific latent heat of vaporization,L_v:
This is the amount of heat required to change 1kg mass of a substance from liquid state to gaseous state constant temperature.
The SI unit of specific latent heat of vaporization is $\boldsymbol{Jkg^{-1}}$.

$$\boldsymbol{Heat\ required = mass \times specific\ latent\ heat\ of\ vaporization}$$

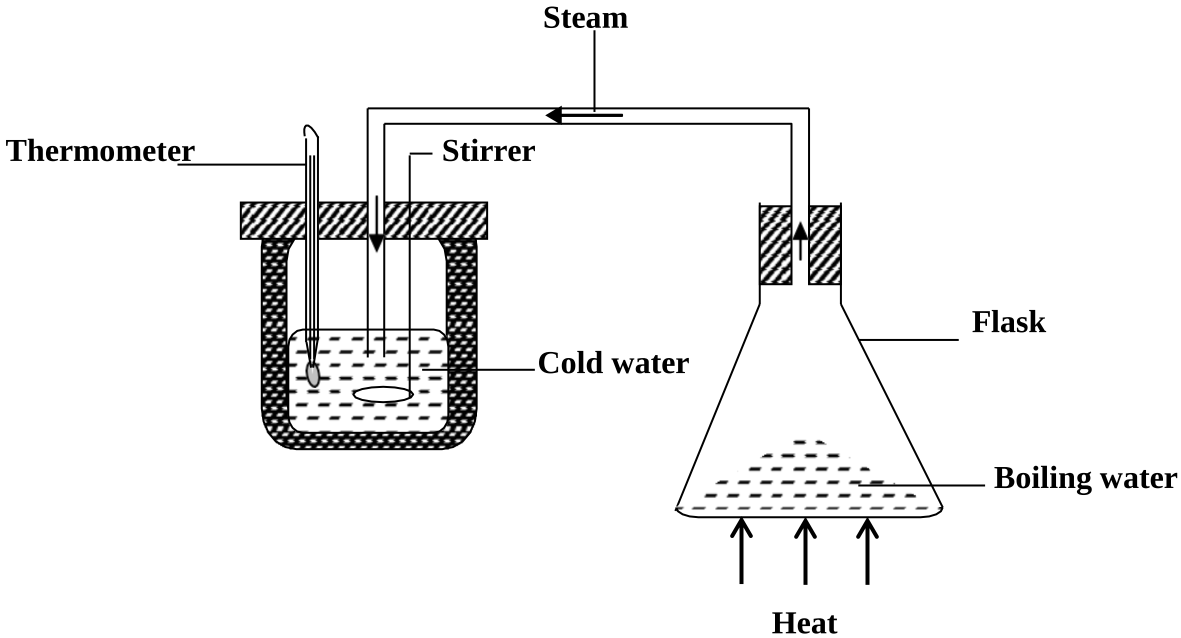
$$\boldsymbol{H = mL_v}$$

Example:

1. How much heat is needed to change 10g of water at 100^{O}C to steam at constant temperature?
   [Specific latent heat of vaporization of water = 2.3 x 10^{6}kg]

$$H = mL_v$$
$$H = \frac{10}{1000} \times 2.3 \times 10^6$$
$$H = 23000J$$

Experiment to determine specific latent heat of fusion of steam by method of mixtures.



- Cold water of mass,m_w and specific heat capacity, c_c is poured in a calorimeter of mass, m_c and specific heat capacity,c_c.
- The initial temperature, θ_1 of cold water and calorimeter is recorded.
- Steam from pure boiling water at 100℃ is passed through the cold water in the calorimeter.
- Stir the mixture gently until a steady final temperature, θ_2 is reached.
- Weigh the calorimeter and its contents to determine the mass, m_s of condensed steam from,
$$m_s = (m_s + m_w + m_c) - (m_w + m_c)$$
- Assuming there is no heat loss during the experiment.

$$Heat\ lost\ by\ steam\ and\ condensed\ water = Heat\ gained\ by\ cold\ water\ and\ calorimeter$$
$$m_sL_v + m_sc_w\Delta\theta = m_wc_w\Delta\theta + m_cc_c\Delta\theta$$
$$m_sL_v + m_sc_w(100 - \theta_2) = m_wc_w(\theta_2 - \theta_1) + m_cc_c(\theta_2 - \theta_1)$$
$$L_v = \frac{m_wc_w(\theta_2 - \theta_1) + m_cc_c(\theta_2 - \theta_1) - m_sc_w(100 - \theta_2)}{m_s}$$

- Hence specific latent heat of vaporization of steam, L_v can be calculated.

Examples:

1. A calorimeter of mass 35.0g and specific heat capacity of $840Jkg^{-1}K^{-1}$ contains 143.0g of water at 7^oC. Dry steam at 100^oC is passed through the water in the calorimeter until the temperature of water rises up to 29^oC. If the mass of steam which condenses is 5.6g, calculate
   i) The heat gained by water and calorimeter
   ii) Specific latent heat of vaporization of water

   (S.H.C of water $4200Jkg^{-1}K^{-1}$

$$\boldsymbol{\theta_1 = 7℃,\quad \theta_2 = 29℃,\quad m_c = 35.0g, m_w = 143.0g, m_s = 5.6g}$$

i)

$$\boldsymbol{Heat\ gained\ by\ water\ and\ calorimeter = m_w c_w \Delta\theta + m_c c_c \Delta\theta}$$

$$\boldsymbol{Heat\ gained\ by\ water\ and\ calorimeter = m_w c_w(\theta_2 - \theta_1) + m_c c_c(\theta_2 - \theta_1)}$$

$$\boldsymbol{Heat\ gained\ = \frac{143}{1000} \times 4200 \times (29 - 7) + \frac{35}{1000} \times 840 \times (29 - 7)}$$

$$\boldsymbol{Heat\ gained = 13213.2 + 646.8}$$

$$\boldsymbol{Heat\ gained = 13860J}$$

ii)

$$\boldsymbol{Heat\ lost\ by\ steam\ and\ condensensed\ water = Heat\ gained\ by\ water\ and\ calorimeter}$$

$$\boldsymbol{m_s L_v + m_s c_w \Delta\theta = 13860}$$

$$\boldsymbol{m_s L_v + m_s c_w(100 - \theta_2) = 13860}$$

$$\boldsymbol{\frac{5.6}{1000} \times L_v + \frac{5.6}{1000} \times 4200 \times (100 - 29) = 13860}$$

$$\boldsymbol{0.0056L_v = 13860 - 1669.92}$$

$$\boldsymbol{L_v = \frac{12190.08}{0.0056}}$$

$$\boldsymbol{L_v = 2,176,800Jkg^{-1}}$$

2. The temperature of water of mass 2kg and specific heat capacity of $4200Jkg^{-1}K^{-1}$ is raised from 20^oC to 80^oC by steam at 100^oC. Calculate the mass of steam needed if the specific latent heat of vaporization of water is $2.3x10^6Jkg^{-1}K^{-1}$. (Neglect heat absorption by container with water)

$$\boldsymbol{Heat\ lost\ by\ steam\ and\ condensensed\ water = Heat\ gained\ by\ water\ and\ calorimeter}$$

$$\boldsymbol{m_s L_v + m_s c_w \Delta\theta = m_w c_w \Delta\theta}$$

$$\boldsymbol{m_s L_v + m_s c_w(100 - \theta_2) = m_w c_w(\theta_2 - \theta_1)}$$

$$\boldsymbol{m_s \times (2.3 \times 10^6) + m_s \times 4200 \times (100 - 80) = 2 \times 4200 \times (80 - 20)}$$

$$\boldsymbol{2300000m_s + 84000m_s = 504000}$$

$$\boldsymbol{2384000m_s = 504000}$$

$$\boldsymbol{m_s = \frac{504000}{2384000}}$$

$$\boldsymbol{m_s = 0.211kg}$$

NOTE:

If the water is not at its boiling point100℃, the heat supplied first increases/raises its temperature to 100℃ so as to be converted to vapour.

3. How much heat is needed to melt 10g of ice at -10^{O}C to steam at 100^{O}C?

[Specific latent heat of fusion of ice = 3.36 x 10^{5}kg, specific heat capacity of ice = 2100Jkg^{-1}K^{-1}, specific heat capacity of water = 4200Jkg^{-1}K^{-1}, specific latent heat of vaporization of water = 2.3 x 10^{6}Jkg^{-1}]

$\boldsymbol{Heat\ supplied =}$

$\boldsymbol{heat\ to\ raise\ temperature\ of\ ice\ from -10℃\ to\ 0℃ + heat\ to\ melt\ ice +}$
$\boldsymbol{heat\ to\ raise\ temperature\ of\ water\ from\ melted\ ice + heat\ to\ change\ water\ to\ steam}$

$$\boldsymbol{H = m_i c_i \Delta\theta + m_i L_f + m_i c_w \Delta\theta + m_i L_v}$$

$$H = \frac{10}{1000} \times 2100(0 - (-10)) + \frac{10}{1000} \times 3.36 \times 10^5 + \frac{10}{1000} \times 4200 \times (100 - 0) + \frac{10}{1000} \times 2.3 \times 10^6$$

$$\boldsymbol{H = 210 + 3360 + 4200 + 23000}$$

$$\boldsymbol{H = 30770J}$$

4. Find the heat required to change 2 kg of ice at 0℃ into water at 50℃.
(S.L.H of fusion of ice = 3.36x10^{5}Jkg^{-1} , $S.\ H.\ C\ of\ water$ = 4200$Jkg^{-1}K^{-1}$).

$\boldsymbol{Heat\ required =}$

$\boldsymbol{heat\ to\ melt\ ice\ to\ water + heat\ to\ raise\ temperature\ of\ water\ to\ 50℃}$

$$\boldsymbol{H = m_i L_f + m_i c_w \Delta\theta}$$

$$\boldsymbol{H = 2 \times 3.36 \times 10^5 + 2 \times 4200 \times (50 - 0)}$$

$$\boldsymbol{H = 672000 + 420000}$$

$$\boldsymbol{H = 1,092,000J}$$

5. An ice making machine removes heat from water at a rate of 20 Js^{-1}. How long will it take to convert 0.5kg of water at 20℃ to ice at 0℃. (S.L.H of fusion of ice = 3.36x10^{5}Jkg^{-1} , S.H.C of water = 4200$J\ kg^{-1}\ K^{-1}$).

$$\boldsymbol{P = 20Js^{-1}, m_w = 0.5kg}$$

$$\boldsymbol{Heat\ gained\ by\ ice\ machine = Heat\ lost\ by\ water\ to\ 0℃ + Heat\ to\ freeze\ water}$$

$$\boldsymbol{P \times t = m_w c_w \Delta\theta + m_w L_f}$$

$$\boldsymbol{20t = 0.5 \times 4200 \times (20 - 0) + 0.5 \times 3.36 \times 10^5}$$

$$\boldsymbol{20t = 42000 + 168000}$$

$$\boldsymbol{t = \frac{210000}{20}}$$

$$\boldsymbol{t = 10,500s}$$

6. A calorimeter with heat capacity of 80J℃$^{-1}$ contains 50g of water at 40℃. What mass of ice at 0℃ needs to be added in order to reduce the temperature to 10℃. Assume no heat is lost to the surrounding (S.H.C of water = 4200Jkg^{-1}℃$^{-1}$, S.L.H of fusion of ice = 3.4x10^{5}Jkg^{-1})

$$\boldsymbol{\theta_1 = 40℃, \qquad \theta_2 = 10℃}$$

$$\boldsymbol{Heat\ lost\ by\ water\ and\ calorimeter = Heat\ gained\ by\ ice\ to\ melt\ and\ cold\ water\ from\ ice}$$

$$\boldsymbol{m_w c_w \Delta\theta + m_c c_c \Delta\theta = m_i L_f + m_i c_w \Delta\theta}$$

$$\boldsymbol{m_w c_w(\theta_1 - \theta_2) + m_c c_c(\theta_1 - \theta_2) = m_i L_f + m_i c_w(\theta_2 - 0)}$$

$$\boldsymbol{\frac{50}{1000} \times 4200 \times (40 - 10) + 80 \times 30 = m_i \times 3.4 \times 10^5 + m_i \times 4200 \times (10 - 0)}$$

$$\boldsymbol{8700 = 382000m_i}$$

$$\boldsymbol{m_i = 0.023kg}$$

7. Steam at 100℃ is passed into a copper calorimeter of mass 150g containing 340g of water at 15℃. This is done until the temperature of the calorimeter and its content is 71℃. If the mass of the calorimeter and its contents is found to be 525g. Calculate the specific latent heat of vaporization of water. (S.H.C of copper = 400Jkg^{-1}K^{-1})

$$m_c = 150g, \quad m_w = 340g \quad \theta_1 = 15℃, \quad \theta_2 = 71℃, \quad m_c + m_s + m_w$$

$$m_s = (m_c + m_s + m_w) - (m_c + m_w) = 525 - (150 + 340) = 35g$$

$$\textit{Heat lost by steam and condensed water} = \textit{Heat gained by cold water and calorimeter}$$

$$m_s L_v + m_s c_w \Delta\theta = m_w c_w \Delta\theta + m_c c_c \Delta\theta$$

$$m_s L_v + m_s c_w (100 - \theta_2) = m_w c_w (\theta_2 - \theta_1) + m_c c_c (\theta_2 - \theta_1)$$

$$\frac{35}{1000} \times L_v + \frac{35}{1000} \times 4200 \times (100 - 71) = \frac{340}{1000} \times 4200 \times (71 - 15) + \frac{150}{1000} \times 400 \times (71 - 15)$$

$$0.035L_v + 4263 = 79968 + 3360$$

$$0.035L_v = 79065$$

$$L_v = \frac{79065}{0.035}$$

$$L_v = 2,259,000Jkg^{-1}$$

<u>EXERCISE</u>:

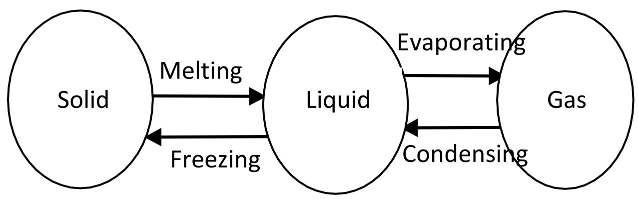
1. Ice at 0℃ is added to 200g of water initially at 70℃ in a vacuum flask. When 50g of ice is added and has all melted, the temperature of the flask and content is 400℃. When further 80g of ice has been added and has been melted, the temperature of the whole becomes 10℃. Calculate the S.L.H of fusion of ice neglecting any heat loss of surrounding.
   Ans; [3.78x10^5 Jkg^{-1}]
2. Calculate the heat required to melt 200g of ice at 0℃ . (S.L.H of ice= 3.4x10^{5}Jkg^{-1})
   Ans; [6.8x10^4 J]
3. Calculate the heat required to turn 500g of Ice at 0℃ into water at 100℃.
   (S.L.H of ice= 3.4x10^{5}Jkg^{-1}, S.H.C of water = 4200Jkg^{-1} **)**
   Ans; [3.8x1]
4. Calculate the heat given out when 600g of steam at 100℃ condenses to water at 20℃ [S.L.H of steam = 2.26x10^6 Jkg^{-1}, S.H.C of water = 4200 Jkg^{-1}].
   Ans; [1.56x10^{6}J]
5. 1kg of vegetables, having a specific heat capacity 2200 Jkg^{-1} at a temperature 373K are plugged into a mixture of ice and water at 273K. How much is melted. [S.L.H of fusion of the ice = 3.3x10^5 Jkg^{-1}]
   Ans; [0.67kg]
6. 0.02kg of ice and 0.10kg water at 0℃ are in a container. Steam at 100℃ is passed in until all the ice is just melted. How much water is now in the container? (S.L.H of vaporistion of steam = 2.3x10^{6}Jkg^{-1}, S.L.H of fusion of ice = 3.4x10^{5}Jkg^{-1}, S.H.C of water = 4.2 x10^{3}Jkg^{-1}K^{-1}
   Ans; [0.1225kg]

<u>QUESTION;</u> Explain why specific latent heat of vaporization of a substance is always greater than specific latent heat of fusion the same substance e.g. (ice, water and steam)

- ✓ **For Latent heat of fusion (solid to liquid); heat required is small because it only increases slightly increases the molecular spacing by breaking the intermolecular forces.**
- ✓ **For latent heat of vaporization (liquid to gas); heat required is large because it has to increase the molecular spacing by breaking the intermolecular forces and also has to provide energy that enables molecules to escape from the surface of the liquid.**

NOTE: The phenomenon above explains why a person feels much heat when burnt by steam than when burnt by water at the same temperature.

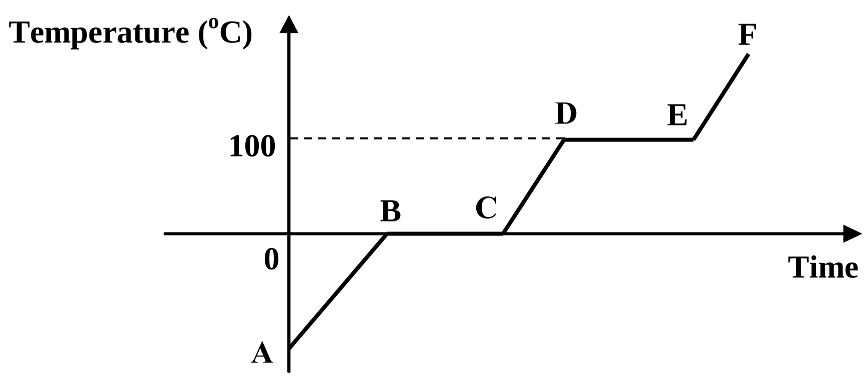
EFFECTS OF HEAT ON MATTER:



When a solid is heated it changes to a liquid at its **melting point**.
Definition:
Melting point is a constant temperature at which a solid changes to a liquid.
When a liquid is cooled it changes to a solid at its freezing point.
Definition:
Freezing point is a constant temperature at which a liquid changes to a solid.
When a liquid is heated it changes to a gas (vapour) at its boiling point.
Definition:
Boiling point is the constant temperature at which a liquid changes into a gas.
When a liquid is cooled it condenses and changes to a liquid.

HEATING AND COOLING CURVES (graphs of temperature against time)

<u>The heating curve when ice below its melting point is heated</u>.



Explanation of the shape of graph.

AB: temperature of ice is increasing from A to its melting point 0℃

BC: ice is changing to water at 0^{o}C

CD: the temperature of water is increasing from 0℃ *to boiling point* 100℃

DE: water is changing to steam at 100^{o}C

EF: temperature of steam is increasing

The states of water along different regions are;

AB – solid state (ice)

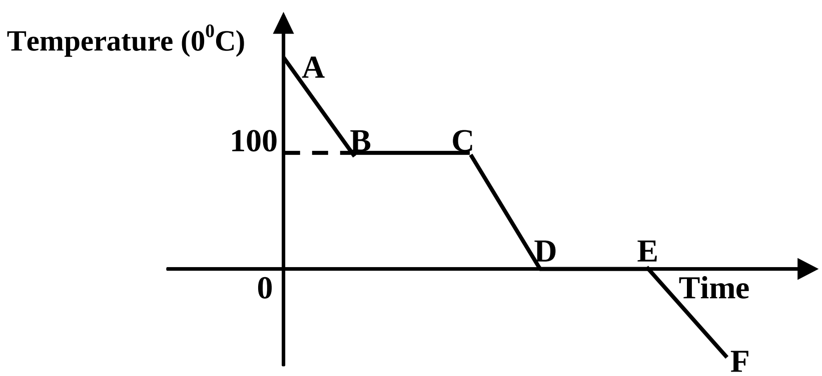
BC – solid state and liquid state (water + ice)

CD – liquid state (water)

DE – liquid state and gaseous state (water + vapour)

EF – gaseous state (steam or vapour)

The cooling curve when water above its boiling point is cooled



Explanation of shape of the graph

AB: temperature of steam is decreasing from to boiling point 100℃.

BC: steam is changing to water at 100^{o}C

CD: the temperature of water is decreasing from 100℃ to freezing point 0℃

DE: water is changing to ice at 0^{o}C

EF: temperature of ice is decreasing

The states of water along different regions are;

EF – solid state (ice)

DE – solid state and liquid state (water + ice)

CD – liquid state (water)

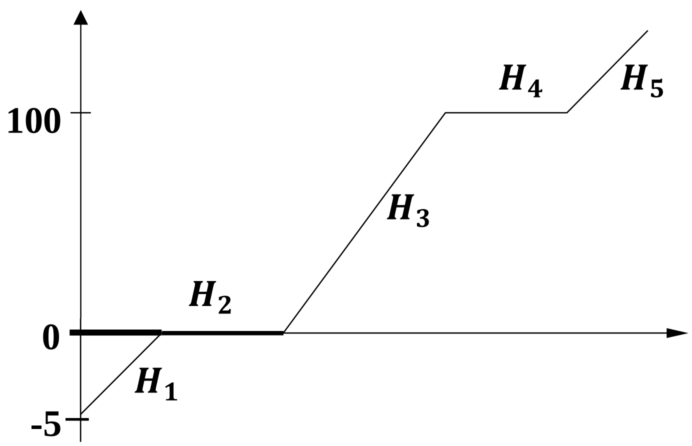
BC – liquid state and gaseous state (water + vapour)

AB – gaseous state (steam or vapour)

Example:

1. 2kg of ice at −5℃ was heated up to steam at 100℃.
   i) Sketch a temperature time graph curve for the ice up to steam
   ii) Find the heat at each section of the graph drawn. (S.H.C of ice = 2000 J $kg^{-1}K^{-1}$, S.H.C of water = 4200 J $kg^{-1}K^{-1}$, S.L.H. of fusion of ice = $3.36x10^5$Jkg^{-1}, S.L.H. of vaporization of water = $2.26x10^6$Jkg)

i)



ii) H_1 *temperature of ice increasing from* -5℃ *to* 0℃

$$H_1 = m_i c_i \Delta\theta$$
$$H_1 = 2 \times 2000 \times (0 - (-5))$$
$$H_1 = 20,000J$$

H_2 *ice melting to water at* 0℃

$$H_2 = m_i L_f$$
$$H_2 = 2 \times 3.36 \times 10^5$$
$$H_2 = 672,00J$$

H_3 *temperature of water increasing from* 0℃ *to* 100℃

$$H_3 = m_w c_w \Delta\theta$$
$$H_3 = 2 \times 4200 \times (100 - 0)$$
$$H_3 = 84,000J$$

H_4 *water changing to steam at* 100℃

$$H_4 = m_w L_v$$
$$H_4 = 2 \times 2.26 \times 10^6$$
$$H_4 = 4,520,000J$$

EXERCISE:

Where necessary assume the following

Specific heat capacity of water	= $4200 Jkg^{-1}K^{-1}$
Specific heat capacity of copper	= $400 Jkg^{-1}K^{-1}$
Specific heat capacity of iron	= $450 Jkg^{-1}K^{-1}$
Specific heat capacity of aluminium	= $880 Jkg^{-1}K^{-1}$
Specific heat capacity of ice	= $2100 Jkg^{-1}K^{-1}$
Specific latent heat of fusion of ice	= $336,000 Jkg^{-1}$
Specific latent heat of vaporization of water	= $2,250,000 Jkg^{-1}$

1. How much heat is required to raise the temperature of 50g of aluminium from $-100^{O}C$ to $120^{O}C$?
   Ans: 9,680J
2. If 98,000J of heat are needed to raise the temperature of 2kg of a substance from $51^{O}C$ to $65^{O}C$. What is the specific heat capacity of a substance?
   Ans: $3500Jkg^{-1}K^{-1}$
3. An electric fire has a power of 1,800W. When used to heat a liquid of 5kg, it takes 6 minutes to raise the temperature by $90^{O}C$. What is the specific heat capacity of the liquid?
   Ans: $1440 Jkg^{-1}K^{-1}$
4. A 30g block of copper is heated from $-20^{O}C$ to $180^{O}C$. How much heat does it absorb during heating?
   Ans: 2400J
5. How much heat energy is needed to melt 0.01kg of ice at $0^{O}C$?
   Ans: 3360J
6. How much heat energy is needed to change 0.2kg of ice at $0^{O}C$ into steam at $100^{O}C$?
   Ans: 601,200J
7. An electric heater marked 225,000W keeps water boiling at $100^{O}C$. What mass of water evaporates in a second?
   Ans: 0.1kg
8. An electric heater was used to heat 2kg of water from $20^{O}C$ to $50^{O}C$ in 25 minutes. If the voltage across the heater was 24V, what was the current through the heater?
   Ans: 7.0A
9. 5kg of ice cubes are removed from the freezing compartment of a refrigerator into a home freezer. The refrigerator‟s freezing compartment is kept at $-40^{O}C$ the home freezer is kept at $-17^{O}C$. How much heat does the freezer‟s cooling system remove from the ice cubes?
   Ans: 241,500J
10. What is the heat capacity of 5.5kg of aluminium?
    Ans: $4,840JK^{-1}$

GAS LAWS

Gas laws describe the behavior of gases when subjected to physical factors such as pressure and temperature.
These laws express the relationships between pressure (P), volume (V) and temperature (T) of a fixed mass of a gas.
There are three gas laws namely;

- Boyle's law.
- Pressure law.
- Charles' law.

Boyle's law:

It states that the volume of a fixed mass of a gas is inversely proportional to its pressure at constant temperature.

$$\boldsymbol{Pressure \propto \frac{1}{Volume}}$$
$$\boldsymbol{P \propto \frac{1}{V}}$$
$$\boldsymbol{P = K\frac{1}{V}}$$
$$\boldsymbol{PV = K}$$
$$Where\ K\ is\ constant\ of\ proportionality$$

If the volume of gas changes from $V_1\ to\ V_2$ and its pressure changes from $P_1\ to\ P_2$.

$$Then, \quad \boxed{\boldsymbol{P_1V_1 = P_2V_2}}$$

Where $P_1 - initial\ pressure$
$P_2 - final\ pressure$
$V_1 - initial\ volume$
$V_2 - final\ volume$

Examples:

1. The volume of a fixed mass of a gas at constant temperature is 250cm^3 when the pressure is 720mmHg. Find the pressure when the volume is increased to 600cm^3.

$$\boldsymbol{P_1 = 720mmHg, V_1 = 250cm^3,\ P_2 = ?, V_2 = 600cm^3}$$
$$\boldsymbol{P_1V_1 = P_2V_2}$$
$$\boldsymbol{720 \times 250 = P_2 \times 600}$$
$$\boldsymbol{\frac{720 \times 250}{600} = P_2}$$
$$\boldsymbol{P_2 = 300mmHg}$$

2. The volume of a fixed mass of a gas at constant temperature is 2.0 x $10^{-5}m^3$ when the pressure is 7.2 x 10^6Pa, find the pressure when the volume is increased to 6.0 x $10^{-4}m^3$.

$$P_1 = 7.2 \times 10^6 Pa,\ V_1 = 2.0 \times 10^{-5} m^3,\ P_2 = ?, V_2 = 6.0 \times 10^{-4} m^3$$
$$P_1V_1 = P_2V_2$$
$$7.2 \times 10^6 \times 2.0 \times 10^{-5} = P_2 \times 6.0 \times 10^{-4}$$
$$\frac{7.2 \times 10^6 \times 2.0 \times 10^{-5}}{6.0 \times 10^{-4}} = P_2$$
$$P_2 = 2.4 \times 10^{-4}$$

3. The volume of a fixed mass of a gas at constant temperature is 4cm^3 when the pressure is 6 atmospheres, find the volume when the pressure is increased to 12 atmospheres.

$$P_1 = 6\ atmospheres, V_1 = 4cm^3, \quad P_2 = 12\ atmospheres, V_2 = ?$$
$$P_1V_1 = P_2V_2$$
$$6 \times 4 = 12 \times V_2$$
$$\frac{6 \times 4}{12} = V_2$$
$$V_2 = 2cm^3$$

4. The pressure of a fixed mass of a gas is 5 atmospheres when its volume is $200cm^3$. Find the pressure when the volume is

i) halved
ii) doubled

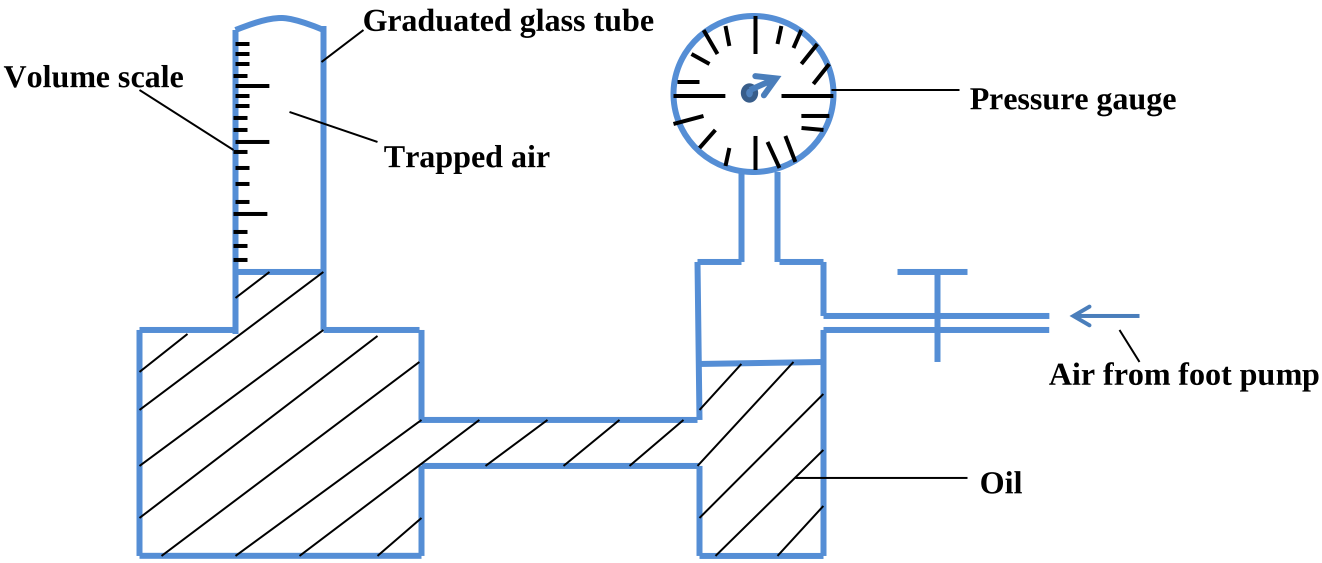
i)

$$P_1 = 5\ atmospheres, V_1 = 200cm^3, \quad P_2 = ?$$
$$P_1V_1 = P_2V_2$$
$$5 \times 200 = P_2 \times \frac{200}{2}$$
$$\frac{5 \times 200}{100} = P_2$$
$$P_2 = 10\ atmospheres$$

ii)

$$P_1V_1 = P_2V_2$$
$$5 \times 200 = P_2 \times (2 \times 200)$$
$$\frac{5 \times 200}{400} = P_2$$
$$P_2 = 2.5\ atmospheres$$

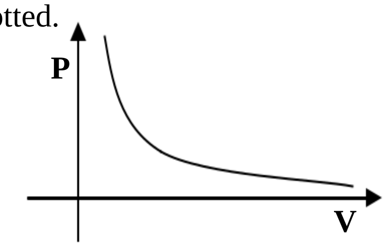
Experiment to verify Boyle's law



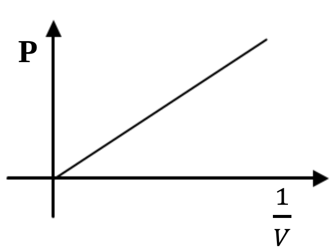
- Trap air above oil in the graduated glass tube.
- Read the initial volume, V and pressure, P of trapped air.
- Increase the pressure of trapped air by using a foot pump connected to a pressure gauge as shown above.
- Allow the air to cool to room temperature.
- Read and record the new values of V and P.
- Increase the pressure again to get different values of V and P.
- Record your results in a suitable table including values of $\frac{1}{V}$

P	V	$\frac{1}{V}$

- A graph of P against V is then plotted.



- A graph of P against $\frac{1}{V}$ is also plotted.



- From the above graphs it shows that pressure is inversely proportional to volume which is Boyle's law.

Pressure law (Gay Lussac law):

It states that the pressure of a fixed mass of a gas is directly proportional to its absolute temperature at constant volume.

$$\boldsymbol{Pressure \propto Absolute\ temperature}$$

$$\boldsymbol{P \propto T}$$

$$\boldsymbol{P = KT}$$

$$\boldsymbol{\frac{P}{T} = K}$$

$$Where\ \boldsymbol{K}\ is\ constant\ of\ proportionality.$$

If the temperature of gas changes from T_1 to T_2 and its pressure changes from P_1 to P_2.

$$Then,\quad \boxed{\boldsymbol{\frac{P_1}{T_1} = \frac{P_2}{T_2}}}$$

Where $T_1 - initial\ temperature$

$T_2 - final\ temperature$

$P_1 = initial\ pressure$

$P_2 = final\ pressure$

Definition:

Absolute temperature is the temperature at which the volume of a gas reduces to zero.

Or **Absolute temperature** the temperature at which the molecules of a gas have the lowest kinetic energy

N.B: The temperature must always be in kelvins.

Examples:

1. The pressure of a fixed mass of a gas at 127^{O}C is 600mmHg. Calculate its pressure at constant volume if the temperature reduces to 27^{O}C.

$$\boldsymbol{P_1 = 600mmHg, P_2 = ?,}$$

$$\boldsymbol{T_1 = 127℃ = 127 + 273 = 400K,\quad T_2 = 27℃ = 27 + 273 = 300K}$$

$$\boldsymbol{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$

$$\boldsymbol{\frac{600}{400} = \frac{P_2}{300}}$$

$$\boldsymbol{P_2 = 450mmHg}$$

2. The pressure of a gas is $75Nm^{-2}$ at −73℃. What is its pressure when a gas is heated up to 127℃.

$$\boldsymbol{P_1 = 75Nm^{-2}, P_2 = ?, T_1 = -73℃ = -73 + 273 = 200K,\ T_2 = 127℃ = 127 + 273 = 400K}$$

$$\boldsymbol{\frac{P_1}{T_1} = \frac{P_2}{T_2}}$$

$$\boldsymbol{\frac{75}{200} = \frac{P_2}{400}}$$

$$\boldsymbol{P_2 = 150Nm^{-2}}$$

3. A sealed flask contains a gas at a temperature of 27℃ and a pressure of 90 kPa. If the temperature rises to 127℃. What will be the new pressure?

$$P_1 = 90kPa = 90 \times 1000 = 90,000Pa, P_2 = ?,$$

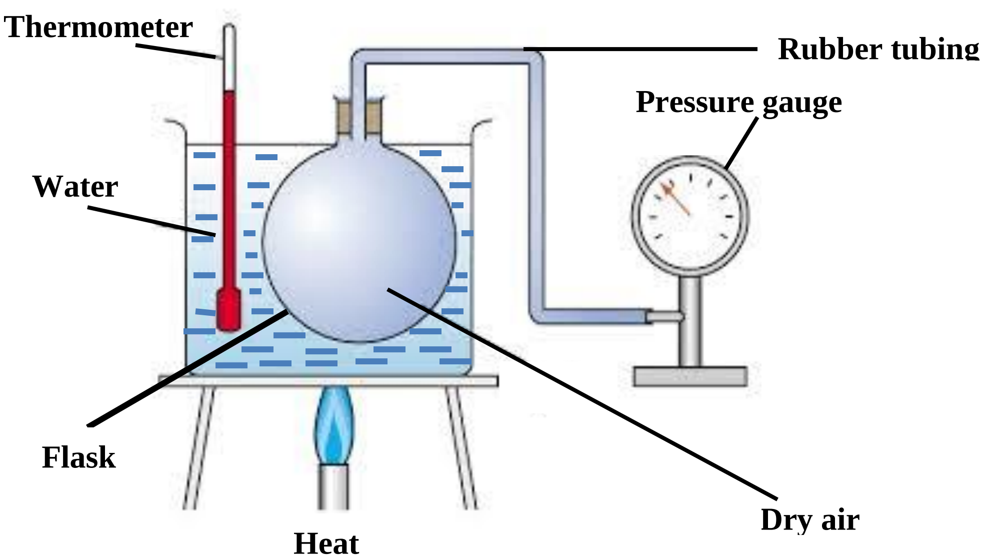
$$T_1 = 27℃ = 27 + 273 = 300K, \quad T_2 = 127℃ = 127 + 273 = 400K$$

$$\frac{P_1}{T_1} = \frac{P_2}{T_2}$$

$$\frac{90000}{300} = \frac{P_2}{400}$$

$$P_2 = 120,000Pa$$

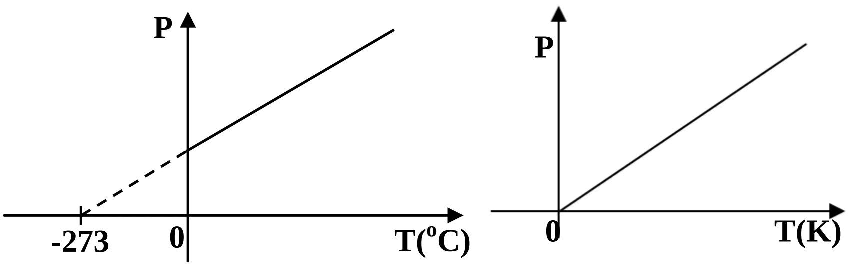
<u>Experiment to verify Pressure law</u>



- The apparatus is set up as shown above.
- The flask containing dry air is placed in a metal can with water such that water is almost to the top of its neck.
- The can is heated from the bottom while stirring.
- Pressure, P is then recorded for different values of temperatures.
- The results are recorded in a suitable table

P	T(^{0}C)	T(K)

- A graph of P against temperature is then plotted.



- From the above graphs it shows that pressure is directly proportional to the temperature which is pressure law.

NOTE: The temperature -273^{O}C (0K) is called **absolute zero temperature.**

Charles' law:

It states that the volume of a fixed mass of a gas is directly proportional to its absolute temperature at constant pressure.

$$\boldsymbol{Volume \propto Absolute\ temperature}$$
$$\boldsymbol{V \propto T}$$
$$\boldsymbol{V = KT}$$
$$\boldsymbol{\frac{V}{T} = K}$$
$$Where\ \boldsymbol{K}\ is\ constant\ of\ proportionality.$$

If the temperature of gas changes from T_1 to T_2 and its volume changes from V_1 to V_2.

$$Then,\quad \boxed{\boldsymbol{\frac{V_1}{T_1} = \frac{V_2}{T_2}}}$$

Where $T_1 - initial\ temperature$
$T_2 - final\ temperature$
$V_1 = initial\ volume$
$V_2 = final\ volume$

Example:

1. The volume of a fixed mass of a gas at 127^{O}C is 300cm^{3}. Calculate its volume at constant pressure if the temperature reduces to 27^{O}C.

$$\boldsymbol{\frac{V_1}{T_1} = \frac{V_2}{T_2}}$$
$$\boldsymbol{\frac{300}{(127 + 273)} = \frac{V_2}{(27 + 273)} \rightarrow \frac{300}{400} = \frac{V_2}{300}}$$
$$\boldsymbol{V_2 = 225cm^3}$$

2. The volume of a fixed mass of a gas at 17^oC is 5.0 x 10^{-4}m^3. Calculate its temperature at constant pressure if the volume reduces to 2.0 x 10^{-4}m^3

$$V_1 = 5.0 \times 10^{-4} m^3, V_2 = 2.0 \times 10^{-4} m^3,$$
$$T_1 = 17℃ = 17 + 273 = 290K, \quad T_2 = ?$$
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$\frac{5.0 \times 10^{-4}}{290} = \frac{2.0 \times 10^{-4}}{T_2}$$
$$\frac{2 \times 290}{5} = T_2$$
$$T_2 = 116K$$

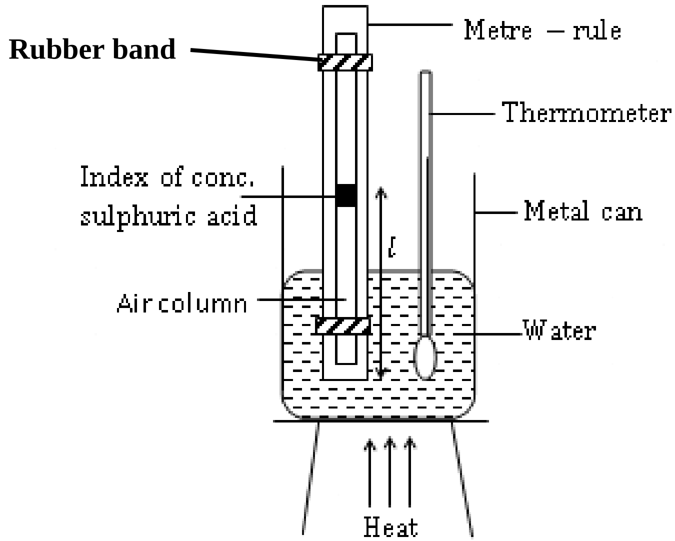
3. The volume of a fixed mass of a gas at 27^oC is 400cm^3. Calculate its volume at constant pressure if the temperature reduces to -123^oC.

$$V_1 = 400cm^3, V_2 = ?,$$
$$T_1 = 27℃ = 27 + 273 = 300K, \quad T_2 = -123 + 273 = 150K$$
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$\frac{400}{300} = \frac{V_2}{150}$$
$$V_2 = 200cm^3$$

4. The temperature of a fixed mass of a gas is 27℃. If the volume is halved, find its new temperature.

$$V_1 = V, \quad V_2 = \frac{V}{2},$$
$$T_1 = 27℃ = 27 + 273 = 300K, \quad T_2 = ?$$
$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$
$$\frac{V}{300} = \frac{\frac{V}{2}}{T_2}$$
$$\frac{V}{300} = \frac{V}{2T_2}$$
$$T_2 = \frac{300}{2}$$
$$T_2 = 150K$$

Experiment to verify Charles' law:

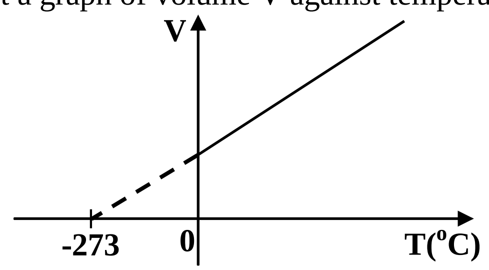


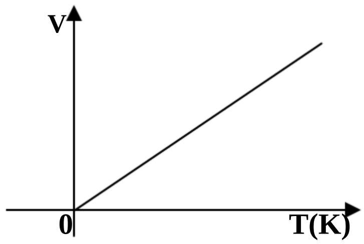
- Trap dry air using the index of concentrated sulphuric acid in a capillary tube.
- Tie the tube on the metre rule using a rubber band.
- Place the tied tube in a metal can containing water.
- Heat the water slowly while stirring gently.
- Read and record the length, L of the trapped air column and the temperature, T from the thermometer.
- Repeat procedures to obtain other values of L for different temperature values.
- Record the results in a suitable table.

L(cm)	T(^{0}C)	V

But L is proportional to volume, V so V=L

- Plot a graph of volume V against temperature T.





- From the above graphs it shows that volume is directly proportional to the absolute temperature which is Charles's law.

Equation of state for an ideal gas:

This is sometimes referred to as ideal gas equation. It combines the three gas laws.
Combining the three gas laws, we get;

$$\frac{PV}{T} = K$$

Therefore if the volume of the gas changes from V_1 *to* V_2, its pressure changes from P_1 *to* P_2 and its temperature from T_1 *to* T_2

$$Then, \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$

NOTE:
At standard temperature and pressure (**s.t.p**)

- Standard absolute temperature = $273K$
- Standard pressure = $76cmHg \text{ or } 760mmHg \text{ or } 1.01 \times 10^5 Pa$

Examples:

1. In an experiment 500cm^3 of a gas was collected at a temperature of 97^{o}C and a pressure of 3.7 x 10^6 Pa. Find the volume of the gas if the pressure changes to 6.0 x 10^6 Pa at a temperature of 27^{o}C.

$$P_1 = 3.7 \times 10^6 Pa, P_2 = 6.0 \times 10^6 P, V_1 = 500cm^3, V_2 = ?$$
$$T_1 = 97℃ = 97 + 273 = 370K, \quad T_2 = 27℃ = 27 + 273 = 300K$$
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$\frac{3.7 \times 10^6 \times 500}{370} = \frac{6.0 \times 10^6 \times V_2}{300}$$
$$V_2 = \frac{3.7 \times 300 \times 500}{370 \times 6}$$
$$V_2 = 250cm^3$$

2. A bicycle pump contains $50cm^3$of air at 17℃ and a pressure of 1 atmosphere. Find the pressure when it is compressed to $10cm^3$and its temperature rises to 27℃.

$$P_1 = 1\, atm, P_2 = ?, V_1 = 50cm^3, V_2 = 10cm^3?$$
$$T_1 = 17℃ = 17 + 273 = 290K, \quad T_2 = 27℃ = 27 + 273 = 300K$$
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$\frac{1 \times 50}{290} = \frac{P_2 \times 10}{300}$$
$$P_2 = \frac{50 \times 300}{290 \times 10}$$
$$P_2 = 5.17\, atm$$

3. In an experiment 58cm^3 of a gas was collected at a temperature of 17^{o}C and a pressure of 8.0 x 10^4 Pa. Find the volume the gas at s.t.p.

$$P_1 = 8.0 \times 10^4 Pa, \quad At\ s.t.p, P_2 = 1.01 \times 10^5 Pa, V_1 = 58cm^3, V_2 = ?$$
$$T_1 = 17℃ = 17 + 273 = 290K, \quad At\ stp, T_2 = 273K$$
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$\frac{8.0 \times 10^4 \times 58}{290} = \frac{1.01 \times 10^5 \times V_2}{273}$$
$$V_2 = \frac{8 \times 273 \times 58}{290 \times 1.01 \times 10}$$
$$V_2 = 43.25cm^3$$

4. 240 cm^3 of oxygen gas was collected when a temperature is 20℃ at a pressure of 50cmHg. Calculate its volume at s.t.p.

$$P_1 = 50cmHg, T_1 = 20℃ = 20 + 273 = 293K, V_1 = 240cm^3,$$
$$At\ s.t.p, \quad P_2 = 76cmHg, T_2 = 273K, V_2 = ?$$
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$\frac{50 \times 240}{293} = \frac{76 \times V_2}{273}$$
$$V_2 = \frac{50 \times 240 \times 273}{293 \times 76}$$
$$V_2 = 147.12cm^3$$

5. The volume of hydrogen at 273℃ is 10 cm^3 at a pressure of 152 cmHg. What is its volume at s.t.p.

$$P_1 = 152cmHg, T_1 = 273℃ = 273 + 273 = 546K, V_1 = 10cm^3,$$
$$At\ s.t.p, \quad P_2 = 76cmHg, T_2 = 273K, V_2 = ?$$
$$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$$
$$\frac{152 \times 10}{546} = \frac{76 \times V_2}{273}$$
$$V_2 = \frac{152 \times 10 \times 273}{546 \times 76}$$
$$V_2 = 10cm^3$$

<u>Kinetic theory of Gas laws</u>:

Recall; Kinetic theory of matter states that matter is made up of small particles called molecules that are in a continuous random motion and possess energy.

<u>Question</u>: **Explain what causes gas pressure**.
Increase in temperature, increases the speed of molecules and hence with the walls of the container thus creating pressure.
N.B: This explains why the pressure of a car tyre increases on a hot day.

<u>Boyle's law</u>:
For a fixed mass of a gas;

When the volume of the fixed mass of a gas is reduced at constant temperature the speed of the gas molecules increases hence the rate of collision with the walls of the container increases thus the pressure of the gas increases.

However increasing the volume of a gas reduces the pressure since the speed of the molecules of the gas reduces hence reducing on the rate of collision with the walls of the container.

<u>Charles' law</u>:
For a fixed mass of a gas;

When the temperature of the fixed mass of a gas is increased at constant pressure, the speed of the molecules of a gas increases and the rate of collision with the walls of a container increases thus increasing the volume of gas.

<u>Pressure law</u>:
For a fixed mass of a gas;

When the temperature of the fixed mass of a gas is increased at constant volume, the speed of the molecules of a gas increases and the rate of collision with the walls of a container increases hence the pressure of the gas increases.

VAPOURS

Vapour is the gaseous state of a substance below its critical temperature.
Critical temperature is the minimum temperature above which the gas cannot be changed back to a liquid.

There are two types of vapours namely;

- Saturated vapour
- Unsaturated vapour

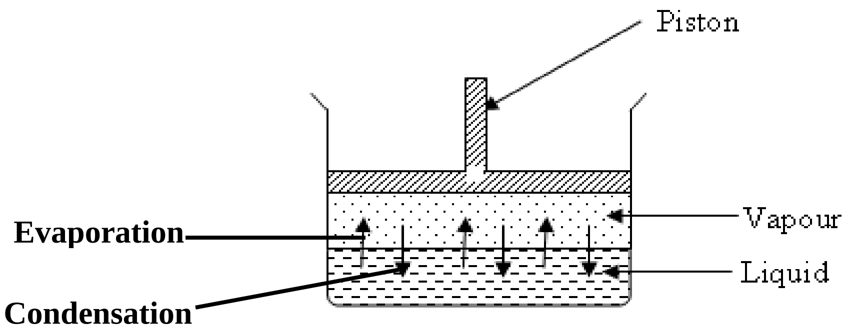
SATURATED VAPOUR

This is the vapour that is in dynamic equilibrium with its own liquid.
i.e. $rate\ of\ evaporation = rate\ of\ condensation$

Saturated vapour pressure;

This is the pressure exerted by a vapour that is in dynamic equilibrium with its own liquid.

Explanation of occurrence of saturated vapour pressure (s.v.p) using kinetic theory



Consider a liquid enclosed in a container with a piston.

When a liquid in a closed container is heated, some of the liquid molecules get enough kinetic energy and break the intermolecular forces and escape from the surface of the liquid and occupy the space just above it and become vapour molecules. This process is called evaporation.

These vapour molecules collide with the walls of the container hence creating vapour pressure.

When these molecules bounce off from the walls of the container, they strike the liquid surface and re-enter the liquid. This process is called condensation.

A state of dynamic equilibrium is attained i.e. (rate of evaporation = rate of condensation) and this point, vapour is said to be saturated and exerting saturated vapour pressure.

Definition: Vapour pressure is the pressure exerted on the walls of the container by the vapour molecules.

NOTE:

Gas laws only apply to a fixed/constant mass of a gas.
Therefore, saturated vapours do not obey ideal gas laws because there masses change due to condensation or evaporation as the conditions change.
It should be noted that saturated vapor occurs for a very short time and at a constant temperature (boiling point).

UNSATURATED VAPOUR

This is the vapour that is not in dynamic equilibrium with its own liquid.
i.e. $rate\ of\ evaporation \neq rate\ of\ condensation$

Unsaturated vapour pressure:
This is the pressure exerted by a vapour that is not in dynamic equilibrium with its own liquid.

Differences between saturated vapour and unsaturated vapour

Saturated vapour	Unsaturated vapour
• It doesn't obey gas laws. • It is the vapour in dynamic equilibrium with its own liquid. • Exists at a fixed temperature.	• It obeys gas laws. • It is the vapour that is not in dynamic equilibrium with its own liquid. • Exists at any temperature.

Other terms;

Super saturated vapour:
This is the vapour whose rate of evaporation is greater than the rate of evaporation.

Ideal gas:
This is a gas whose intermolecular forces are negligible.

Real gas:
This is a gas whose intermolecular forces are not negligible.

Dew point:
This is the temperature at which atmospheric air is saturated with water vapour.
OR
This is the temperature at which water vapour condenses to liquid water (dew)

Note;
Fog or cloudy film forms on windscreens of cars because the dew point of water vapour has been exceeded.

EVAPORATION:

This is the process by which a liquid changes into gas (vapour).

OR

This is the escape of molecules of a liquid from its surface.

Evaporation takes place only at the surface of the liquid.

It takes place at all temperatures but it is greatest when the liquid is at its boiling point.

Explanation of evaporation according to kinetic theory:

(How evaporation causes cooling)

According to kinetic theory, molecules of a liquid are in a state of continuous random motion and their speed depend on the temperature of the liquid.

Faster moving molecules with the most kinetic energy reach the liquid surface and weaken the intermolecular forces of attraction and then escape from the surface of liquid causing evaporation.

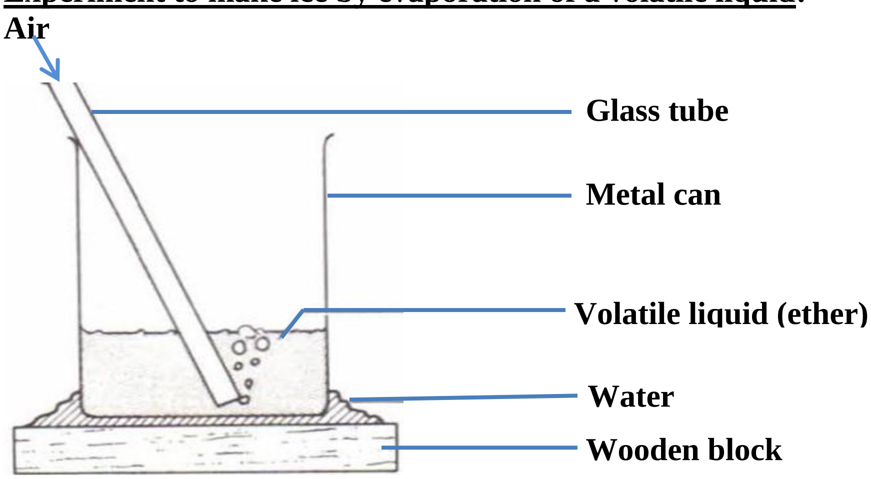
The slow moving molecules with the lowest kinetic energy remain in the liquid thus cooling the liquid.

Recall: Temperature decreases with decrease in speed of molecules. Since some molecules have low speeds, so they are cold.

Applications of cooling as a result of evaporation:

- Panting of dogs.
- Making of ice by evaporation of a volatile liquid.
- Refrigerators.

Experiment to make ice by evaporation of a volatile liquid:



Procedures:

- Place a metal can filled with ether (volatile liquid) on a film of water on top of a wooden block.
- Blow air through the glass tube.

Observation:

- It is observed that the water under the can turns into ice i.e. it freezes.

Explanation:

Ether will evaporate when it gets necessary heat from water and blowing in air increases the rate of evaporation.

Since water is supplying heat to ether, it loses heat thus its temperature decreases hence water freezes to ice.

Definition:

Volatile liquid is a liquid with a low boiling point.

Factors that affect the rate of evaporation:

Rate of evaporation indicates the number of molecules that escape from liquid surface per second.

The following factors affect the rate of evaporation;

(i) Surface area:

Increasing the surface area increases the rate of evaporation because a large surface exposes many energetic molecules to escape while small surface exposes fewer molecules to escape.

- This explains why a plate cools porridge faster than a cup since the plate is wider than the cup.

(ii) Temperature:

Increasing temperature increases the rate of evaporation and decreasing the temperature decreases the rate of evaporation. At high temperature, more molecules will move faster to escape from the liquid surface but at low temperature fewer molecules move faster to escape from the liquid surface.

(iii) Wind (air currents):

The rate of evaporation increases if there is too much wind/air blowing because wind blows away molecules which have already escaped from the liquid so they can't return back to the liquid.

This explains why a person can cool porridge while blowing air through it.

(iv) Pressure:

Reducing pressure of air above the liquid surface (atmospheric pressure) increases the rate of evaporation since low pressure is exerted on the liquid surface.

(v) Intermolecular forces of a liquid:

The stronger the intermolecular forces, the slower the rate of evaporation since molecules will need much heat to break these forces.

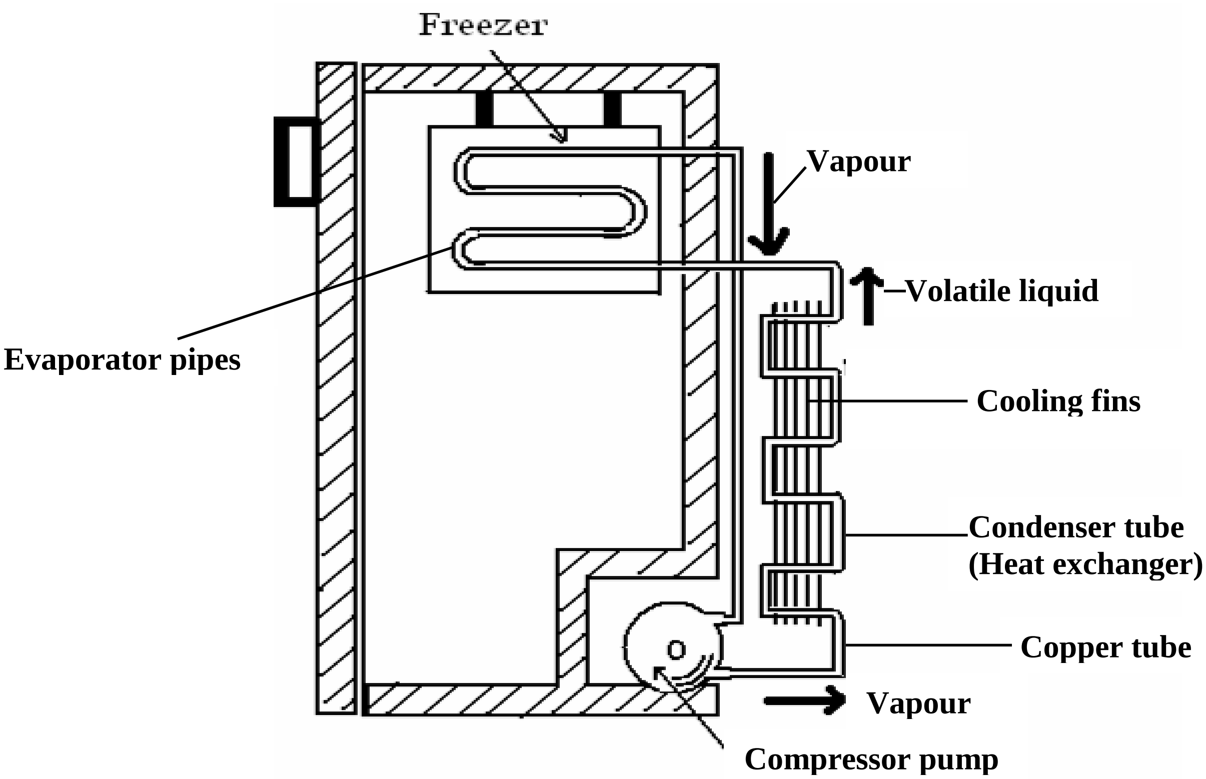
REFRIGERATOR:

This is a cooling device which transfers heat from objects in it to the surrounding.
It is used in preservation of;

- Food in homes and supermarkets
- Blood in hospitals
- Medicines in hospitals and pharmaceuticals.

In a refrigerator, heat is taken in at one point and given out at another point by a volatile liquid or refrigerant.

HOW A REFRIGERATOR WORKS



Mode of operation:

- The copper tube contains a volatile liquid which enters the evaporator pipes in the freezer.
- The volatile liquid gets latent heat from the refrigerator contents thus evaporating to vapour.
- This causes cooling of the contents since they lose heat.
- The vapour formed is compressed into the condenser tube and turns into a liquid thus giving out latent heat.
- The heat given out is lost to the surrounding through the cooling fins by convection and radiation.
- The liquid returns to the freezer and the process continues.

FUNCTIONS OF THE PARTS:

(a) Compressor pump:
This removes the vapour formed in the freezer and forces the vapour to the condenser tube.

(b) Condenser tube (Heat exchanger):
This where vapour is turned into a liquid giving out latent heat of vaporization to the surrounding air.

(c) Cooling fins:
These are painted black so that they can give out heat to the surrounding air.
Black colours are good emitters of heat.

(d) Evaporator pipe:
This absorbs heat from the refrigerator contents and gives it to the volatile liquid so as to evaporate.

BOILING:

Definition:

Boiling is a process which occurs when atmospheric pressure is equal to saturated vapour pressure.

OR

Boiling is a process by which a liquid changes to vapour at its boiling point.
Boiling occurs at a fixed temperature called boiling point and it takes throughout the liquid.
Boiling involves formation of bubbles.

Differences between boiling and evaporation

Boiling	Evaporation
• It occurs at a fixed temperature. • It takes place throughout the liquid. • Doesn't cause cooling. • Involves formation of bubbles.	• It occurs at any temperature. • It takes place at the liquid. • Causes cooling. • Doesn't involve formation of bubbles.

FACTORS THAT AFFECT BOILING POINT OF A LIQUID

(i) Pressure:
The lower the atmospheric pressure, the lower the boiling point (temperature needed to boil a liquid). But if pressure is increased, the boiling point also increases.
This is because if the atmospheric pressure is decreased, then the liquid will boil more easily since it will take less time for its saturated vapour pressure to equal to atmospheric pressure.
This explains why;

- Cooking takes longer at higher altitudes.
- In a pressure cooker, food cooks more quickly.
- During cooking we cover our saucepans.

(ii) Impurities:

Addition of impurities like salt raises the boiling point of a liquid.
Salts in a water will cause water molecules to be more attracted to the salts thus a higher temperature is required to break the forces of attraction between water molecules thus increasing the boiling point of water.
This explains local salt **"kisula"** is added to beans so as they boil easily.

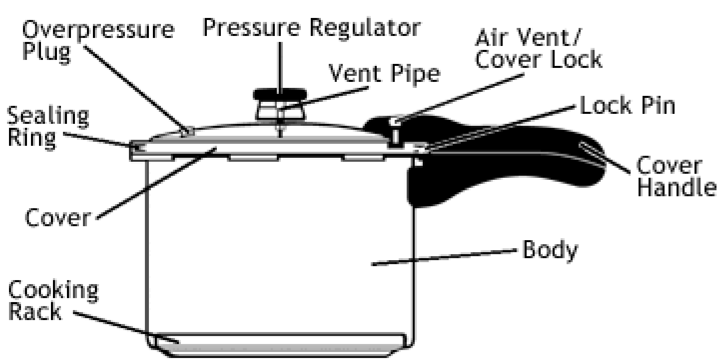
QUESTION:

Why cooking takes a lot of time to boil at high altitudes.

This is because at high altitude, the atmospheric pressure is low therefore, the boiling point of water is also low. This causes water to boil faster before food is properly cooked.
Hence it takes a lot of time for saturated vapour pressure to equal to the atmospheric pressure.

PRESSURE COOKER:

Pressure cookers are useful in places where the atmospheric pressure is low e.g. at the top of a mountain because they raise the boiling point of a liquid thus reducing time for cooking.



How a pressure cooker works.

- A pressure cooker has a lid (cover) that prevents steam from escaping.
- As water inside is heated, steam accumulates thus an increase in steam pressure causing the boiling point of water to rise above 100^0C.

Thus food boils quickly thereby saving time and fuel.

FREEZING POINT AND MELTING POINT

Freezing is the process by which a liquid changes to a solid. Freezing occurs at constant temperature called freezing point.

Melting is the process by which a solid changes to a liquid. Melting occurs at a constant temperature.

Freezing point is a constant temperature at which a substance changes from liquid state to solid state.

Melting point is a constant temperature at which a substance changes from solid state to liquid state.

Factors that affect freezing and melting points of a substance.

(i) Pressure:

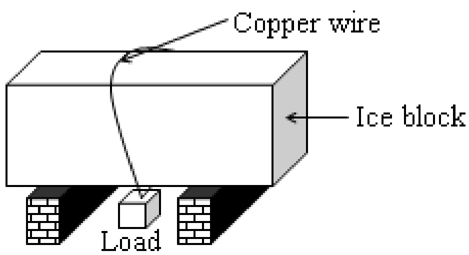
Increase in pressure lowers the melting/freezing point of a substance and vice versa

(ii) Impurities:

Addition of impurities lowers the melting/freezing points of a substance and vice versa.

- This explains why ice melts why ice melts quickly when salt is sprinkled on it.

Effect of pressure on melting point of ice.



When pressure is increased on the ice by the copper wire;

- The copper wire passes through the ice block since increased pressure by the copper wire lowers the melting point of ice. So it melts easily at a low temperature.

HEAT ENGINE

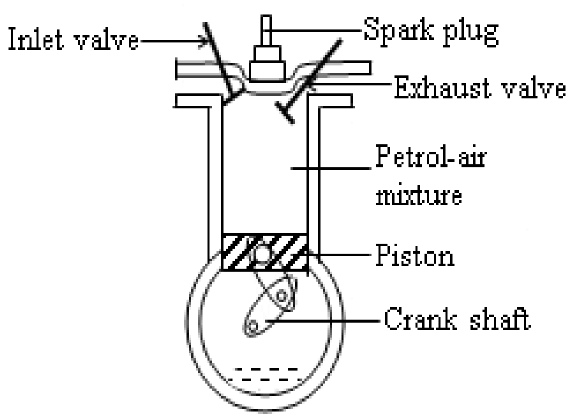
A heat engine is a device used to convert heat energy to kinetic energy (mechanical energy).

Why engines are always less than 100% efficient.

- Because some of the energy is lost in overcoming friction since it has moving parts. This is friction is reduced by lubricating engine parts.
- Some heat is lost to surrounding due to conduction.
- Some energy is wasted in lifting useless loads like pistons.

PETROL ENGINE

It is also called the four stroke cycle engine.



OPERATION OF A FOUR STROKE CYCLE ENGINE (PETROL ENGINE)

Intake (inlet) stroke:
- Piston moves down causing a vacuum.
- Inlet valve opens and the air –fuel mixture is forced into the cylinder from carburetor.
- Exhaust valve closes.

Compression stroke:
- Both valves close.
- The piston moves up compressing the air-fuel mixture.
- The fuel is ignited by a spark plug.

Power stroke:
- A spark jumps across the points of a spark plug and explodes the air-fuel mixture.
- Piston is forced to move down.

Exhaust stroke:
- The outlet valve opens pushing the exhaust gases out of the cylinder.

NOTE:
- The operation of a diesel engine is the same as that of a petrol engine.
- The diesel engine use diesel as a fuel yet petrol engines use petrol as a fuel.

Differences between diesel and petrol engines.

Diesel engine	Petrol engine
• Uses diesel as a fuel.	• Uses petrol as a fuel.
• No spark plug used.	• Spark plug is used.
• Has a fuel injector instead of carburetor.	• Has a carburetor instead of fuel injector.
• Produces a lot of smoke.	• Produce less smoke.
• Uses less fuel.	• Uses a lot of fuel.
• They are expensive.	• They are cheap.
• They are heavy	• They are lighter.

EXERCISE:

1. 200litres of a gas at $0^{O}C$ are kept under a pressure of 150kPa. If the temperature is raised to $273^{O}C$, its pressure is raised to 400kPa. Calculate its volume.
   Ans: 150 litres
2. The density of argon gas at $27^{O}C$ is $0.27kgm^{-3}$. A volume of $50m^3$ of argon gas is kept under constant pressure at $27^{O}C$. What will be the density of argon if its temperature is raised to $51^{O}C$?
   Ans: 0.25kgm^{-3}
3. The volume of a fixed mass of a gas at constant temperature is $150cm^3$ when the pressure is 76cmHg. Calculate the volume when the pressure is 38cmHg.
   Ans: 300cm^3
4. The volume of a fixed mass of a gas at constant pressure is $400cm^3$ at a temperature of $27^{O}C$. Calculate the volume when the temperature is raised to $78^{O}C$.
   Ans: 468cm^3
5. The pressure of a fixed mass of a gas at constant volume is 600mmHg at a temperature of $127\ ^{O}C$. Calculate the pressure when the temperature falls to $27^{O}C$.
   Ans: 450mmHg
6. Air in a 2.5litre vessel at $127^{O}C$ exerts a pressure of 3 atmospheres. Calculate the pressure that the same mass air would exert if contained in a 4litre vessel at $-73^{O}C$
   Ans: 0.9375atmospheres.
7. State differences between boiling and evaporation
8. Distinguish between saturated vapour and un-saturated vapour
9. What are the factors that affect the rate of evaporation of a liquid and how
10. Use the kinetic theory to explain effect of increasing temperature of the gas at constant pressure

EXAMINATION QUESTIONS:

1. a) Define specific heat capacity
   b) 0.05kg of water at $80^{o}C$ is mixed with 0.06kg of water at $10^{o}C$ contained in a vessel of heat capacity $28Jkg^{-1}$. What is the final temperature of the mixture?
   Ans: $400^{0}C$
   c) i) Define specific latent heat of fusion
   ii) Describe a simple method to determine the specific latent heat of fusion of ice
   c) When 0.005kg of ice at $0^{o}C$ is added to 0.02kg of warm water at $30^{o}C$ the final temperature attained is $8^{o}C$. Find the specific latent heat of fusion of ice.
   Ans: $336{,}000Jkg^{-1}$

2. a) i) State Boyle"s law
   ii) With the aid of a labeled diagram describe the experiment to show the relationship between the volume and the temperature of a fixed mass of a gas at atmospheric pressure.
   b) A cylinder with a movable piston contains $0.1m^3$ of air at a temperature of $27^{o}C$. Calculate the volume of the gas if it is cooled to $-33^{o}C$ at constant pressure.
   Ans: 0.08m^3

c) Define the term specific heat capacity
d) A copper block of mass 200g is heated to a temperature of 145^{o}C and then dropped into a well lagged copper calorimeter of mass 250g which contains 300cm^3 of water at 25^{o}C
   i) Calculate the maximum temperature attained by the water
   ii) Sketch a graph to show the variation of temperature of water with time

Ans: i) 31.7^{0}C

3. a) i) Define heat capacity of a substance
   ii) Describe an experiment to determine specific heat capacity of a substance by method of mixtures
   iii) State the precautions necessary for accuracy during the experiment above

   b) A well lagged copper calorimeter of mass 85g contains 80g of water at 60^{o}C. Dry ice at 0^{o}C is added to the calorimeter and after stirring the mixture attains a steady temperature of 20 ^{o}C. Find the mass of ice added

   Ans: 35.2^{0}C

   c) i) Describe an expiration to show that evaporation produces cooling.
   ii) Explain why evaporation produces cooling.
   iii) State one application of cooling by evaporation.

4. a) i) What is a saturated vapour
   ii) Explain why the boiling point of a liquid depends on altitude.

   b) i) Define specific heat capacity.
   ii) Describe an experiment to determine the specific heat capacity of a solid

   c) A copper block of mass 250g is heated to a temperature of 145°C and then transferred to a cooper calorimeter of mass 250gwhich contains 250cm^{3}of water at 20°C
   i) Calculate the maximum temperature attained by water
   ii) Sketch the graph to show the variation of temperature with time

   Ans: i) 300C

   d) i) What is meant by the term temperature
   ii) Give two physical properties which change with temperature

5. a) Define the following terms as used in heat
   i) Specific heat capacity
   ii) Latent heat of vaporization

   b) Describe an experiment to determine the specific heat capacity of a liquid

   c) Steam from boiling water is bubbled through 1.5kg of water at 20^{o}C. After this process, the mass of water was found to be 1.54 kg. What is the new temperature of water?

   Ans: 35.99^{0}C

   d) State four ways in which heat losses can be minimized in a calorimetry experiment

6. a) Define specific latent heat of fusion

   b) Describe an experiment to determine the specific latent heat of fusion of ice

   c) A copper block of mass 300g is heated to a temperature of 245^{o}C and then dropped into a well lagged copper calorimeter of mass 350g containing 400g of water at 35^{o}C.

Calculate the maximum temperature attained by the water.

Ans: 43.3^{0}C

d) i) What is meant by absolute zero temperature

ii) A sealed flask contains gas at a temperature of 27^{o}C and a pressure of 900Pa. if the temperature rises to 127^{o}C. What will be the new pressure?

Ans: ii) 1200Pa

7. a) i) Define temperature.

ii) The fundamental interval of a mercury-in-glass thermometer is 192mm. Find the temperature in degrees Celsius when mercury thread is 67.2mm long

b) With the aid of a labeled diagram describe the experiment to show the relationship between the volume and the pressure a fixed mass of a gas at constant temperature.

c) A copper block of mass 150g is heated to a temperature of 95^{o}C and then dropped into a well lagged copper calorimeter of mass 200g containing 250g of water at 15^{o}C. Calculate the maximum temperature attained by the water.

Ans: 19.0^{0}C

d) State any two differences between boiling and evaporation

8. a) Define specific latent heat of vaporization

b) A calorimeter of mass 35g and specific heat capacity 840Jkg^{-1}K^{-1} contains 143g of water at 7^{o}C. Dry steam at 100^{o}C is bubbled through water in the calorimeter until the temperature of the water rises to 29^{o}C. If the mass of steam which condenses is 5.6g,

i) Calculate heat gained by the water and calorimeter

ii) Obtain an expression for the heat lost by the steam in condensing at 100^{o}C and in cooling to 29^{o}C.

iii) Find the specific latent heat of vaporization of water

Ans: i) 13860J ii) 0.0056Lv + 1669.92 iii) 2,176,800

c) Explain in terms of molecules what is meant by a saturated vapour?

d) Describe briefly one application of vaporization

9. a) i) Describe the fixed points of a Celsius scale of temperature

ii) Give two advantages of mercury over alcohol as thermometric liquid

iii) Convert -200^{o}C to Kelvin

Ans iii) 73^{0}C

b) Use the kinetic theory to explain the following

i) Cooling by evaporation

ii) Why the temperature of a gas contained in a cylinder increases when it is compressed

c) Explain briefly the transfer of thermal energy by conduction in metals

d) A battery of e.m.f 12V and internal resistance 1Ω is connected for 3minutes across a heating coil of resistance 11Ω immersed in a liquid of mass 0.2kg and specific heat capacity 2.0 x 10^{3}Jkg^{-1}K^{-1}. Find the rise in temperature of the liquid. State clearly any assumptions made.

Ans: 4.95^{0}C

10. a) With the aid of a labeled diagram, describe the experiment to show the relationship between temperature and pressure a fixed mass of a gas at constant volume.

b) A gas of volume 1000cm^3 at a pressure of 4.0 x10^5 Pa and temperature of 17^{o}C is heated to 89.5^{o}C at constant pressure. Find the new volume of the gas.

Ans: 1250cm^3

c) A balloon is filled with 50cm^3 of hydrogen and tied to the ground. The balloon alone and the container it carries have a mass of 2kg. If the densities of hydrogen and air are 9.0 x 10^{-2}kgm^{-3} and 1.29kgm^{-3} respectively, how much load can the balloon lift when released

11. a) What is meant by conduction

b) Draw a labeled diagram of a thermos flask and explain how it is able to keep a liquid cold for a long time

c) With the aid of a diagram, describe how you would determine the upper fixed point of un -calibrated thermometer

d) Explain the following observations;

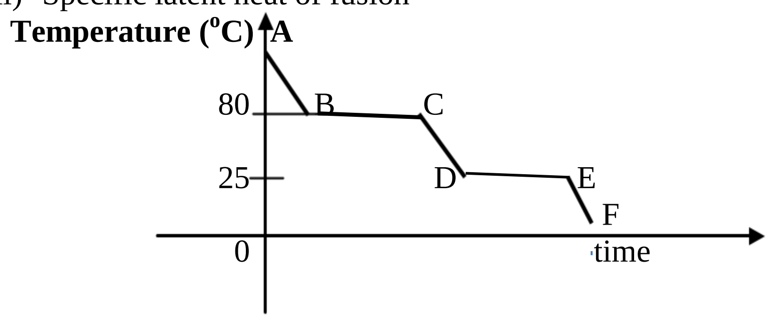
i) A bare cement floor feels colder than a carpeted one

ii) A beam with a notch that is used for constructing a bridge lasts longer when the notch is on its top surface than when the notch is on its lower surface

12. a) Define the following terms

i) Specific heat capacity

ii) Specific latent heat of fusion



b) The figure above shows a cooling curve of a liquid whose boiling point is 80^{o}C and freezing point is 25^{o}C.

i) Give the states over regions AB, BC, DE and EF

ii) What is happening over region BC?

iii) Use the kinetic theory to explain the differences in states over regions AB and EF

c) An iron rod of mass 0.8kg is pushed into an insulator solid substance through a distance of 2.3m against frictional force of 400N. The temperature of iron rises by 2.5^{o}C. Calculate the specific heat capacity of iron

Ans: 460Jkg^{-1}K^{-1}

d) i) Explain why when water in a saucepan is heated, the level first falls and then rises after some time

ii) The length of mercury thread of un-calibrated thermometer is 10cm when the bulb is in pure melting ice and rises to 20cm in steam. What is the reading of the thermometer when the mercury thread is 18cm?

Ans: ii) 800C

13. a) Define specific latent heat of vaporization
    b) Describe an experiment to determine specific latent heat of vaporization of steam
    c) A copper calorimeter of heat capacity $60Jkg^{-1}$ contains 0.5kg of water at 20^oC. Dry steam at 100^0C is passed into the water in the calorimeter until the temperature of the water and the container reaches50^oC. Calculate the mass of steam condensed

    Ans: 4.61kg

    d) i) What is meant by saturated vapour pressure
    ii) Explain what may happen when one is to cook food from a very high altitude
14. a) i) Define latent heat of fusion.
    ii) Describe with the aid of a labeled diagram, an experiment to show the effect of increase in pressure on the melting point of ice
    b) If the melting point of lead is 327^oC, find the amount of heat required to melt 200g of lead initially at 27^oC given that specific latent heat of fusion of lead is $2.5 \times 10^6 Jkg^{-1}$ and specific heat capacity of lead is $660Jkg^{-1}K^{-1}$.

    Ans: 539,600J

    c) What is meant by the terms?
    i) Temperature
    ii) Heat
    d) State two physical properties which change with temperature.

15. a) Describe an experiment to determine the specific latent heat of fusion of ice
    b) i) 2 kg of ice initially at -10^oC is heated until it changes to steam at 100^oC
    ii) Sketch the graph to show how temperature changes with time
    iii) Calculate the energy required at each end of the graph

    Ans: 42,000J 672,000J 840,000J 4,500,000J

16. a) Differentiate between conduction and convection
    b) Describe an experiment which can be performed to show convection in a liquid
    c) i) Draw a labeled diagram of a vacuum flask
    ii) Explain how a vacuum flask minimizes heat losses
    d) Why is a car radiator made of fins and painted black

17. a) State the kinetic theory of matter
    b) i) State the law of volume and temperature
    ii) The volume of a fixed mass of a gas at a given pressure is $1.5m^3$ at 300K. at what temperature will the volume of the gas be at the same pressure
    c) Describe an experiment to determine the fixed points of a thermometer
    d) i) Mention any three reasons for not using water as a thermometric liquid
    iii) When a Celsius thermometer is in a boiling liquid, the mercury thread rises above the lower fixed point by 19.5cm. Find the temperature of boiling liquid if the fundamental interval is 25cm.

    Ans: 78^0C

18. a) What is meant by latent heat of vaporation
    b) With the aid of a labeled diagram describe how a refrigerator works

c) The cooling system of a refrigerator extracts 0.7kW of heat. How long will it take to convert 500g of water at 20^oC into ice?
Ans: 300s

d) Explain how evaporation takes place

19. a) What is meant by conduction

b) Draw a labeled diagram of a vacuum flask and explain how it is able to keep a liquid hot a long time

c) With the aid of a labeled diagram describe an experiment to determine the upper fixed points of an un-calibrated thermometer

d) Explain the following observation a bare cement floor feels colder than a carpeted one

20. a) i) Define latent of fusion

ii) Describe with the aid of a labeled diagram, an experiment to show the effect of increase in pressure on the melting point of ice

b) What is meant by the terms?

i) Temperature

ii) Heat

c) The fundamental interval of mercury in glass is 192mm. find the temperature in degrees Celsius when the mercury thread is 67.2mm below the upper fixed point.

Ans: 65^0C

d) State two physical properties which change with temperature