6. $1cm^3$ of oleic acid was dissolved in 99 cm^3 of alcohol to form 100 cm^3 of solution. A 1-cm^3 drop of the solution was put on a water surface sprinkled with lycopodium powder. The alcohol dissolved in water leaving the acid which spread to form a patch of diameter 14 cm^3.
   (i) Explain why lycopodium powder was used
   (ii) Calculate the volume of the acid in the 1-cm^3 drop of the solution.
   (iii) Estimate the size of oleic acid molecule.

7. In an experiment to determine the thickness of an oil molecules the following were done;
   ❖ $1cm^3$ of oil was dissolved in $99cm^3$ of ether and $1cm^3$ of the solution was diluted to $200cm^3$
   ❖ 0.4 cm^3 of the dilute solution was dropped onto the surface of water.
   ❖ The diameter of film formed was found to be 7cm. from the above. Calculate the thickness of the oil molecules. (Ans:t $=5.19 \times 10^{-7}$ cm).

8. A solution was made by dissolving $1cm^3$ of cooking oil in $199cm^3$ of methanol. When $0.004cm^3$ of the solution was dropped onto the water surface, an oil film of diameter 12cm was obtained. Find the thickness of the oil molecule.

9. See UNEB

1987 Qn.36 and Qn.7	1987 Qn.2
1997 Qn.13	2001 Qn.43
1999 Qn.13	2003 Qn.3
2006 Qn.19	2005 Qn.49
1992 Qn.31	1993 Qn.7
2007 Qn.25	2002 Qn.45

(b) MECHANICAL PROPERTIES OF MATTER

Mechanical properties of matter are the behavior of matter under action of an external force.

Materials are things used in the construction of structures like buildings bridges, dams, etc. Before a material is put to use the following mechanical properties should be considered; strength, stiffness, ductility, brittleness and elasticity.

Strength: It is the ability of a material to resist forces that want to deform it.
Is the ability of a material to resist breaking when stretched, compressed or sheared.

$$\text{Braking stress} = \frac{\text{Force}}{\text{Cross} - \text{sectional area}}$$

The strength depends on
i) Dimensions of the material, in that a large force is applied in order to bend a material of large diameter.

ii) Nature of the substance
Materials of same size but of different substance require different force to be broken. E.g. a large force is applied to a steel rod compared to a piece of wood of the same size.

iii) Magnitude of force applied

Stiffness (toughness): Is the ability of a material to resist bending or to resist forces, which try to change its shape or size so that it is not flexible. A material which is more stiff always needs a large force in order to bend e.g. wood is more stiff than rubber.

Ductility: Is the ability of a material to deform when a force is applied.
Is the ability of a material to be changed/rolled/hammered/pressed/bent or stretched into other shapes with out breaking.
Ductile materials can be hammered, bent or drawn into various shapes with out breaking.
A Ductile material is one, which stretches elastically then plastically before it breaks when tensile force acts on it

Examples;
- Wet clay, plasticine, Metals, steel, e.t.c.

Properties of ductile material.
i) can be molded into any shape.
ii) can be bent without breaking. Because of the above properties of ductile materials, they can be rolled into sheets drawn into wires or worked into other useful shapes without breaking.

Brittleness: Is the ability of a material to break suddenly without bending.
A brittle material is one, which bends very little, then suddenly cracks without undergoing plastic deformation.
When a brittle material breaks, its pieces fit together almost exactly and can be glued back.

Properties of brittle material
i) Can bend very little and suddenly break without undergoing plactic deformation.
ii) Cannot be molded into any shape.

Examples;
- Glass, chalk, stones, concrete, cast iron bricks, alloys like brass, and bronze.

Elasticity: Is the ability of a material to recover its original shape and size after a deformation force has been removed.

The material stretches due to the particle being pulled further apart from one another.
A material, which does not recover its original shape and size but is deformed permanently, is plastic.

Examples;
- Rubber, steel, e.t.c.

Hooke's law:
Hook's law states that the extension of a material is directly proportional to the applied force provided the elastic limit is not exceeded.
i.e. the material returns to its original length when the stretching force is removed, provide the elastic limit is not exceed

In short: $\mathbf{Force} \propto \mathbf{extension}$
$$\mathbf{Force} = \mathbf{k}(\mathbf{extension})$$
$$\mathbf{F} = \mathbf{ke}$$

Where k is the proportionality constant or material constant in **Nm^{-1}**, Where, F is the stretching force in newtons and e is the extension in metres.

Extension, e = New length − Original length

$$\boldsymbol{e = l_n - l_o}.$$

It is also important to note that;

$$\frac{F_1}{e_1} = \frac{F_2}{e_2} \quad \textbf{Or} \quad \frac{F_1}{F_2} = \frac{e_1}{e_2}$$

Where F_1 is stretching force producing extension e_1 and F_2 is stretching force producing extension e_2 on the same material.

Example1:

A spring is stretched by 0.05m by a weight of 5N hung from one end.

(i) What weight will stretch it by 0.03m?

(ii) Determine the spring constant.

Solution:

Given; e_1=0.05m, e_2=0.03m, k=?, F_1=5N, F_2=?.	
Then from; $\frac{F_1}{e_1} = \frac{F_2}{e_2}$ $\frac{5}{0.05} = \frac{F_2}{0.03}$	$F_2 = \frac{5}{0.05} \times 0.03$ $F_2 = 3N$

Example 2:

A spring increases its length from 20 cm to 25cm when a force is applied. If the spring is constant is 100N/m. Calculate the force.

Solution:

Given; l_o=20cm, l_n=25cm, k=100Nm^{-1}.	
$e = l_n - l_o$. e = 25 − 20 e = 5cm $e = \frac{5}{100} = 0.05m$	From Hooke's law; F = ke F = 100(0.05) F = 5N

Exercise:

1. A vertical spring of length 30 cm is stretched to 36 cm when an object of mass 100g is place in the pan attached to it. The spring is stretched to 40 cm when a mass of 200g is placed in the pan. Find the mass of the pan.

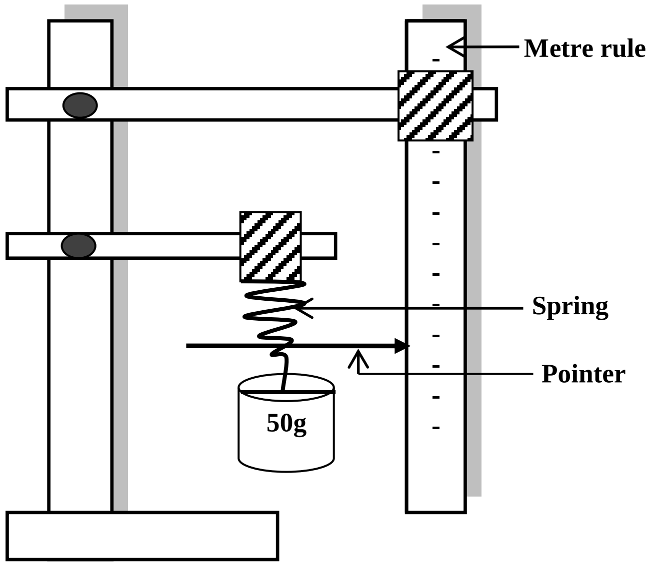
2. A force of 500N extends a wire by 2mm. If the force is reduced by a half, what will be the new length of the wire, if the original length is 10cm.

3. A spring constant of natural length 8.0×10^{-2} m extends by 2.5×10^{-2} mm when a weight of 10N is suspended on it.

(i) Find the spring constant.

(ii) Determine the extension when a weight of 15N is suspended on the spring

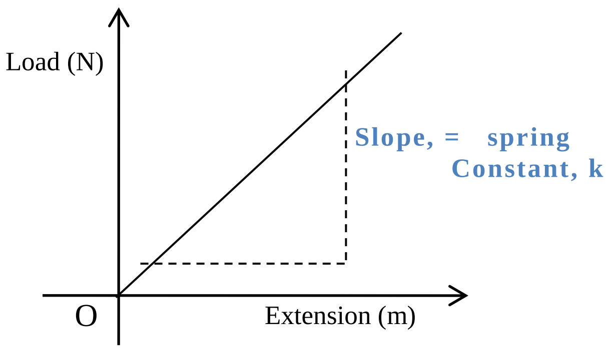
Experiment to verify Hook's law.



- Original length of the spring $\boldsymbol{l_o}$ is noted.
- Then various loads are suspended on the spring and the corresponding new length, $\boldsymbol{l_n}$ of spring for each is noted.
- The extension, **e** produced is calculated from; Extension, $\boldsymbol{e = l_n - l_o}$
- The readings are noted in a table below.

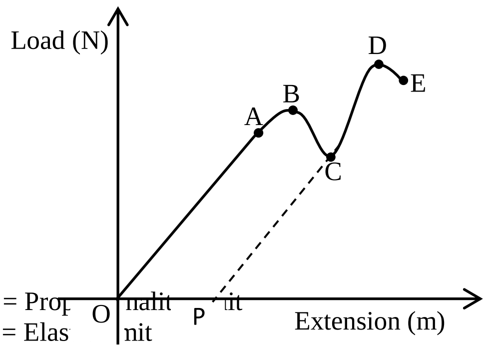
Load(N)	l_n (m)	e(m)
-	-	-
-	-	-

- A graph of load against extension is drawn, and a straight-line graph is obtained whose slope is equal to the spring constant.



- Thus, the load is directly proportional to the extension "e". This verifies Hooke's law.

A graph of load against extension



A = Proportionality limit
B = Elastic limit
C = Yield point (minimum stress)
D = Hecking point (maximum stress)
E = Breaking point
OP = Permanent deformation

Explanation
Along OB, the load is proportional to extension in that the extension increases as the load increases.
Point "B" is called elastic limit.

Beyond B (elastic limit), the graph is not a straight line meaning that extension is no longer proportional to the load. The material becomes plastic. This is indicated by a kink at C, which is called yield point.

Beyond C, the material behaves plastically. i.e. it does not regain its shape and size. Therefore, it undergoes plastic deformation. This goes on to the breaking point E.

Point D represents the maximum stress (Breaking stress) the material can withstand fracturing.

Explanation of sketch of load against extension according to kinetic theory
OB the molecules are pulled slightly farther apart but can move back to original position when stretching force is removed. The deformation is called elastic.

Beyond C, layers of atoms slip over each other. The molecule move farther apart but cannot move back to original position when stretching force is removed.

Tensile stress, Tensile strain and Young's modulus.

Tensile stress:
Is the force acting per cross section area of a material. Its S.I unit is Nm^{-2} or Pa.

$$\text{Stress}=\frac{\text{Force}}{\text{Cross section area}}=\frac{F}{A}$$

Tensile strain:
Is the ratio of extension to original length of a material. It has no units.

$$\text{Strain}=\frac{\text{Extension}}{\text{Original length}}=\frac{e}{l_o}$$

Young's modulus:
This is the ratio of tensile stress to tensile strain.
It is the gradient of the straight line in the elastic region. Its S.I unit is Nm^{-2} or Pa.

$$\text{Young's modulus}=\frac{\text{stress}}{\text{strain}}=\frac{F\,l_o}{Ae}$$

Note: This holds only when the elastic limit of a material is not exceeded.

Example 3:
A wire of cross section area $3m^2$ increases in length from 20cm to 25cm, when a force of 5N is applied. Calculate the;
(i) tensile strain.
(ii) tensile stress
(iii) Young's modulus.

Solution:
(i) Given; l_o=20cm, l_n=25cm, F=5N, $A = 3m^2$
$e = l_n - l_o \Leftrightarrow e = (25-20) = 5\text{cm}$

$e = \frac{5}{100}$ = 0.05m

(i) Tensile train= $\frac{e}{l_o}$ Tensile train= $\frac{5}{20}$ = 0.25 (ii) Tensile stress= $\frac{F}{A}$ Tensile stress= $\frac{5}{3}$ Tensile stress=1.67Nm^{-2}	(iii) Young's modulus= $\frac{\text{stress}}{\text{strain}}$ Young's modulus= $\frac{1.67}{0.25}$ Young's modulus=6.67Nm^{-2}

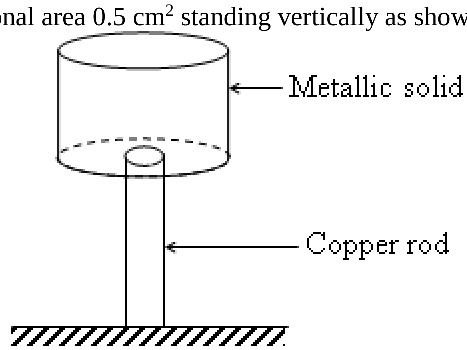
Example 4:
Calculate the tensile stress when a force of 25N acts on a wire of cross sectional area $5m^2$.

Given; $A = 5m^2$, F = 25N

Tensile stress $=\frac{F}{A}$

Tensile stress= $\frac{25}{5}$
Tensile stress=5Nm^{-2}

Question:
A metallic solid of mass 45kg rests on a copper rod of cross sectional area 0.5 cm^2 standing vertically as shown below,



Calculate the stress in the rod.
A. $9.0 \times 10^2 Nm^{-2}$ B. $9.0 \times 10^5 Nm^{-2}$
C. $9.0 \times 10^6 Nm^{-2}$ D. $9.0 \times 10^8 Nm^{-2}$

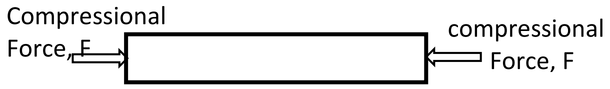
CRYSTALS:
Crystals have hard, flat sides and straight edges. Crystals of the same substance have the same shape. This will be observed when salt crystals grow as water evaporates from the salt solution on glass slide as seen through a microscope.

This fact suggests that crystals are made of small particles called atoms or molecules arranged in orderly way in plates. Metals consist of tiny crystals.

<u>Tensile, shear and compression force.</u>

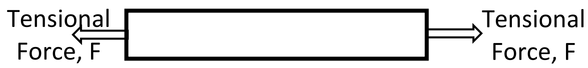
(i) Compression force

Compression is when the force acts as in the diagram below. This results in the particles to be pressed more closely together. So the length of the material decreases but the thickness of the material increase.



(ii) Tensile force

Tensile force is when the force acts as in the diagram below. This result in the particle of the material to be pulled further apart from one another. So tensile forces increase the length of the material but its thickness decreases.

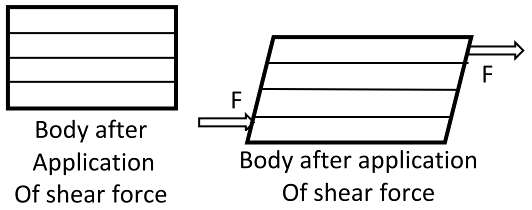


Differences between tensile and compression force.

Tensile force	Compression force
i) Particles are pulled further apart	i) Particles are pulled close together
ii) Length of the material increases	ii) Length of material decreases
iii) Thickness of the material decreases	iii) Thickness of the material increases

(iii) Shear force

Shear force is the force needed to fracture the material in a direction parallel to the applied force in that one section (or layer) of the material slides over its neighbour.
A shear is produced when two equal but opposite forces are applied to a body. The effect depends on the turning effect or movement of the force.



Important materials used for construction.

(a) <u>Metals:</u>

Large varieties of metals are available from which different alloys or combinations of these metals are made into various shapes. Metal can be rolled, pressed, and drawn, and are usually strong, rigid and elastic.

Some of the common metals are; copper, Zinc, Lead, Tin, Nickel, Chromium. e.t.c

(b) <u>Alloys:</u>

Alloys are made by mixing one metal with one or more other metals and in some cases non metals.

- <u>Steel alloys</u>. Steel is an alloy of Iron and carbon. Iron is alloyed with a variety of the other materials like:-

Examples of steel

- Mild steel (Iron and carbon) used in making cars, ships etc.
- Stainless steel has high corrosion resistance due to its composition of chromium and nickel. It is used in making knives, watch casing etc.
- Lead and sulphur steel. It is used in the making of screws because it is easy to cut.

- Duralium is an alloy of aluminium and is used in the making of aircrafts because of its lightness and strength.

- Nickel-Chromium alloys
  i) Have good resistance to corrosion
  ii) The electrical conductivity is independent of temperature
  iii) Have a high melting point.

For these properties, nickel-chromium alloys are useful for making elements of electrical heaters.

- Invar: is a nickel-iron alloy with low expansivity. It can be used to make accurate measuring tape and parts of watches.
- Brass: Is copper-zinc alloy? It is ductile and with high tensile strength. It is used in stamping, pressing or drawing. It is used in the making plumbing fittings.

- Bronze: Is an alloy of copper and tin is harder and stronger than brass. It is useful in ornamental work.

(c) <u>Stony materials</u>

- Bricks: Are made by moulding a mixture of clay and water and beating the mixture strongly.
- Concrete: A concrete is a stony material which is a mixture of cement, sand gravel and water. This is left to harden in desired form.

<u>Properties of concrete which makes it a suitable building material</u>
i) It is resistant to weather
ii) It is resistant to compression
iii) It is very durable
iv) It is resistant to fire

Concrete can be primarily subjected to compression like column and arches because it compression strength is high. However, concrete is relatively brittle material whose tensile strength is small compared to its compressional strength. This makes concrete unsuitable for use in structure membranes which are subjected to tension like tie rods, beam.

In order to overcome the limitation of low tensile strength, steel (with high tensile strength) is interlocked and completely surrounded by hardened concrete mass to form integral part of the membranes called reinforced concrete.

Reinforced concrete is a combination of steel rods, Cement, sand, gravel and water.

Concrete is reinforced by interlocking and surrounding the steel rods with the hardened concrete mass.

Advantages of reinforced concrete.
i) It has high compressive strength
ii) It has high tensile strength
iii) It has much greater ductility
iv) It is tough
v) It is weather and fire resistant

However, the disadvantage of concrete is its volume instability caused by shrinkage of concrete, which results in cracks.

The cracks can be filled with mixture of special tar, sand, cement and water.

Cement Mortar: Cement mortar is composed of sand, cement mixed with water and left to harden.

Reinforcement: sisal-fibre, bamboo stripes, wood strands are also used in reinforcing concrete and cement mortars.

The reinforcing improves on tensive strength and weather resistance of the materials.

Glass: Glass can be melted and formed into various shapes.

Advantages of glass which makes it useful as construction material.
i) It is transparent
ii) Its surface quite harder
iii) Very few chemicals react with glass.
iv) Can be melted and formed into various desired shapes.

Safety glass: Is used motor vehicle windscreen safely glass is made by heating plate glass cooling the two surfaces in a stream of air.

These contract and compress the glass in the middle resulting a very strong glass which when hit hard enough breaks into small fragment that are less dangerous than large pieces.

Wood: Wood is a poor conductor of both heat and electricity.
The hardness and strength of wood varies from one sample to another.

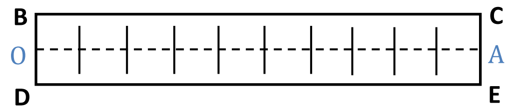
Thin sheets of wood are glued together to form a laminate (plywood) which is stronger than solid wood of the same thickness.

BEAMS AND STRUCTURES

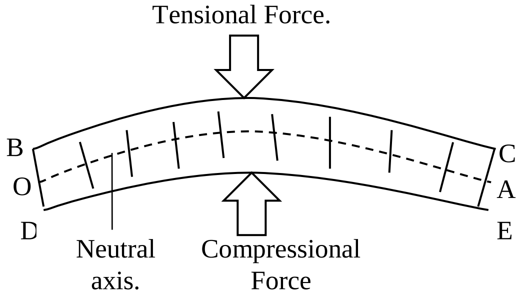
A beam is a large and long straight piece of materials with uniform cross-sectional area.

A girder is a small piece of material used to strengthen a beam.

A beam is the simplest but one of the most important structures. When a beam bends, one side is compressed, the other is stretched (tensile) and the centre is unstretched neutral plane.



Above is the diagram of rubber marked with lines as shown. When the rubber is bent as shown below,

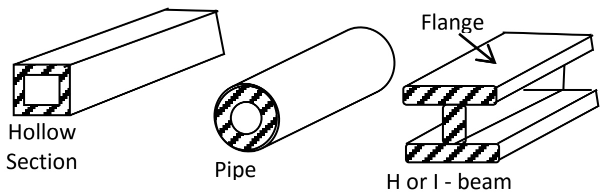


The lines above OA move further apart. Showing that the above parts are in tension.

The lines below OA move closer showing that the below part are in compression.

Along OA the lines are at the same distance apart as before implying neutral axis.

From above it can be noted that materials from neutral plane can withstand compression and tensile force due to loading.



The top and bottom flanges have the shape shown.

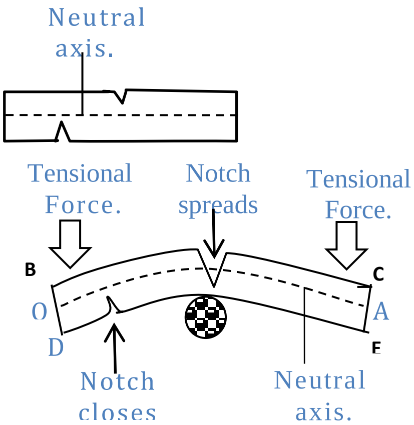
Because they are beams that have had material removed from the neutral plane, so can with stand compression and tensile forces due to loading.

In general, pipes for construction of structures like bicycles, bridges are made hollow for the following advantages.
- They are beams that have had materials removed from the neutral plane so can withstand tensile and compression forces.
- Notches cannot spread easily hence less risk of breaking.
- Less material is used for construction
- The finished structure is lighter

- Provide room for expansion and contraction.

The Notch effect:
Cracks and fractures:
A notch is a cut or weak point in the surface of a material.

When a notch is made in the reinforcing material, the fibres, stripes and strands in the length of concrete or mortar are broken down.
This result in such materials to fail to withstand compression or tensile force.



Glass tubes are easily broken after notch is made on the side.

A notch, crack or scratch on the surface of brittle material like concrete and glass, spreads more readily under tensile force than under compression.

Reducing notch effect:

(a) For concrete and cement mortar;
Notch effect can be reduced by; pre-stressed concrete containing steel rods that are in tension because they were stretched while the concrete was poured on them.

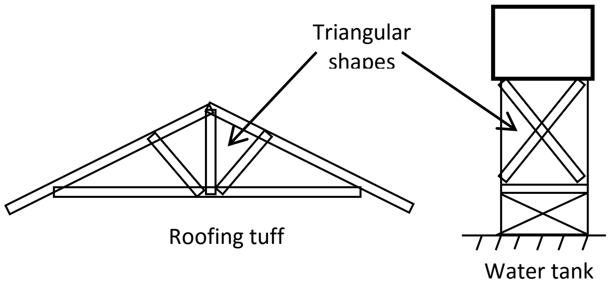
This is advantageous in that as well as resisting tension forces they keep the concrete in concrete in compression even if the whole structure is not.

(b) For glass:
Notches can be removed from glass
i) By making the surface of glass as smooth as possible. So glass usually making smooth to reduce the breaking due to notches.
ii) For safety glass used in motor vehicle screen is made by heating plate glass and cooling the two surfaces in a stream of air where they contract and compress the glass in the middle. This is called thermal toughening.
iii) By reinforcing glass with transparent polythene.

(c) For wood;
Thin sheet of wood are glued together to form a laminated structure which is able to resist notches more than solids because for solid structures, the crack or a notch goes right through while in a laminated structure it may be stopped by one of the layers.

STRUCTURES:
A structure is rigid meaning that it can support weight.

Triangular structures are more rigid than others. So a rectangular structure can be made rigid by adding a diagonal piece so that the rectangular change into two a triangular structure, which are more rigid. This is why doors, water tanks and roofing tuffs are made with triangular shapes.



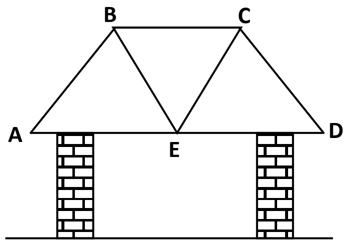
Struts and Ties
In any structure, there are parts, which are under action of tensional forces and others under action of compressional forces.

Ties are girders, which are under tension.
This occurs when a girder results in the points it joins to moves further apart on the removal of such girder in a tie.

Properties of ties:
- ✓ It is under tension
- ✓ When removed, the point it joins move further apart.
- ✓ It can be replaced by a rope or strong string.

Struts are girders, which are under compression.
This occurs when a girder result in the point to move closer together on removal girder in struts.

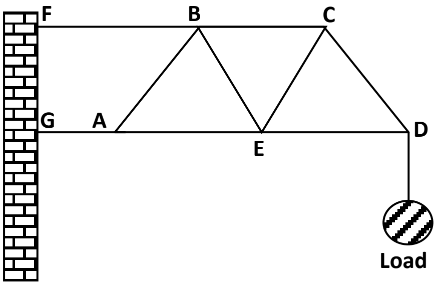
Properties of struts:
- ✓ It is under compression
- ✓ When removed, the point it joins move closer to each other.
- ✓ It cannot be replaced by a rope or strong string.



In order to determine each of the girders whether its a tie or a strut, each of the girders is removed and the effect is noted.
- ❖ If the points move further apart then the girder is tie and if the points move closer together then the girder is strut.
- ❖ When BC is removed, point B moves close to point C showing that girder BC is strut.
- ❖ When AB is removed, point A moves close to B. so girder AB is strut.
- ❖ When AE is removed, point A moves further apart from E meaning that girder AE is tie. Similarly, girder ED is tie.

For structures

When BE is removes point B move further apart from E meaning the girder BE tie.



CD is a tie
BF is a tie
BC is a tie
CE is a strut
AD is a strut
DE is a strut

When BF is removed, the structure turns about point G. B will move further away from F hence BF is a tie.
When BC is removed, the structure will bend at E. Thus, C will move in the direction of the load, far away from B. This means BC is under tension and hence it is a tie.

When CD is removed, point D moves down wards with the load. Point D moves away from C, so CD is a tie.

When DE is removed, CD will be vertical due to the load. Thus, point D moves nearer to E meaning that girder DE is a strut. Similarly, girder EG is a strut.

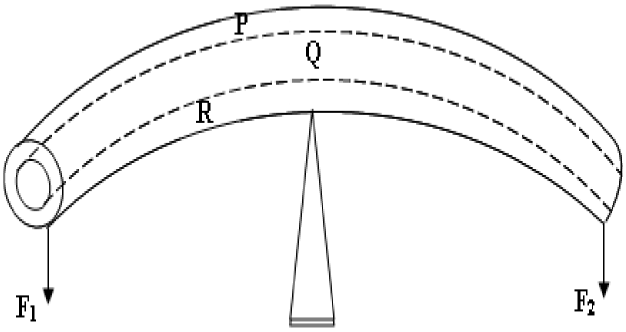
When CE is removed, the load moves down wards and part BCD will be straight due to the load. Thus, point C moves nearer to E meaning that girder CE is a strut. Similarly, girders BE and AB are struts.

Exercise:

1. Roofing structures and many bridges are made designed triangular sections to;
   (i) Minimize the material used
   (ii) Withstand compression forces
   (iii) Minimize tensile force under compression.

A. (ii) only B.(ii) and (iii) only.
C. (i) and (iii) only. D. (i) , (ii) and (iii)

2. The beam shown below is being acted upon by forces F_1 and F_2 as shown.



The regions **P**, **Q** and **R** are respectively,
A. tension, compression, neutral axis
B. neutral axis, compression, tension
C. tension, neutral axis, compression
D. compression, neutral axis, tension

3. A notch on a material spreads more rapidly when the material is;
A: reinforced B: in tension
C: pre stressed D: in compression

4. see UNEB

1993 Qn.10 and Qn. 26 1997 Qn.19 1989 Qn. 10 1994 Qn. 4 1996 Qn. 21 2006 Qn. 8	2007 Qn. 40 1987 Qn. 9 1990 Qn. 5 1994 Qn. 5 2002 Qn.47

1: 6. MACHINES

A machine is a device on which a force applied at one point, is used to overcome a force at another point.

A machine is a device, which simplifies works by magnifying the effort.

.

Principle of machines:

It states that a small force (effort) moves over a large distance to produce a bigger force that moves the load over a small distance.

Effort: Is the force applied at one point of a machine to overcome the load.

Load: Is the force, which is overcome by the machine using the effort.

Mechanical Advantage (M.A):

This is the ratio of load to effort.

i.e; $M.A = \frac{\text{Load}}{\text{Effort}}$

Note:-Mechanical advantage has no units.

-M.A is the number of times the load is greater than the effort. Alternatively, it gives the number of times the machine magnifies the effort.

Velocity ratio (V.R):

This is the ratio of the distance moved by the effort to the distance moved by the load.

i.e; $V.R = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$

Note: It is the ratio of the velocity of the effort to the velocity of the load in the same time.

It is independent of friction.

Efficiency (η):

This is the ratio of work output to the work input expressed as a percentage.

i.e; $\text{Efficiency } (\eta) = \frac{\text{Work output}}{\text{Work input}} \times 100\%$

$\text{Work out put} = \text{Load} \times \text{load distance}$

$\text{Work input} = \text{Effort} \times \text{Effort distance}$

$$\text{Efficiency} = \frac{\text{Load} \times \text{load distance}}{\text{Effort} \times \text{Effort distance}} \times 100\%$$

$$= \frac{\text{Load}}{\text{Effort}} \times \frac{\text{Load distance}}{\text{Effort distance}} \times 100\%$$

$$= M.A \times \frac{1}{V.R} \times 100\%$$

$$\textbf{Efficiency } (\eta) = \frac{\mathbf{M.A}}{\mathbf{V.R}} \times \mathbf{100}\%$$

NOTE:

The efficiency of a machine system is always less than 100% because of;

- Friction in the moving parts of the machine.
- Work wasted in lifting useless weights like movable parts of the machine.

The efficiency can be improved by;

- Oiling or greasing the movable parts.
- Using lightweight materials for movable parts.

SIMPLE MACHINES:

A simple machine is a device that work with one movement and change the size and direction of force.

Examples of simple machines:

1.Lever system 2.Wheel and Axle machine 3. Gear system 4. Pulley systems	5.Screws 6.Inclined Planes 7. Wedges

(a) LEVER SYSTEM:

A lever is a rigid bar, which is free to move about a fixed point called fulcrum or pivot.

It works on the principle of moments.

Classes of levers:

Class of lever	Position of F,E,L	Examples
1st	**F** is between E and L	Pair of scissors
2nd	**L** is between E and F	Wheel barrow
3rd	**E** is between F and L	Human arm

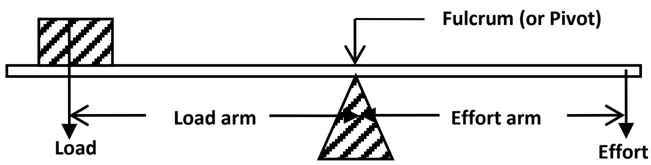
Class of lever	Examples
(i) First class lever: Is a lever system where the fulcrum (or pivot) is between the load and the effort.	• See-saw • Pair of scissors • Pair of pliers • Weighing scale • Claw Hummer
(ii) Second class lever: Is a lever system where the load is between the fulcrum (or pivot) and the effort.	• Wheel barrow • Nutcracker • Bottle opener
(iii) Third class lever: Is a lever system where the Effort is between the fulcrum (or pivot) and the load.	• Fishing rod • Pair of tongs • Human arm • Spade • Forceps

NOTE: -Load arm is the distance of the load from pivot.

-Effort arm is the distance of effort from pivot.

$-\mathbf{M.A} \approx \mathbf{V.R} \Rightarrow \frac{\textbf{Load}}{\textbf{Effort}} \approx \frac{\textbf{Effort arm}}{\textbf{Load arm}}$

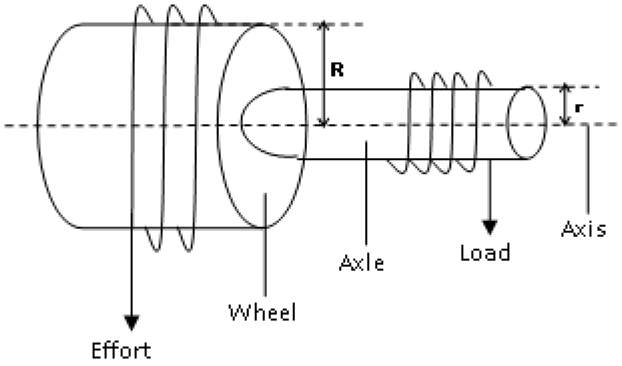
Hence, a lever system is more efficient compared to other machines.



(b) WHEEL AND AXLE MACHINE :

This consists of two wheels of different radii on the same axis. The axle has the same attachment on the wheel.

The effort is applied to the wheel and a string attached to the axle raises the load.



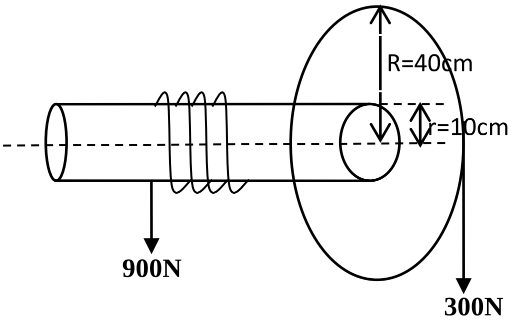
For a complete turn or rotation;

- The effort moves through a distance equal to the circumference of the wheel. $\mathbf{C = 2\pi R}$, R= radius of wheel.
- The load moves through a distance equal to the circumference of the axle. $\mathbf{C = 2\pi r}$, r= radius of axle.
- Thus, from; V.R = $\frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$

$$= \frac{2\pi R}{2\pi r}$$

$$\mathbf{V.R = \frac{R}{r}}$$

Example1:
The figure below shows a wheel land axle system, which uses an effort of 300N to raise a load of 900N using an axle of radius 10cm.



Calculate the; (i) velocity ratio
(ii) Efficiency of the system

Solution:

<table>
<tr><td colspan="2">R= 40cm, r =10cm; L= 900N, E=300N;
Thus, from; V.R = $\frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{2\pi R}{2\pi r}$</td></tr>
<tr><td>(i)
$V.R = \frac{R}{r} = \frac{40}{10} = 4$
Thus, the velocity ratio is 4.</td><td>(ii).
M.A = $\frac{\text{Load}}{\text{Effort}} = \frac{900}{300} = 3$
M.A = 3</td></tr>
<tr><td colspan="2">Efficiency (η) = $\frac{M.A}{V.R} \times 100\%$
$\eta = \frac{3}{4} \times 100\%$
η = 75%
Thus, efficiency is 75%</td></tr>
</table>

Example2:
A wheel and axle machine is constructed from a wheel of diameter 20cm and mounted on an axle of diameter 4cm.
(a) Calculate the;
 (i) Velocity ratio of the machine
 (ii) Greatest possible value of mechanical advantage.
(b) Explain why the mechanical advantage is likely to be less than this value.

Solution:
D =20cm⟹ R = 10cm, d = 4cm ⟹ r = 2cm
(a)(i)

$$V.R = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{2\pi R}{2\pi r}$$

$$= \frac{R}{r}$$

$$= \frac{10}{2}$$

V.R = 5.
Thus, the velocity ratio is 5.

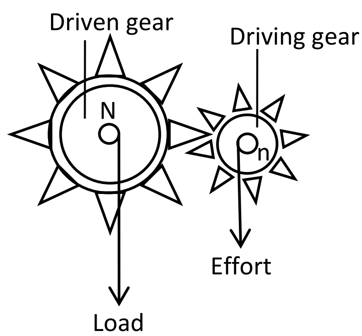
(a)(ii)
For the greatest (or maximum) mechanical advantage, the system is 100% efficient.
Hence M.A=V.R= 5

(b) The M.A is likely to be less than 5 because work needs to be done against friction

Example3:
A common windlass is used to raise a load of 480N by application of an effort 200N at right angles to the handle. If the crank is33cm from the axis and the radius of the axle is 11cm, calculate the;
(i) Velocity ratio. (Ans: V.R=3)
(ii) Efficiency of the windlass. (Ans: η =80%)

(c) GEAR SYSTEM:

A gear is device consisting of toothed wheels.
These are rigidly fixed to the axis and turn with their axis.



They change direction and speed of rotation when the effort applied is not changed.
The direction of the driven gear is opposite to that of the driving gear.
The number of rotations of the gear wheels depends on the ratio of number of teeth and the radii of the wheels.

The effort and the load are applied on the shafts connected to the gear wheels. A large V.R is obtained only when the effort is applied on a small gear so that it drives the large gear.

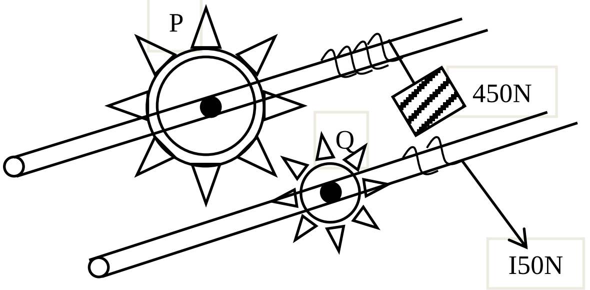
$$\text{V.R} = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driving gear}} = \frac{\mathbf{N}}{\mathbf{n}}$$

Example 1:
Two gearwheels A and B with 20 and 40 teeth respectively lock into each other. They are fastened on axles of equal diameters such that a weight of 400N attached to a string wound around one-axle, raises a load of 600N attached to a string wound around the other axle. Calculate the:
(a) Velocity ratio of the system when; (i) A drives B
(ii) B drives A
(b) Efficiency when; (i) A drives B
(ii) B drives A

Solution:
(a) N=40cm, n=20cm
L=600N, E=400N
(i)Thus, from; $\text{V.R} = \frac{\text{Number of teeth on driven gear}}{\text{Number of teeth on driving gear}} = \frac{\text{N}}{\text{n}}$

V.R $= \frac{N_B}{n_A}$ $= \frac{40}{20}$ V.R = 2. The velocity ratio is 2. (ii) V.R $= \frac{N_A}{n_B}$ $= \frac{20}{40}$ V.R = 0.5. The velocity ratio is 0.5.	(iii) M.A = $\frac{\text{Load}}{\text{Effort}} = \frac{600}{400} = 1.5$ V.R = 2. Efficiency (η) = $\frac{\text{M.A}}{\text{V.R}} \times 100\%$ $\eta = \frac{1.5}{2} \times 100\%$ η = 75% (ii) M.A=1.5 V.R =2 Efficiency (η) = $\frac{\text{M.A}}{\text{V.R}} \times 100\%$ $\eta = \frac{1.5}{0.5} \times 100\%$ η = 300%

Example 2:



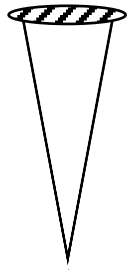
Two gear wheels P and Q with 80 and 20 teeth respectively, lock each other. They are fastened on axles of equal diameters such that a weight of 150 N attached to a string wound around one-axle raises a load of 450N attached to a string wound around the other axle. Calculate the;
(i) Velocity ratio of the gear system. (Ans: V.R=4)
(ii) Efficiency of the system. (Ans: η =75%)

Example: 3
Two gear wheels P and Q with 25 and 50teeth respectively lock into each other. They are fastened on axles of equal diameters such that a weight of 400N attached to the string wound around one axle raises a load of 600N attached to a string wound around the other axle. Calculate the:
(i) Velocity ratio and efficiency when Q drives P.
[Ans: V.R = 0.5, Efficiency = 300%]

(ii) Velocity ratio and efficiency when P drives Q.
[Ans: V.R = 2, Efficiency = 75%]

(d) SCREW MACHINE :

A screw is a nail or bolt with threadlike windings.
It is like a spiral stair case.
It is an essential feature of machines like the vice and the screw jack.



- The distance between any two successive threads of a screw is called a **Pitch.**
- An effort is applied on a handle like in a vice or in a car jack.
- For a complete turn (or rotation) of the effort, the load moves through a distance equal to 1pitch while the effort moves a distance equal to the circumference of the handle

.

$$\text{V.R}=\frac{\text{Distance moved by effort}}{\text{Distance moved by load}}=\frac{\text{circumference of handle}}{\text{1Pitch}}$$

$$\textbf{V.R} = \frac{2\pi l}{\textbf{1Pitch}}$$

Example 1:
In a screw jack, the length of the handle is 56cm and a pitch of 2.5mm. It is used to raise a load of 2000N. Calculate the;
(i) Effort required to raise the load. (Ans: E = 1.42N).
(ii) V.R (Ans: V.R = 1408).
(iii) Efficiency of the screw, hence explain the significance of your value of efficiency. (Ans: η =100%)

Example 2:
A load of 800N is raised using a screw jack whose lever arm is 49cm has a pitch of 2.5cm.If it is 40% efficient, Find the
(i) V.R
(ii) M.A

Example 3:
A certain screw machine has a pitch of 3.5mm. The effort is applied using a handle, which is 44cm long. Calculate its velocity ratio. (Ans: V.R = 3.95)

Example 4:
A screw jack with a lever arm of 56 cm, has threads which are 2.5mm apart is used to raise a load of 800N. If its 25% efficient, find the;

(i) Velocity ratio (Ans: V.R = 1408)
(ii) Mechanical advantage (Ans: M.A = 352)

Solution:

(a) Radius (lever arm), l = 56cm, Pitch of a screw $= \frac{2.5}{10} =$ 0.25cm

L = 800N.

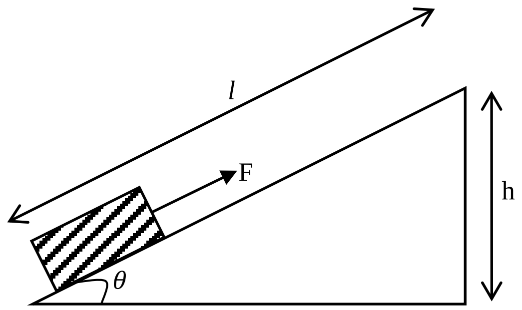
$$\text{V.R of a screw} = \frac{2\pi l}{1\text{Pitch}}$$

$$\text{V.R of a screw} = \frac{2 \times 3.14 \times 56}{0.25}$$

$= 1406.72$

(e) INCLINED PLANE

An inclined plane is a slope, which allows a load to be raised more gradually by using a smaller effort than when lifting vertically upwards.



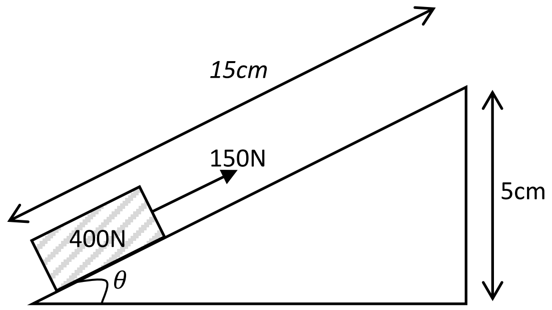
$$\text{V.R} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{\text{length of the plane}}{\text{height of the plane}}$$

$$= \frac{\mathbf{l}}{\mathbf{h}}$$

$$\text{OR: V.R} = \frac{\mathbf{1}}{\mathbf{\sin\theta}}$$

Example:

A load of 400N is pulled along an inclined plane as shown below.



Calculate the;

Solution:

(i) V.R (=3)

l=15cm, h=5cm

(i)Thus, from;

$$\text{V.R} = \frac{\text{length of the plane}}{\text{height of the plane}} = \frac{\boldsymbol{l}}{\boldsymbol{h}}$$

$$\text{V.R} = \frac{\boldsymbol{l}}{\boldsymbol{h}}$$

$$\text{V.R} = \frac{\mathbf{15}}{\mathbf{5}}$$

V.R = 3.

Thus, the velocity ratio is 3.

(iii) M.A(=5N)

L=400N, E=150N

$$\text{M.A} = \frac{\text{Load}}{\text{Effort}} = \frac{400}{150}$$

$= 2.67$

(iv) Efficiency

$$(\eta) = \frac{\text{M.A}}{\text{V.R}} \times 100\%$$

$$\eta = \frac{2.67}{3} \times 100\%$$

$\eta = 88.9\%$

(v) Work input

Work input = Effort × Effort distance

Work input = 150 × 15

= 2250J

(vi) Work out put

Work out put = Load × load distance

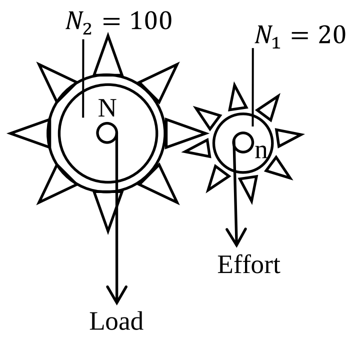
Work out put = 400 × 5

= 2000J

Practice Question:

1. A wooden plank, 3m long is used to raise a load of 1200N through a vertical height of 60cm. If the friction between the load and the plane is40N, calculate the:
   (i) effort required [Ans: E = 280N]
   (ii) Mechanical advantage [Ans: M.A = 4.29]

2. In the gear system in figure 3 below N_1 and N_2 are the number of teeth on the wheels. The efficiency of the gear system is 60%.



Find the;
   (i) Velocity Ratio.
   (ii) Load that can be raised by an effort of 200N.
   (iii) Explain why its preferred to use a longer ladder to a shorter ladder when climbing a tree.

(f) PULLEY SYSTEM:

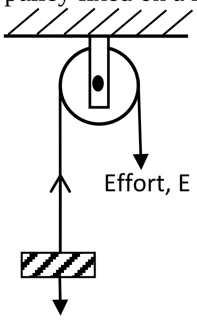
A pulley is a wheel with a grooved rim over which a string passes.

Types of pulleys.

(i) Single fixed pulley
(ii) Single movable pulley
(iii) Block and tackle pulley system

(i) **Single fixed pulley**

This is the type of pulley fixed on a rigid support.



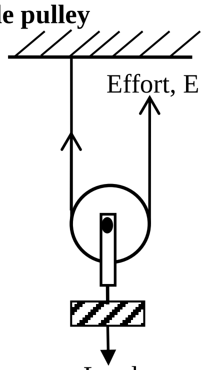
It is applied in:

- ❖ Raising a flag
- ❖ Lifting building materials during construction

Here, -load distance = effort distance
-tension is the same throughout the string.
-If no friction is considered, Load = Effort. Hence $\text{M.A} = \frac{\text{Load}}{\text{Effort}} = \frac{E}{E} = 1.$ (since $L = E$)

However, in practice the mechanical advantage and V.R of a single fixed pulley is less than **one**. Because of the following;
(i) Some energy is wasted in overcoming friction.
(ii) Some energy is wasted in lifting useless loads like threads.

(ii) Single movable pulley



Here, the effort distance is twice the load distance.
Here, -load distance = 2 x effort distance
-tension is the same throughout the string.
-If no friction is considered, Load = Effort. Hence $\text{M.A} = \frac{\text{Load}}{\text{Effort}} = \frac{2E}{E} = 2.$ (since $L = 2E$)

At balancing;
Sum of upward force = sum of downward forces
$L = E + E$
$\underline{L = 2E}$

$$\text{M.A} = \frac{\text{Load}}{\text{Effort}} = \frac{2E}{E} = 2. \text{ (since } L = 2E)$$

M.A and V.R of a single movable pulley is two
However, in practice, the M.A. of a single movable pulley is less than **two**. Because of the following reasons;
(i) Some energy is wasted in overcoming friction.
(ii) Some energy is wasted in lifting useless loads like threads.

A single movable pulley is more advantageous than a single fixed pulley. In that, for a single movable pulley the effort required to raise a load is less that the load.

(ii) Block and tackle pulley system

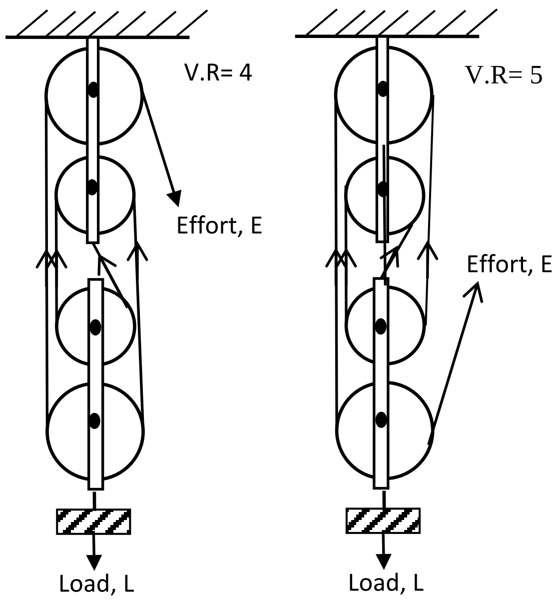
This is consists of two blocks each having one or more pulleys, combined together to form a machine. This is done in order to have high velocity ratio and a higher mechanical advantage.

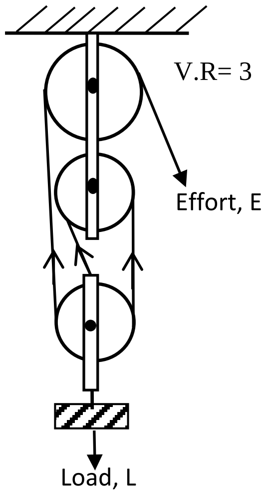
It is applied in:

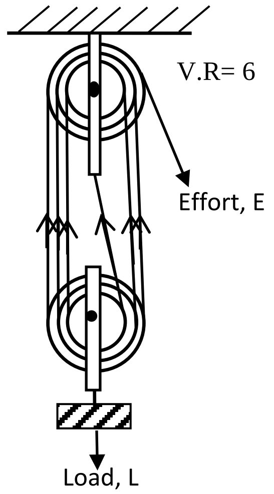
- ❖ Cranes
- ❖ Brake downs
- ❖ lifts

} For raising heavy loads

Note: (i) The number of portions of the string supporting the lower block is equal to the velocity ratio of the system.
(ii) The effort applied is equal to the tension in each string supporting the movable block.
E.g. If the effort is 6N, the tension in each string is also 6N.
(iii) For an odd number of pulleys in a system, the upper block contains one more pulley than the lower block. In addition, the string starts from the lower block.



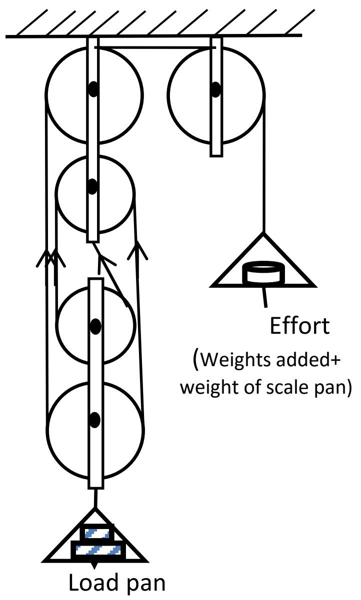




Passing the string

- ❖ If the number of pulley wheels is odd, then the string should be tied down to the movable block.
- ❖ For even number of pulley wheels, the string should be tied up to the fixed block.

Experiment to measure mechanical advantage and efficiency of pulley system.



Determining effort: A known load is place on the load pan and knows weights are added to effort pan until the load just rises steadily when given a gentle push.

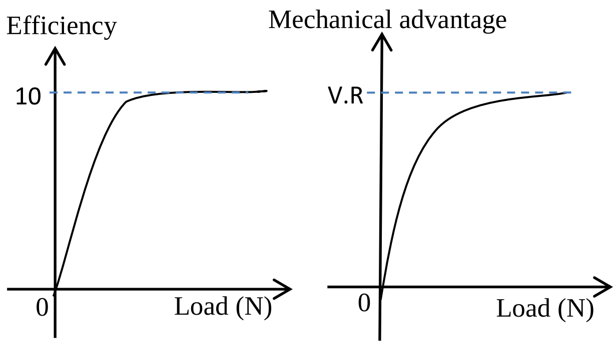
Repeating: The experiment is repeated with different loads and the results are recorded in table shown bellow:

V.R=……….

Load (N)	Effort (N)	$M.A=\frac{Load}{Effort}$	$Efficiency=\frac{M.A}{V.R}\times 100$
……….	……	………..	…………….

Drawing the graph:

From the table a graph of efficiency or mechanical advantage against the load is plotted.



Explanation of the shape of the graphs:

- ❖ As the load increases, the efficiency also increases
- ❖ This is because the weight of the movable pulley block and friction become very small compared to the load.

Note:

In practice, the movable block has some weight (w) and there is friction (F). These two together with the load (L) act downwards and they become part of the total downward forces.

Thus, the efficiency do not increase beyond 100% because;

i) some energy is wasted on overcoming friction

ii) Some energy is wasted on lifting useless loads like movable pulley blocks.

Therefore at Equilibrium**;**

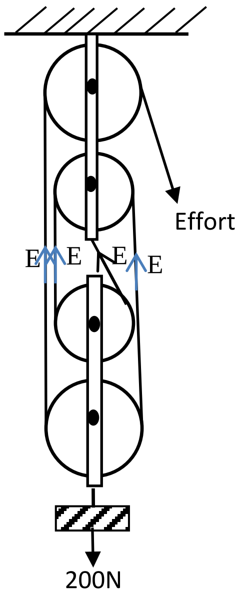
Sum of upward forces = sum of downward force

$$\begin{bmatrix}\textbf{Sum of tensions}\\ \textbf{suporting lower}\\ \textbf{block, (V.R) E}\end{bmatrix} = \textbf{Load(L)+Weight(W)+Friction(F)}$$

$$\textbf{V.R} = \textbf{L+W+F}$$

Example 1:

Below is a pulley system of mass 0.4kg, and there is friction of 5N



(a) Calculate the;

(i) Velocity ratio of the system

$V.R = \begin{pmatrix}\text{Number of portions of the string} \\ \text{suporting the movable block}\end{pmatrix}$

$V.R = 4$

(ii) Effort required to raise the load.

Solution

Data

L=200N, m =0.4Kg, F=5N, E=?,

W=mg = 0.4 x 10

W=4N

Sum of upward forces = sum of downward force

$E + E + E + E = L + W + F$

$4E = L + W + F$

$4E = 200 + 4 + 5$

$4E = 209$

$\frac{4E}{4} = \frac{209}{4}$

$E = 52.25N$

(iii) Mechanical advantage of the system

$M.A = \frac{\text{Load}}{\text{Effort}}$

$= \frac{200}{52.25}$

$M.A = 3.83$

(b) If the load is raised through 6m, calculate the distance the effort moves at the same time.

Example 2:

Data

L.D =6m, E.D =?

$V.R = \frac{\text{Effort distance}}{\text{Load distance}}$

$4 = \frac{E.D}{6}$

$E.D = 4 \times 6$

$E.D = 24m$

Example 2:

A pulley system has two pulleys on the bottom block. A load of 1000N is hung from the bottom block, it is found that an effort of 300N to raise the load.

(i) How much energy is supplied, if the effort moves through 5m?

Solution

Data

L=1000N, E=300N, E.D =5m

Work in put $= \text{Effort} \times \text{Effort distance}$

$= 300 \times 5$

$= 1500N$

(ii) If the effort moves through 5m, find how far the laod rises.

Solution

Data

E.D =5m, V.R=4, L.D=?

$V.R = \frac{\text{Effort distance}}{\text{Load distance}}$

$4 = \frac{5}{L.D} \Rightarrow 4L.D = 5 \Rightarrow L.D = \frac{5}{4} \Rightarrow \mathbf{L.D = 1.25m}$

(iii)Find how much energy is gained by the load if the effort moves through 5m.

Work out put $= \text{Load} \times \text{distance}$

$= 300\times5$

$= 1500N$

Example 2:

A pulley system of velocity ratio 3 is used to lift a load of 100N. The effort needed is found to be 60N.

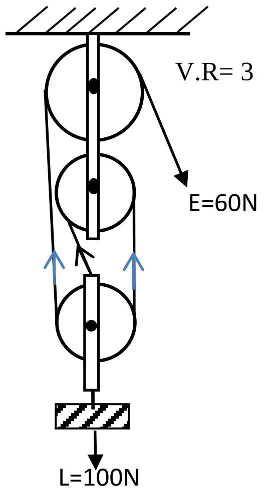
(a) Draw the arrangement of the pulley system.

Solution

Velocity ratio is odd. then;

Number of pulley wheels on each block $= \frac{\text{Velocity ratio}}{2} = \frac{3}{2} =$ 1 remainder 1.

The remainder wheel is added to fixed block.



(b) Calculate the efficiency of the system.

Solution

V.R =3 $M.A = \frac{\text{Load}}{\text{Effort}}$ $= \frac{100}{60}$ M.A= 1.67	Efficiency$= \frac{M.A}{V.R} \times 100\%$ Efficiency$= \frac{1.67}{3} \times 100\%$ Efficiency $= 55.56\%$

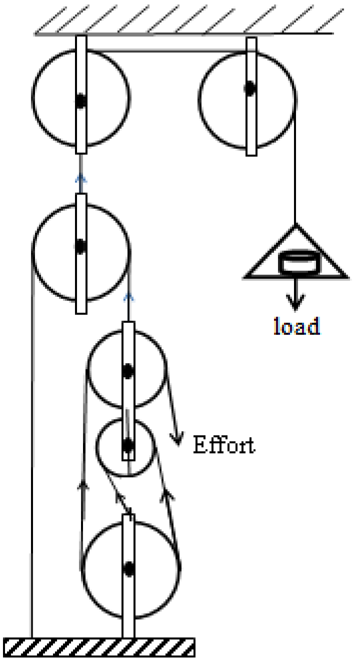
Coupled machines

If two or more machines are, coupled machines such that the output of one is connected to the input of the other, the over all performance is summed up by:

Overall -V.R $= V.R_1 + V.R_2$

-M.A. $= M.A_1 + M.A_2$

-Eff $= Eff_1 + Eff_2$



The diagram above shows a pulley system used by a sailor for hoisting. Calculate the:

(a) Velocity ratio of the system

Solution

Velocity ratio of lower block = 4
Velocity ratio of middle = 2
Velocity ratio of upper block = 1
Overall V.R = 4 + 2+ 1 = 7

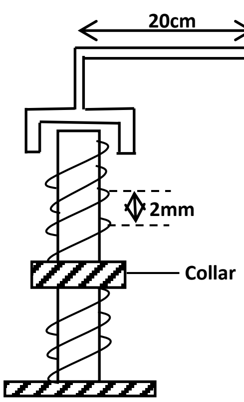
(b) The effort required to lift the load if the efficiency of the system is 75%.

Solution

Efficiency= $\frac{\text{M.A}}{\text{V.R}} \times 100\%$ 75%= $\frac{\text{M.A}}{7} \times 100\%$ 0.75= $\frac{\text{M.A}}{7}$ M.A =0.75×7 $\text{M. A} = 5.25$	Then from; M. A= $\frac{\text{Load}}{\text{Effort}}$ 5.25= $\frac{1500}{\text{E}}$ 5.25E= 1500 $\text{E} = 285.7\text{N}$

Example:

The diagram below shows a screw jack being used to lift a car in order that a wheel may be charged.



If the car bears down on the car with a force of 5000N and that efficiency of a screw jack is 15%. Calculate the;

a) V.R.

Given; $\text{Radius}, r = 2\text{cm} = \frac{2}{100} = 0.02\text{m}$

$\text{Pitch}, \text{P} = 2\text{mm} = \frac{2}{1000} = 0.002\text{m}$

Then; V.R= $\frac{\text{Effort Distance}}{\text{Load Distance}}$ V.R= $\frac{2\pi r}{Pitch}$ V.R= $\frac{2(3.14)(0.02)}{0.002}$ V.R=62.8 Mechanical Advantage Given;Efficiency=15% , V.R= 62.8 Then; Effi = $\frac{\text{M.A}}{\text{V.R}} \times 100\%$ 15%= $\frac{\text{M.A}}{62.8} \times 100\%$ $0.15 = \frac{\text{M.A}}{62.8}$ $\text{M. A} = 0.15(62.8)$ $\text{M. A} = 9.42$	(b)The effort required to turn the handle M.A= $\frac{\text{Load}}{\text{Effort}}$ 9.42 = $\frac{5000}{\text{E}}$ 9.42E =5000 $\frac{9.42\text{E}}{9.42} = \frac{5000}{9.42}$ E=530.79N (c)Work done by the operator in order to raise the side or the car by 25cm. $\text{Eff} = \frac{\text{Work output}}{\text{Work input}} \times 100\%$ Work output=Load × Load distance Work output=5000× $\left(\frac{25}{100}\right)$ Work output=1250J

NB: Work input is the work done by the effort. Sometimes it is considered as the work done by operator.

$$\text{Efficiency} = \frac{\text{Work output}}{\text{Work input}} \times 100\%$$

$$15\% = \frac{1250}{\text{W}_{\text{in}}} \times 100\%$$

$$0.15 = \frac{1250}{\text{W}_{\text{in}}}$$

$$0.15\text{W}_{\text{in}} = 1250$$

$$W_{in} = 8333.33\text{J}$$

In general;

Work wasted = work input - work output
= 8333.33 – 1250
= 7083.33J

From above, it is noted that work input is greater than workout put due to;

i) some work wasted in lifting useless loads,
ii) Some work wasted in reducing friction.

Note: For the screw the velocity ratio is very high because the length of the handle is very big compared to the pitch of the screw.

1: 8 PRESSURE

Pressure is the force acting normally per unit area of the surface.

i.e $\quad \textbf{Pressure} = \dfrac{\textbf{Force(N)}}{\textbf{Area}(\mathbf{m^2})}$

The S.I unit of pressure is a newton per square metre, ($\mathrm{N/m^2}$ or $\mathbf{Nm^{-2}}$) or a pascal(**Pa**).

A pascal is the pressure exerted when a force of **1N** acts normally on an area of $\mathbf{1\ m^2}$**.**

1:8:1. PRESSURE IN SOLIDS:

Pressure in solids depends on;

- Magnitude of force applied
- Cross sectional area in contact

Maximum and Minimum Pressure

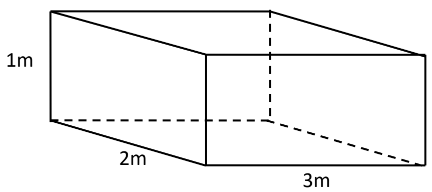
Pressure increases when the area decreases and decreases when the area increases.

Thus: $\text{Maximum Pressue} = \dfrac{\text{Force or weight}}{\text{Minimum Area}}$: i. e. $\mathbf{P_{max}} = \dfrac{\mathbf{F}}{\mathbf{A_{min}}}$

$\text{Minimum Pressue} = \dfrac{\text{Force or weight}}{\text{Maximum Area}}$: i. e. $\mathbf{P_{min}} = \dfrac{\mathbf{F}}{\mathbf{A_{max}}}$

Example 1:

The box below weighs 60N. Determine the maximum and minimum pressures it exerts on the ground.



Solution

Given:
-Dimensions**;** 1m x 2m x 3m
-Force, F=W = 60N
-Acceleration due to gravity, g = $10ms^{-2}$

$\text{Force}, F = \text{Weight}$

$F = 60N$

$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$

$A_{min} = (1 \times 2) = 2m^2$

Then: $P_{max} = \dfrac{F}{A_{min}} = \dfrac{60}{2} = 30\ Nm^{-2}$ or 30 Pa

$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length)}\end{pmatrix}$

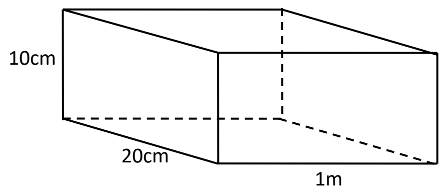
$A_{max} = (3 \times 2) = 6m^2$

$P_{min} = \dfrac{F}{A_{max}} = \dfrac{60}{6} = 10\ Nm^{-2}$ or 10 Pa

Example 2:

A box of dimensions 20cm by 1m by10cm weighs 30kg. Determine the maximum and minimum pressures exerted by the box on the ground.

Given: -Dimensions**;** cm x 10cm x 20cm
-Mass, m = 30kg
-Acceleration due to gravity, g = $10ms^{-2}$



Given:
-Dimensions**;** 1m x 2m x 3m
-Mass, m = 30kg
-Acceleration due to gravity, g = $10ms^{-2}$

$\text{Force}, F = \text{Weight}$
$= mg$
$F = 30 \times 10$
$F = 300N$

$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$

$A_{min} = \left(\dfrac{10}{100} \times \dfrac{20}{100}\right) = 0.02m^2$

Then: $P_{max} = \dfrac{F}{A_{min}} = \dfrac{300}{0.02} = 15000\ Nm^{-2}$ or 15000 Pa

$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length}\end{pmatrix}$

$A_{max} = \left(1 \times \dfrac{20}{100}\right) = 0.2m^2$

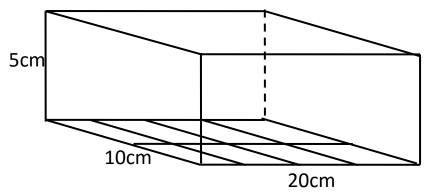
$P_{min} = \dfrac{F}{A_{max}} = \dfrac{300}{0.2} = 1500\ Nm^{-2}$ or 1500 Pa

Example 3:

The dimension of a cuboid are 5cm x 10cm x 20cm and the mass of the cuboid is 6kg. Calculate the maximum and minimum pressures the cuboid exerts on the ground.

Solution

Given: - Dimensions**;** 5cm x 10cm x 20cm
-Mass, m = 6kg
-Acceleration due to gravity, g = $10ms^{-2}$



Then: $P_{max} = \dfrac{F}{A_{min}}$

$\text{Force}, F = \text{Weight}$
$F = mg$
$F = 6(10)$
$F = 60N$

$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$

$$A_{min} = \left(\frac{5}{100} \times \frac{10}{100}\right) = \frac{1}{200}\text{ m}^2 = 0.005\text{ m}^2$$

$$P_{max} = \frac{F}{A_{min}} = \frac{60}{0.005} = 12000\text{ Nm}^{-2}\text{ or }12000\text{ Pa}$$

$$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length}\end{pmatrix}$$

$$A_{max} = \left(\frac{20}{100} \times \frac{10}{100}\right) = \frac{1}{50}\text{ m}^2 = 0.02\text{ m}^2$$

$$P_{min} = \frac{F}{A_{max}} = \frac{60}{0.02} = 3000\text{Nm}^{-2}\text{ or }3000\text{ Pa}$$

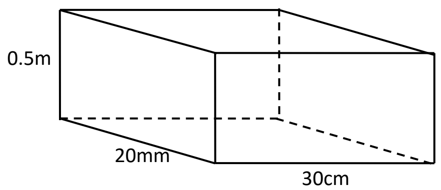
Example 4:

The tank below has a mass of 2.5kg. Determine the minimum and maximum pressure exerted by the tank on the ground; When it is;

(i) empty

(ii) filled with water up to the brim.

(iii) half filled with water. (Density of water =1000kgm^{-3})



Solution

(i) When empty

Given: - Dimensions**;** 5cm x 10cm x 20cm

-Mass, m = 2.5kg

-Acceleration due to gravity, g = 10ms^{-2}

$$\text{Force, }F = \text{Weight}$$
$$F = mg$$
$$F = 2.5 \times 10$$
$$F = 25N$$

$$\begin{pmatrix}\text{Smallest}\\ \text{Area}\end{pmatrix} = \begin{pmatrix}\text{Smallest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next smaller}\\ \text{length}\end{pmatrix}$$

$$A_{min} = \left(\frac{20}{1000} \times \frac{30}{100}\right) = 0.006\text{m}^2$$

$$P_{max} = \frac{F}{A_{min}} = \frac{25}{0.006} = 4166.67\text{Nm}^{-2}\text{ or }4166.67\text{ Pa}$$

$$\text{Largest Area} = \begin{pmatrix}\text{Longest}\\ \text{length}\end{pmatrix} \times \begin{pmatrix}\text{Next longer}\\ \text{length}\end{pmatrix}$$

$$A_{max} = \left(0.5 \times \frac{30}{100}\right) = 0.15\text{m}^2$$

$$P_{min} = \frac{F}{A_{max}} = \frac{25}{0.15} = 166.67\text{Nm}^{-2}\text{ or }166.67\text{ Pa}$$

(ii) When filled with water to the brim

$$\text{Force, }F = (\text{Weight ofempty tank}) + (\text{weight of water})$$
$$F = m_t g + m_w g$$
$$F = m_t g + V_w \rho_w g$$

Where Volume of water, $V_w = l \times w \times h$

$$V_w = \frac{30}{100} \times \frac{20}{1000} \times 0.5$$
$$V_w = 0.003\text{m}^{-3}$$

$$F = 2.5 \times 10 + (0.003) \times (1000) \times 10$$
$$F = 25 + 30$$
$$F = 50N$$

$$P_{max} = \frac{50}{0.006} = \frac{50}{0.006} = 8333.33\text{Nm}^{-2}\text{ or }8333.33\text{ Pa}$$

$$P_{min} = \frac{50}{0.15} = 333.33\text{ Nm}^{-2}\text{ or }333.33\text{Pa}$$

(iii) When half filled with water.

$$\text{Force, }F = (\text{Weight ofempty tank}) + (\text{weight of water})$$
$$F = m_t g + m_w g$$
$$F = m_t g + V_w \rho_w g$$

Where Volume of water, $V_w = l \times w \times h$

$$V_w = \frac{30}{100} \times \frac{20}{1000} \times 0.25$$
$$V_w = 0.0015\text{m}^{-3}$$

Then, $F = 2.5 \times 10 + (0.0015) \times (1000) \times 10$

$$F = 25 + 15$$
$$F = 40N$$

$$P_{max} = \frac{40}{0.006} = 666.67\text{Nm}^{-2}\text{ or }666.67\text{Pa}$$

$$P_{min} = \frac{40}{0.15} = 266.67\text{Nm}^{-2}\text{ or }266.67\text{Pa}$$

Note: when calculating pressure, the unit of area of base should always be in m^2. From the above calculations it is noted that: the greater the area over which the force acts normally the less is the pressure.

- ❖ A tractor with wide wheels can pass over soft ground because the greater area of wide wheel exerts less pressure.
- ❖ A hippopotamus of wide feet is able to walk on soft grounds without sinking because the greater area of wide hooves exerts less pressure.
- ❖ When the same force is applied on a needle and nails both placed on the hand, one tends to feel more pain from the needle because the small area of needle exerts greater pressure.
- ❖ A sharp knife cuts well than a blunt one.

Exercise:

1. Explain the following observations;

(i) A large reservoir is much wider at the base than at the top

(ii) In supply of water, smaller pipes are preferred to larger ones.

2. A rectangular block of metal weighs 5 N and measures 2 cm × 3 cm × 4 cm. What is the least pressure which it can exert on a horizontal surface?

A. 2.10 × 10^{-7} Pa   B. 4.17 × 10^{-5} Pa

C. 6.25 × 10^{-5} Pa   D. 8.30 × 10^{-5} Pa

3. See UNEB

1994. Qn.25	1991. Qn.5
2003. Qn.10	1995. Qn.15

1999. Qn.33	1996. Qn.39
1988. Qn.13	2002. Qn9

1: 8 :2. PRESSURE IN FLUIDS:

ATMOSPHERIC PRESSURE

The layer of air surrounding the earth is called the atmosphere.

Atmospheric pressure is the pressure exerted by the weight of air on all objects on the earth's surface.

Atmospheric Pressure depends on altitude.

The density of air above the earth decreases as the altitude increases leading to the decrease of atmospheric pressure at high altitude and the vice versa. At sea level, the atmospheric pressure is 1.0×10^5Pa.

Though the value of atmospheric pressure is large we do not normally feel it because:

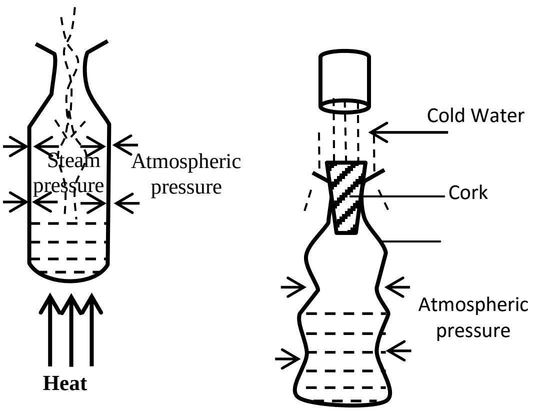
-Blood pressure is slightly greater than atmospheric pressure

-Atmospheric pressure acts equally in all direction.

Experiments to Demonstrate Existence of Atmospheric Pressure.

a) Collapsing Can or Crushing Can Experiment.

If air is removed from the can by a vacuum pump, the can collapses because the air pressure inside becomes less than the atmospheric pressure.



- A small quantity of water is boiled in a can until steam forms.
- The steam drives out all the air inside the can, hence reducing the pressure inside the can.
- The stopper is then tightly fitted onto the can and the heat source removed.
- Cold water is then poured over the can. This causes the steam inside to condense producing water and water vapour at very low pressure.
- The excess atmospheric pressure outside the can causes it to collapse inwards.

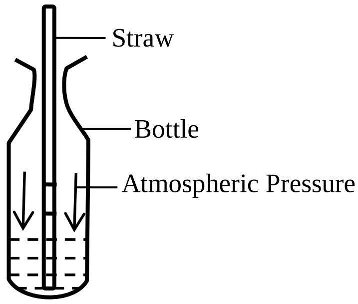
Importance of atmospheric pressure

a) Drinking straw

When sucking, lungs expand and air is driven out from the inside of the straw to the lungs.

This reduces the pressure inside the straw.

Then atmospheric pressure acting on surface of the liquid in the bottle is greater than air pressure in straw and so it forces the liquid up to the mouth.



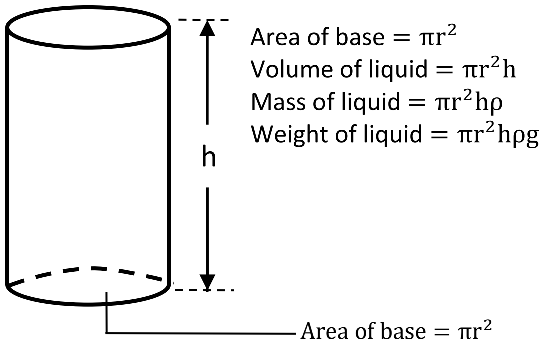
b) Rubber sucker

When the sucker is moistened and pressed on a smooth flat surface, the air is pushed out. Atmospheric pressure then holds it firmly against the surface.

Suckers are used for attaching car licenses to windscreen and in industry for lifting metal sheets.

Defining pressure in fluids

Fluids refer to gas or liquids. These take up the shape of the container, so the volume of the liquid filling a cylindrical container is equal to the volume of that cylindrical container.



Then from the definition of pressure:

$$\text{Pressure} = \frac{\text{Force(N)}}{\text{Area(m}^2)} = \frac{(\pi r^2)h\rho g}{(\pi r^2)} = h\rho g$$

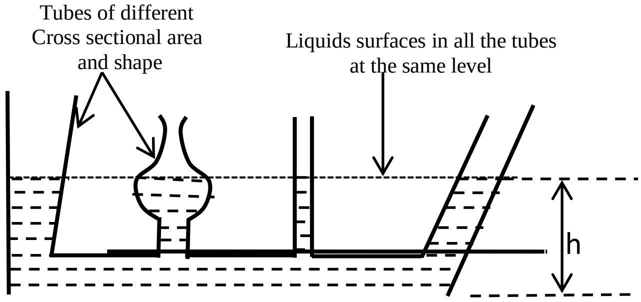
$$\textbf{Pressure} = \mathbf{h\rho g}$$

Properties of fluids related to pressure

(i) A liquid finds its own level:

Pressure in liquids does not depend on cross sectional area and shape of vessel containing the liquid.

This can be illustrated by an experiment using a communicating tube as shown below.



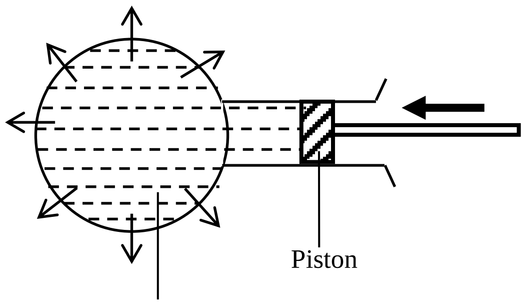
A liquid is poured into the communicating tubes of different cross-sectional areas.

The liquid is found to stand at the same level in each tube. This shows that pressure at same level is the same.
This is because the same atmospheric pressure acts on the surface of water in each tube.

(ii) Pressure at a given depth acts equally in all directions:

Pascal`s principle of transmission of pressure in fluids
It states that pressure in an enclosed fluid is equally transmitted through out the fluid in all directions.
Pascal`s principle works because liquids are incompressible. That is to say, their volumes can`t be reduced by squeezing.

An experiment to verify Pascal`s principle.

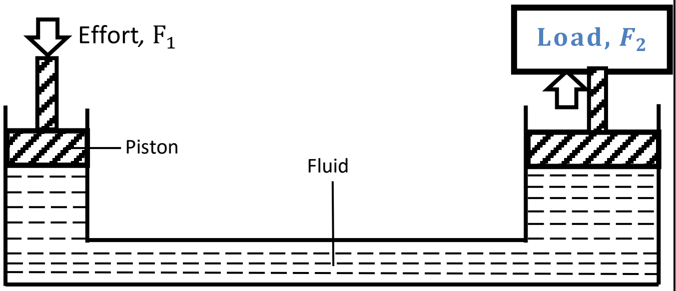


Holes of equal size are drilled in a round bottomed flask and covered with cork.
The flask is then filled with water and the piston pushed inside the flask.
Water shoots out equally in all directions, and travels equal distances. This verifies Pascal`s principle.

Hydraulic machines
Pascal's principle states that: When a force exerted on a liquid, pressure is produced which is transmitted equally throughout the liquid.

The above principle is applied in hydraulic press, hydraulic brakes and hydraulic jacks. Liquids are almost uncompressible so they can pass on any pressure applied to them.
In hydraulic press a small force is applied to a small piston in order to raise, large force (load) placed on large piston.

(a) Hydraulic press
It consists of two interconnected cylinders of different diameters enclosed by means of pistons which fit tightly in the cylinders.
A high-density liquid like oil is used to fill the system.
Effort applied on the smaller piston can be used to overcome a larger load on the bigger piston.
When a force (effort) is acting on the smaller piston, exerts pressure on the liquid. According to Pascal's principle, the pressure will be transmitted equally to every point of the liquid since the system is enclosed by the cylindrical pistons.
The same pressure then acts on the bigger piston, where it overcomes a bigger force (heavy load) because of the large area of the piston.



Thus assuming a hydraulic press, which is 100% efficient, then,

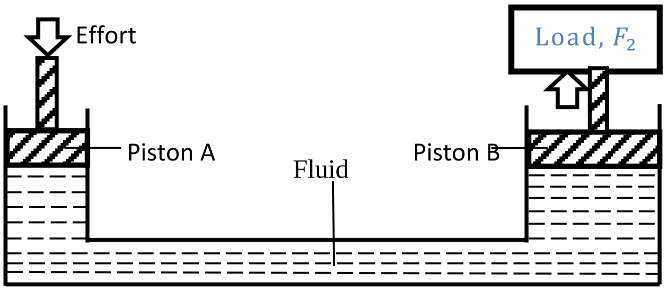
$$\frac{\textbf{Effort}}{\textbf{Load}} = \frac{\textbf{Area of smaller piston}}{\textbf{Area of bigger piston}}$$

$$\frac{F_1}{F_2} = \frac{A_1}{A_2}$$

$$\frac{F_1}{F_2} = \frac{\pi r^2}{\pi R^2} \Rightarrow \frac{F_1}{F_2} = \frac{r^2}{R^2}$$

Where **r** and **R** are the radius of the smaller and bigger pistons respectively.

Example 1:
A hydraulic press is made of two cylinders of cross-section areas $20cm^2$ and $120cm^2$ respectively fitted tightly with pistons A and B. A force of 10N applied on A is used to raise a load on piston B. Calculate the maximum possible force that can be raised on piston B.
Solution:
;Then from $\frac{F_1}{F_2} = \frac{A_1}{A_2}$



$$\frac{10}{F_2} = \frac{20}{120}$$

20F=1200
F= 60N

2: A hydraulic press requires an effort of 100N acting on a piston of area $20cm^2$ to press a bale of cotton placed on a piston of area $240cm^2$. If the percentage efficiency of the press is 80%, calculate the force applied on the bale.

Solution:

Then from; $\frac{F_1}{F_2} = \frac{A_1}{A_2}$

$$\frac{100}{F_2} = \left(\frac{80}{100} \times \frac{20}{240}\right)$$

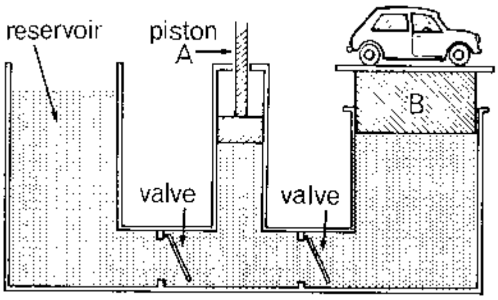
$$\frac{100}{F_2} = \left(\frac{16}{240}\right)$$

$16F_2=24000$

$F_2= 1500N$

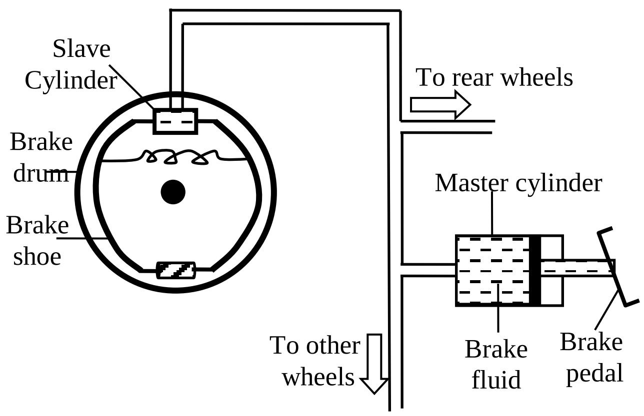
Advantage
A small force applied on small piston can overcome a large place load placed on a large piston.

Hydraulic lift



This is commonly used in garages; it lifts cars so that repairs and service on them can be done easily underneath the car.
A force applied to the small piston, raises the large piston, which lifts the car. One valve allows the liquid to pass from The small cylinder to the wider one, a second valve allows more liquid (usually oil) to pass from oil reservoir on the left to the small cylinder. When one valve is open, the other must be shut.

(b) **Hydraulic brake:**



When the brake pedal is placed, the pressure exerted inside the master cylinder is transmitted equally to all the slave cylinders.

At the slave cylinder, the pressure acts on the pistons which are connected to the brake shoes (pads).

This presses the brake shoes against the brake drum (disc) hence creating friction, which opposes the rotation drum and therefore the wheel. This results in the stopping of the car.

Exercise:

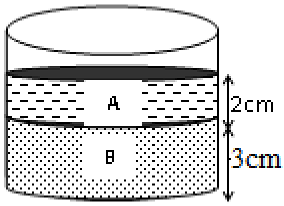
1. A hydraulic press machine is used to raise a load W placed on a piston of cross-sectional area of $100cm^2$ by using an effort of 20N at a piston of cross-sectional area of $2cm^2$.
Calculate the;
(i) Pressure transmitted through out the liquid [P=100000Pa]
(ii) Load, W. [W=1000N]

2. A force of 100N is applied on a small piston of area $0.002m^2$. Find the maximum load that can be lifted by a piston of area $0.8m^2$.

3. Calculate the pressure at the bottom of a swimming pool 1000cm deep.{density of water = $1000kgm^{-3}$}

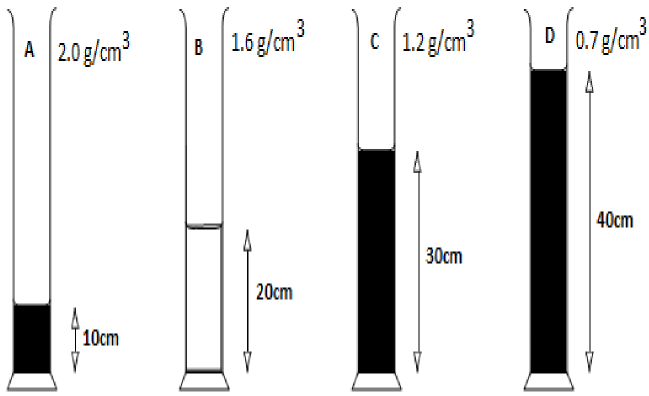
4. A diver dives to a depth of 20m below the surface of sea water of density $1200kgm^{-3}$. Calculate the pressure Experienced.

5. The tank below contains mercury and water. Find the total pressure experienced at the bottom.
{Density of mercury = $13600kgcm^{-3}$, Density of water = $1000kgm^{-3}$}



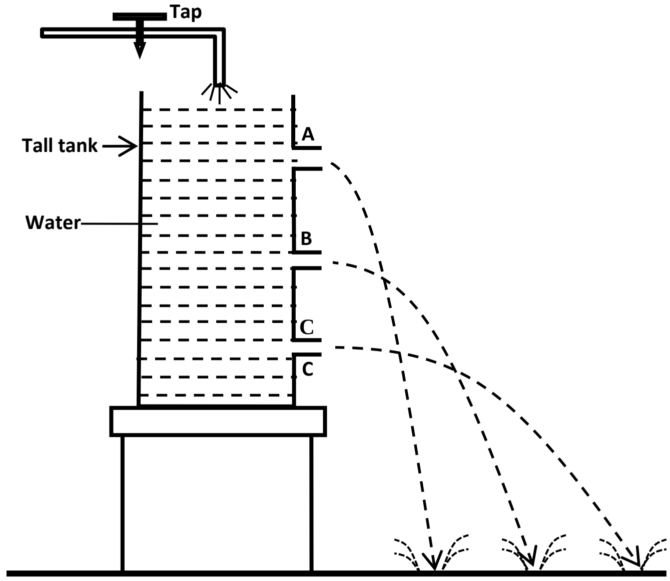
6. (a) (i) Define Pressure and state its S.I unit.
(ii) Describe how a hydraulic car Brake system works.
(b) A hydraulic press has cylindrical pistons of radii 2cm and 0.4m respectively. Calculate the maximum Load at that can be overcome by a force of 78N.

7. Four different liquids are poured into identical measuring cylinders. The diagrams show the depths of the liquids and their densities. Which liquid causes the largest pressure on the base of its measuring cylinder?



Factors affecting pressure in fluids
Generally, pressure at any point in a liquid is the same in all direction and depends on the following factors:
i) Depth "h" below the surface of the liquid
ii) Density **ρ** of the liquid
iii) Pressure exerted on the surface of the liquid.

Experiment to* show *that pressure increases with depth.

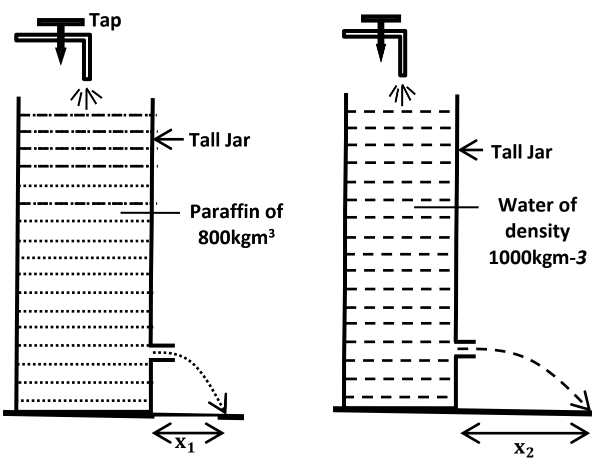


Procedures:
Equally, spaced holes A, B and C of the same size are drilled at different depths along one vertical side of a cylindrical can.
The holes are then closed using corks.
Water is then poured into the can to full capacity.
The corks are then removed at the same time and the distance from the can to where water fom each hole lands noted.

Observation:
Water comes out fastest and lands furthest from the lowest hole C followed by B and then least from A.
This means that pressure is highest at C, which is deepest. Hence, pressure in liquids increases with depth.

Water supply system:
Water supply often comes from reservoirs at a higher ground level. In a very tall building, it is necessary to pump water to a large tank in the roof.
All the above are done because the lower the place supplied the greater the water pressure at it.

Experiment to show that pressure depends on density



Two tall jars of the same size and height, each with a hole punched at equal depth are used.

The jars are then filled to the same height, with liquids of different densities e.g paraffin and water.

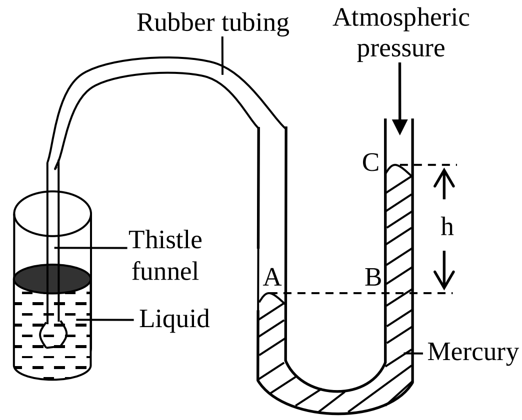
The distance to which the liquids jet out is observed and compared.

It is observed that water jets furthest compared to paraffin i.e; $x_2 > x_1$.Thus the higher pressure is exerted by water than paraffin at the same depth.
Therefore, the higher the density, the higher the pressure.

MEASURING FLUID PRESSURE

(a) Using a manometer

(i) Measurement of Liquid pressure

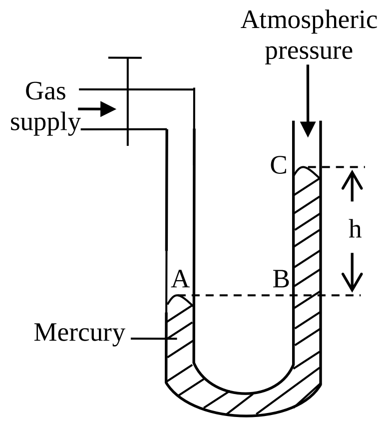


One arm of the manometer is connected to a thistle funnel whose base is covered with a thin membrane and the other end remains open to the atmosphere.

The difference in the liquid surface levels, h gives the pressure at point A and it is called the gauge pressure or absolute pressure.

$$\textbf{Absolute pressure} = H + h\rho g$$

(ii) Measurement of Gas pressure



-Connect a manometer to a gas supply as shown above
-Turn on the gas.
-The gas exerts a pressure at a point A. This causes the liquid to rise in the opposite arm until the pressure in both arms is the same.

-The gas pressure in one arm (limb) is equal to the pressure in the opposite limb.

Pressure at A = Pressure at B

$$\text{Pressure at A} = \begin{pmatrix}\text{Atmospheric}\\ \text{pressure}\end{pmatrix} + \begin{pmatrix}\text{pressure due}\\ \text{to mercury column}\end{pmatrix}$$

$$\textbf{Gas pressure} = \quad \mathbf{H} \quad + \quad \mathbf{h\rho g}$$

(b) Using a bourdon gauge

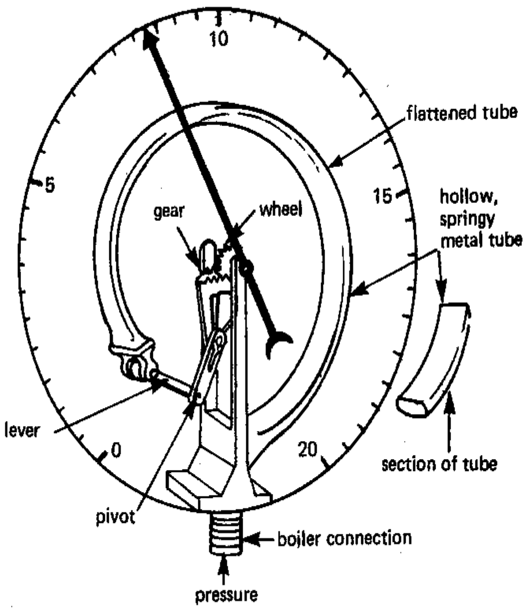
This gauge measures the very high pressures of liquids or gases, e.g. the pressure of steam in boilers.

It is a hollow curved tube of springy metal closed at one end. The tube straightens slightly when pressure acts on the inside.

The closed end of the tube is joined to a series of levers and gear wheels which magnify the slight movement.

A pointer moving over a scale (usually graduated in 10^5 pa, which is about 1 atmosphere pressure) records

Then, the recorded pressure is the excess pressure of liquid or gas over atmospheric pressure, but some gauges can record the actual pressure.

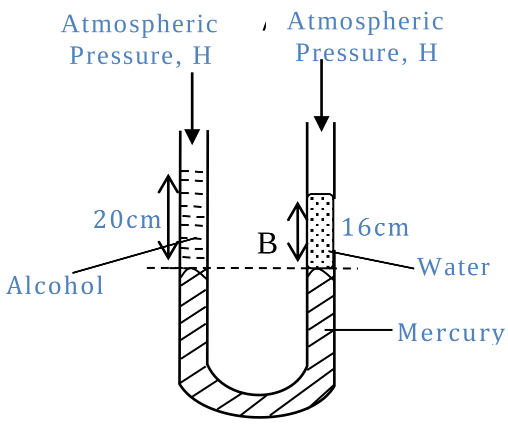


Bourdon gauges are commonly used at filling stations.

Example:1

Mercury was poured in a U- tube such that it finds its own level. When a column of 20cm of alcohol was poured on one side of the tube, it was necessary to pour 16cm of water on the other side to maintain equal mercury levels on both sides as shown below. Find the density of alcohol.

Solution



From; $P = h\rho g$,

$$h_a\rho_a g = h_w\rho_w g$$

$$\rho_a(20)(10) = 1000 \times 16 \times 10$$

$$\rho_a = 800\text{kgm}^{-3}$$

Expressing cmHg or mmHg pressure in Nm^{-2} or Pa

This is done by applying of formula **pressure = hρg** where **h** is the liquid column which should be in meters, **ρ** is the density of the liquid and it should be in kgm^{-3} and g is the acceleration due to gravity ($\boldsymbol{g = 10ms^{-2}}$).

Example 1

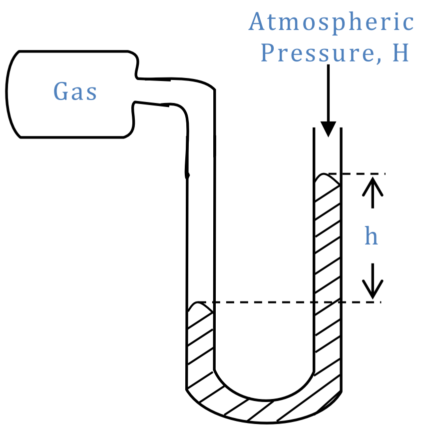
Express a pressure of 75cmHg given that the density of mercury (Hg) is 13600kgm^{-3}.

Solution

Given:	Then from,
h =75cm, $= \frac{75}{100}$m $= 0.75$m. ρ =13600Kgm^{-3} $g = 10\text{ms}^{-2}$	Pressure = hρg Pressure = (0.75) × (13600) ×10 =102000Pa Thus, 75cmHg =102000Pa.

Example 2

The manometer contains mercury so the atmospheric pressure is 76cm Hg. Calculate the gas pressure in cm Hg and Nm^{-2}.



Gas pressure $= H_{atm} + h$ Gas pressure $= 76 + 54.4$ $= 130.4\text{cmHg}$	Expressing in Nm^{-2} Gas pressure $= (H_{atm} + h)\rho g$ $= \left(\frac{130.4}{100}\right) \times 13600 \times 10$ $= 177344\text{Nm}^{-2}$

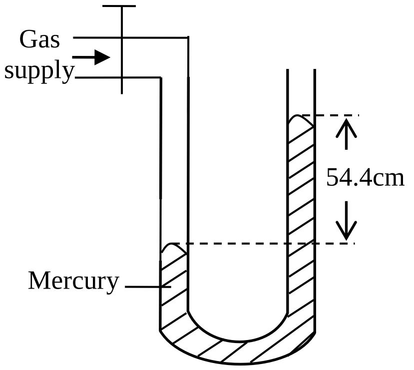
Exercise:

1. In an experiment to compare density of two liquids, water and spirit were used. The height of water was found to be 8cm and that of spirit was 12cm. Given that the density of water is **1000kgm^{-3}**. Find the density of the spirit. [Ans: **666.67kgm^{-3}]**

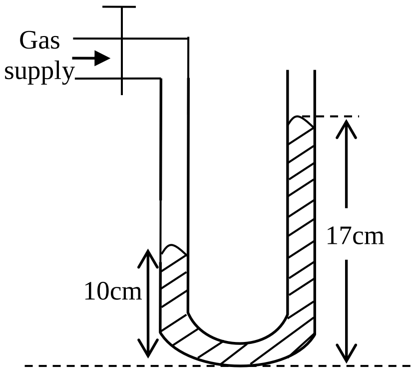
2. The manometer tubes below contain mercury and connected to a gas supply. Find the gas pressure.

[Atmospheric pressure =103360Pa].

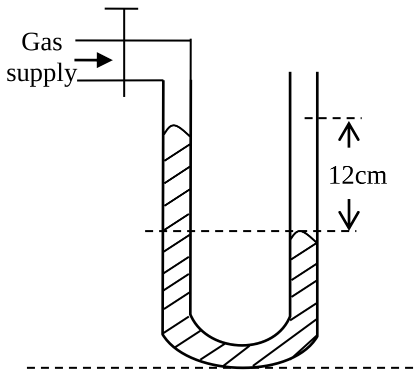
(a) [Ans:177344Pa]



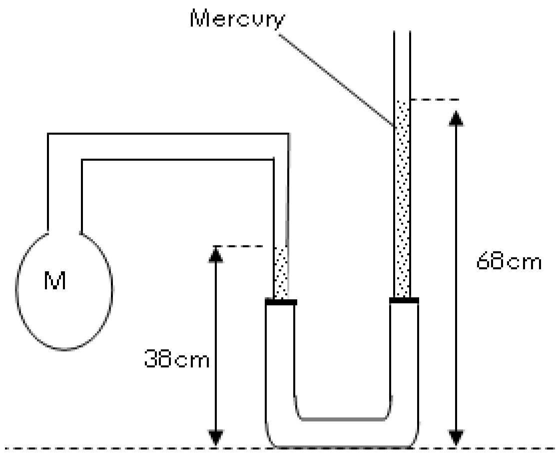
(b) [Ans:109620Pa]



(c)



5. In the figure below, a fixed mass of dry gas is trapped in bulb M.



Determine the total pressure of the gas in M, given that the atmospheric pressure is 760mm of mercury.

A) 114cm Hg B) 106cm Hg
C) 30cm Hg D) 46cm Hg

A simple barometer of mercury

A barometer is a manometer which measures atmospheric pressure.

<u>Describing how a simple mercury barometer is made in the laboratory.</u>

The description involves the following the following points:-

❖ Filling a 1m long thick walled tube

A 1 m long thick walled tube is filled with mercury

❖ Inverting the filled tube

The above filled is inverted several time with finger over the open end. This is done in order for the large air bubble to run up and down collecting any air small air bubble in mercury.

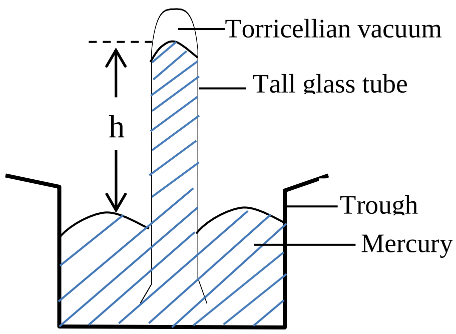
❖ Refilling the tube

After inverting several times, the tube is refilled with mercury.

❖ Inverting the filled tube into a bowl.

With a finger on the open end, the filled tube is inverted into a bowl of mercury.

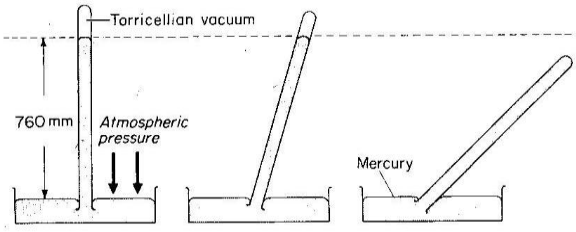
When the finger is removed, the mercury column falls until it is equal to atmospheric pressure.



From the above apparatus, when the air above the mercury in the bottle is pumped out, the column falls.

Testing the vacuum
If the vacuum is faulty and contains air or water-vapour, the barometer reads than the true atmospheric pressure.

Testing for the vacuum of a mercury barometer.
This is done by tilting the tube until at a position when mercury was a vacuum.



When the tube is tilted as in the diagram, the vertical height of column "h" of mercury remains the same but the length of mercury increases.

When a mercury barometer is taken from sea level to the top of a mountain i.e. low altitude to high altitude, the mercury column falls.

This is because the atmospheric pressure decreases at the top of the mountain. The decrease in atmospheric pressure is due to density of air decreasing because air is less compressed above. Deep-sea divers must return slowly to the surface because the sudden decrease in pressure when they return fast from deep water is very painful

Pilots operating at great heights must have protective headgear to prevent nose bleeding because atmospheric pressure at great height is much smaller tan blood pressure.

Calculating the height of the reading of the mercury barometer at high altitude:

This is calculated from;
Pressure change for air=Pressure change for mercury

$$\mathbf{h_a\rho_a g = (H_{a4m} - h_m\rho_m g)}$$

$$\mathbf{h_a\rho_a g = (H_{atm} - h_m)\rho_m g}$$

Where: $\mathbf{h_a}$ is the height of altitude, $\boldsymbol{\rho_a}$ is the density of air, $\mathbf{h_m}$ is the mercury column barometer at that altitude and $\mathbf{H_{atm}}$ is atmospheric pressure before rising.

Example; 1
A barometer is taken to the top of a mountain 440cm high. If the atmospheric pressure is 76cm Hg at sea level, the average density of air = 1.2Kg/m³ and mercury is 13600Kg/m³. Calculate the barometer reading.

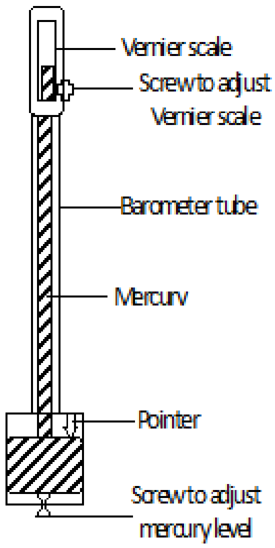
Solution:

$P_{atm} = 76cm = \frac{76}{100} = 0.76mHg$ $\rho_{mer} = 13600kgm^{-3}$ $\rho_{air} = 1.2kgm^{-3}$ $h_{Hg} = ?$ $h_{air} = 440m$	$\begin{pmatrix}\text{Pressure change}\\ \text{for air}\end{pmatrix} = \begin{pmatrix}\text{Pressure change}\\ \text{for mercury}\end{pmatrix}$ $h_a\rho_a g = (H_{atm} - h_m)\rho_m g$ $h_a\rho_a = (H_{atm} - h_m)\rho_m$ $440 \times 1.2 = (0.76 - h) \times 13600$ $528 = 13600 \times (0.76 - h)$
	$\frac{528}{13600} = 0.76 - h$ $h = 0.7212m$

Exercise:
1. The pressure difference between the top and the bottom of a mountain is $1.0 \times 10^4 Nm^{-2}$. If the density of air is $1.25kgm^{-3}$. Find the height of the mountain. [Ans: 800m]

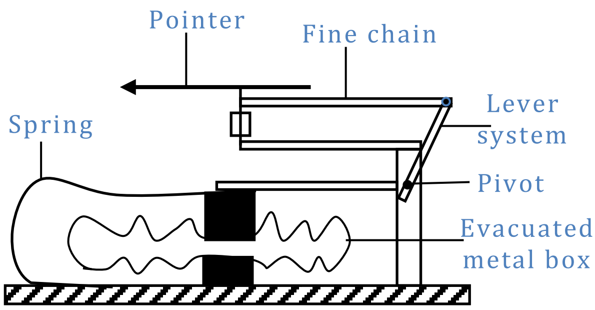
2. A barometer reads 780mmHg at the foot of the mountain which is 450m high. What is the barometer reading at the top of the mountain.(Density of air is $1.25kgm^{-3}$ and that of mercury is $13600kgm^{-3}$). [Ans: 738.9mmHg]

Other types of Barometers.
1) **Fortin Barometer**



It is constructed like a simple mercury barometer but with a provision for accurate determination of atmospheric pressure.
There is a vernier scale for accurate reading of the mercury level.

2) **Aneroid Barometer**
It does not use any liquid.



- ❖ It consists of a sealed flat box (chamber) with flexible walls.
- ❖ The box is evacuated but prevented from collapsing by means of a spring.
- ❖ The box expands and contracts in response to changes in atmospheric pressure.
- ❖ The movements of the box are magnified by a system of levers and transmitted to a fine chain attached to a pointer, which moves along a suitably calibrated scale.

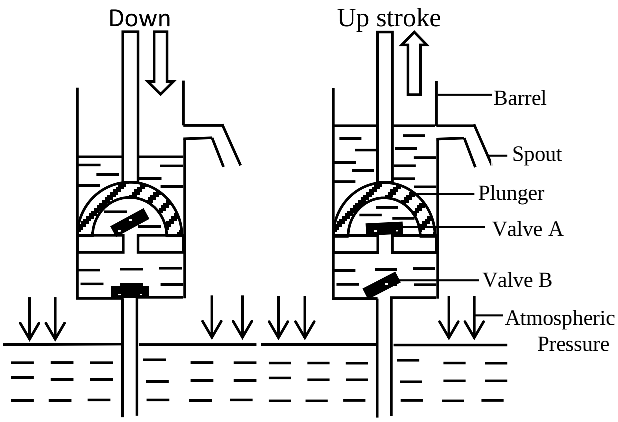
APPLICATIONS OF ATMOSPHERIC PRESSURE:

1. The Lift Pump:

Lift pumps are used to raise water from deep under ground wells.

Structure

It consists of a long cylindrical barrel, inside which is a plunger (piston). It has two valves one at the entry point to the barrel and the other at the plunger.



Action

The action of the lift pump is explained in terms of what happens when the plunger is moving upwards (up stroke) and when moving downwards (down stroke).

Up stroke.

- Valve A closes due to the weight of water above it.
- The weight above valve B reduces. This causes the atmospheric pressure acting on the surfsce of water in the well, to push the water up through the pipe into the burrel.
- Consquently, water above the plunger is lifted upwards and it flows out through the spout.

Down stroke.

- Valve B closes due to the pressure on it, while valve A opens due to the pressure exerted by water in the burrel.
- Water the passes upwards through valve A into the area above the plunger.

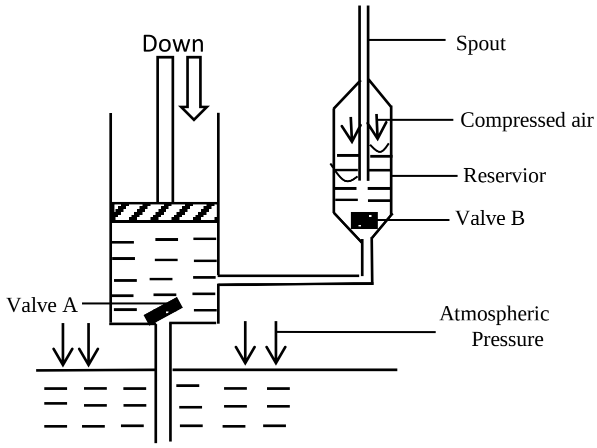
Limitations of the lift pump

It can only raise water to a maximum height of 10 metres. This is because the atmospheric pressure can only support a water column of 10 metres.

2. The Force Pump:

The force pump is designed to overcome the limitations of the lift pump. It can raise water to heights greater than 10metres.

Structure



Action

The action of the force pump is also explained in terms upstroke and down stroke.

Up stroke.

- Valve B closes and the atmospheric pressure forces the water into the barrel through valve A.

Down stroke.

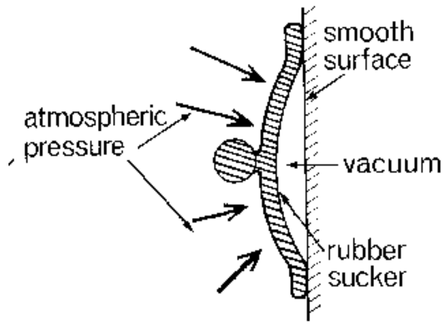
- Valve A closes due to the weight of the water above it.
- The water in the barrel is forced through valve B into the reservoir, C and out of the spout D.
- The air trapped in the reservoir is compressed and as aresult, it keeps on pushing the water out of the reservoir through the spout even when in upstoke.

3. Other Applications of atmospheric Pressure:

(i) Drinking straw
(ii) Sunction pad
(iii) Siphon
(iv) Rubber suckers
(v) Bicycle pump
(vi) Water supply system

Rubber Sucker

This is circular hollow rubber cap before it is put to use it is moisturized to get a good air seal and firmly pressed against a small flat surface so that air inside in pushed out then atmospheric pressure will hold it firmly against surface as shown below

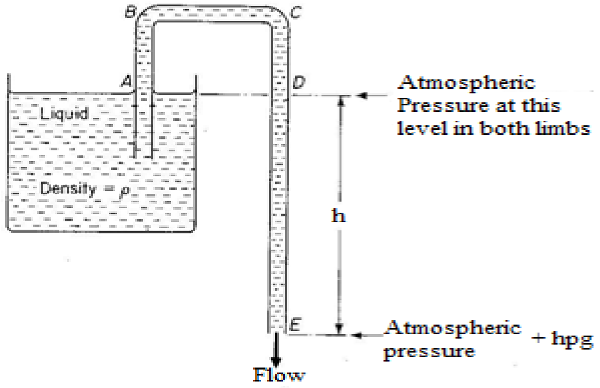


Uses of rubber sucker;

-It is used printing machines for lifting papers to be fed into the printer.

The siphon;

This is used to take the liquid out of vessels (eg. Aquarium, petrol tank)



How a siphon works

The pressure at A and D is atmospheric, therefore the pressure at E is atmospheric pressure plus pressure due to The column of water DE. Hence, the water at E can push its way out against atmospheric pressure..

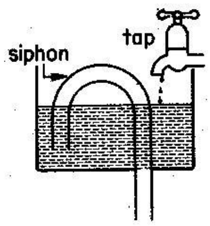
NB: To start the siphon it must be full of liquid and end A must be below the liquid level in the tank.

Applications of siphon principle

1. **Automatic flushing tank**:

This uses siphon principle.

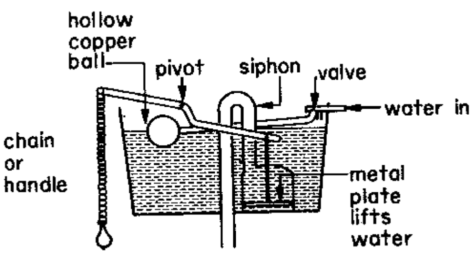
Water drips slowly from a tap into the tank. The water therefore rises up the tube until it reaches and fills the bend In the pipe siphon action starts and the tank empties (the water level falls to the end of the tube).The action Is then repeated again and again.



2. **Flushing tank of water closet:**

This also uses the siphon principle.

When the chain or handle is pulled, water is raised to fill the bend in the tube as shown below:

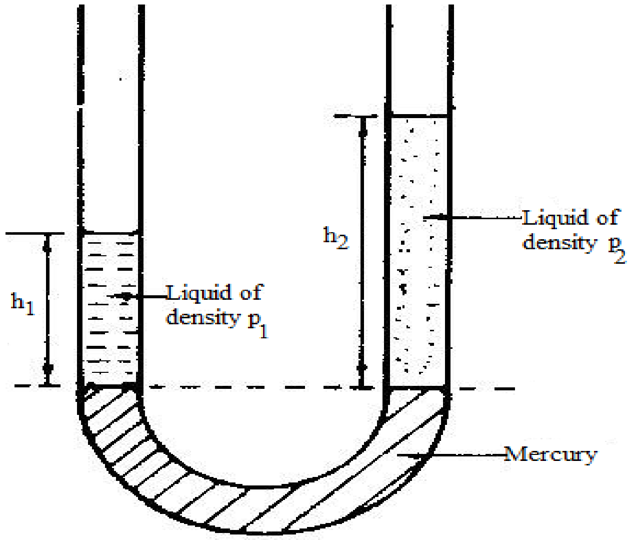


The siphon action at once starts and the tank empties.

Comparison of densities of liquids

(i) Miscible liquids

Here, a third liquid usually mercury is used to separate the two miscible liquids.

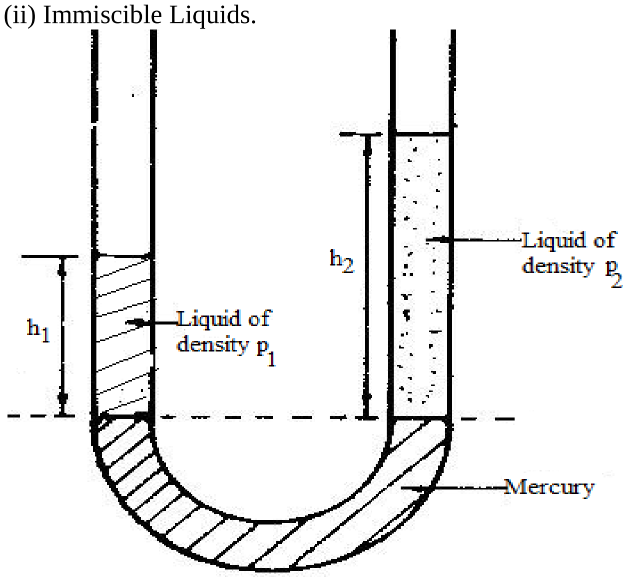


-Pour one liquid in one arm of a manometer and pour the second liquid in the other arm.

-Measure the height of the liquids in the two arms, h_1 and h_2.

$$P_A = P_A$$
$$H + h_1\rho_1 g = H + h_1\rho_1 g$$
$$h_1\rho_1 = h_1\rho_1$$

(ii) Immiscible Liquids.



-Pour one liquid in one arm of a manometer and pour the second liquid in the other arm.

-Measure the height of the liquids in the two arms, h_1 and h_2.

$$P_A = P_A$$
$$H + h_1\rho_1 g = H + h_1\rho_1 g$$
$$h_1\rho_1 = h_1\rho_1$$

Comparison of densities of liquids using Hare's apparatus

2 Related explanations

- ✓ Metallic utensils being good conductors of heat, they absorb heat (from food) which would be carried away by the volatile liquid to the cooling fins thus delaying the refrigerating process. Such utensils are not recommended to be used in refrigerators.

- ✓ Milk in a bottle wrapped in a wet cloth cools faster than that placed in a bucket exposed to a drought. This is because the wet cloth speeds up the rate of evaporation thus more cooling.

- ✓ It advisable for a heavily perspiring person to stand in a shade other than drought because drought speeds up evaporation thus faster cooling which may lead to over cooling of the body and eventually this over cooling may lower the body's resistance to infections.

- ✓ When taking a bath using cold water, the individual feels colder on a very shiny day than on a rainy day because on a shiny day, the body is at high temperatures such that on pouring cold water on the body, water absorbs some of the body's heat thus its cooling. Yet on a rainy day the body is at a relatively low temperature implying that less heat is absorbed from it when cold water is poured on it.

Two individuals; **A** (suffering from serious malaria) and **B** (normal) taking a bath of cold water at the same time of the day, **A** feels colder than **B** because the sick person's body is at relatively higher temperature than of a normal person. When cold water is poured on the sick person's body, much heat is absorbed from it compared to that absorbed from a normal person thus more coldness.

Two normal identical individuals; **A** (takes a bath of water at 35℃) and **B** (takes a bath of water at 25℃) after the bath, **A** experience more coldness than **B**. This is because Water at 35℃ raises the body's temperature more than that at 25℃. This means that after the bath, the individual who takes a bath of water at 35℃ looses more heat to the surrounding than what one who takes a bath of water at 25℃ would lose to it.

Water bottles are made of plastic other than glass and not fully filled because when water cools, it expands such that ice takes up a bigger volume. The un filled space is to cater for increase in volume on solidification and the bottle is made plastic to with stand breaking due to increase in volume.

Exercise: See UNEB

1987 Qn.15	**1997 Qn.16**	**1988 Qn.10**
1989 Qn.35	**2001 Qn.6**	**1997 Qn.9**
1990 Qn.10	**2008 Qn.4**	**1995 Qn.4**
1991 Qn.31	**Section B**	**2008 Qn.41**

3. OPTIC

3. OPTICS (LIGHT)

Definition:

Light is a form of energy which enables us to see. Or the form of energy that gives visual sensation.

Light can travel through a vacuum because light is in the form of electromagnetic waves. All electromagnetic waves have a speed of 3.0×10^{8} ms^{-1} in a vacuum, hence the speed of light.

An object is seen only when light from the object enters the eyes.

Sources of light.

(i) *Luminous light sources*:

These are objects which give their own light. Examples include the sun, stars, glow warms – these are natural. And the man made include electric bulbs, lamps, candles, etc.

(ii) *Non – luminous light sources:*

These scatter or reflect light from other sources e.g the moon, mirror, reflecting surface.

Transmission of light:

Light travels from its source onto another place through a vacuum or a medium; the media include:

(i) <u>Transparent Medium</u>

A media which allows almost all of the light to pass through it and allows objects to be seen. E.g. colourless water, paraffin and colourless glass.

(ii) <u>Translucent Medium</u>

A medium which allows some light to pass through it but does not allow an object to be seen clearly. E.g. cloudy liquid, frosted glass and oily paper.

(iii) <u>Opaque Medium</u>

A medium which does not allow light to pass through it at all and we cannot see thru them. E.g wood, bricks, plastic etc

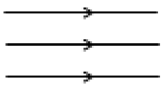
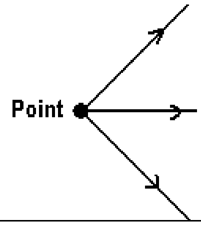
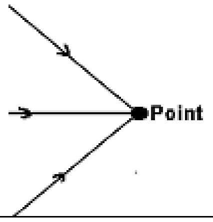
N/B: incandescent bodies give off light because they are hot while fluorescent bodies give off light without being hot.

Fluorescence: the emission of light by a material after it has absorbed heat for some time.

RAYS AND BEAMS

A ray is the direction of the path in which light is travelling. It is represented by a straight line with an arrow on it.

A beam is a collection of rays or a stream of light energy. There are three kinds:

(i) Parallel beam	*(ii) Divergent beam*	*(iii) Convergent beam*
A collection of rays which do not meet.	A collection of rays which originates from one point and spread out in different directions	A collection of rays originating from different directions and coinciding/collecting at the same point
		

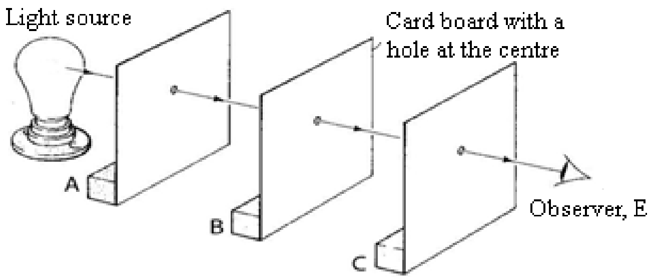
RECTILINEAR PROPAGATION OF LIGHT

Definition:

This is the process by which light travels in straight lines when produced from a source.

It is propagated (sent outward) and it travels in straight lines.

Experiment to show that light travels in a straight line



Procedures

Arranging cardboards

Three cards A, B, and C are arranged with their holes in a straight line such that they are some distance apart.

This is ensured by passing a string through the holes of the cardboards and drawing a string taut.(straight n tight)

Observation

When the eyes is placed at E, light from the source is seen.

The cardboards are displaced such that their holes are not in straight line, no light is seen at E.

Conclusion

This shows that light travels in a straight line

SHADOWS

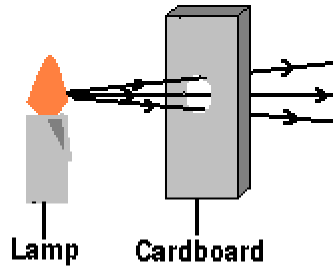
A shadow is a region of darkness formed when an opaque object obstructs the path of light.

Shadows are formed because light travels in a straight line.

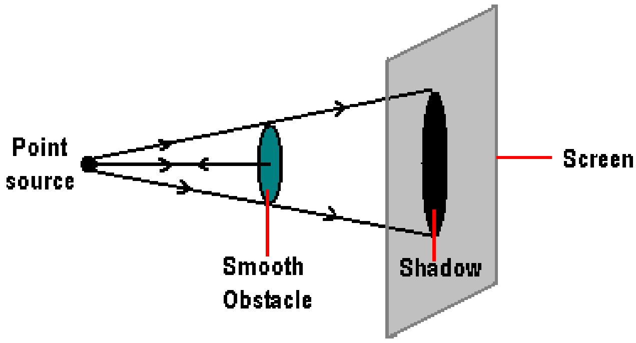
Shadow formation

a) Point Source:

A point source is a very small source of light. It can be obtained by placing a cardboard with a small hole in front of a lamp as shown below.



Shadow formation by a point source of light.

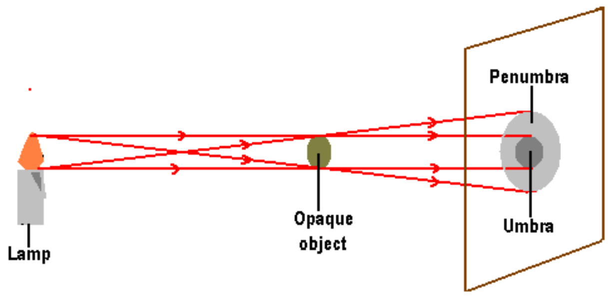


For a point source, a sharp shadow is formed, i.e. the shadow is also equally dark all over.

For a point source: When the opaque object is moved near the source, then the size of the shadow increases. However, when the object is moved near the screen, the size of the shadow is decreased.

b) Extended Source

When the cardboard is removed then the lamp becomes an extended source



The shadow has the central dark patch called umbra surrounded by a lighter ring called penumbra.

Umbra

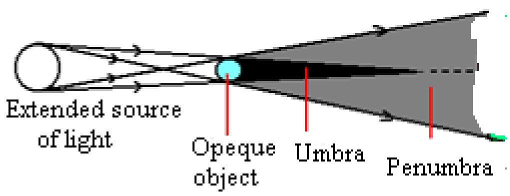
A region of shadow where no light reaches at all.

Penumbra

A region of the shadow where some light reaches.

Note:

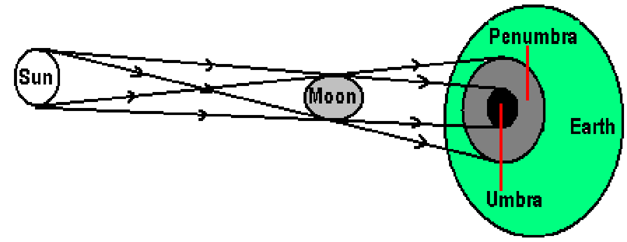
For an extended source: When the opaque object is moved near the source, the size of umbra decreases, but the size of penumbra increases. When the object is moved near the screen, the size of umbra increases, but the size of penumbra decreases.



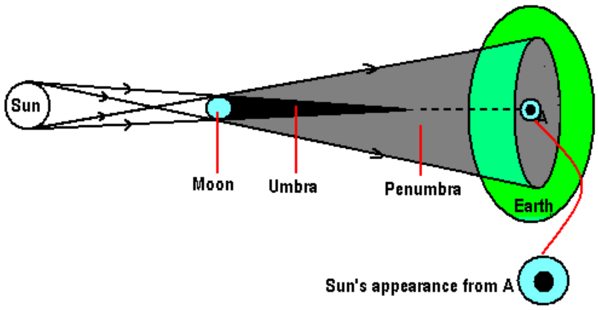
The umbra may fail to reach the screen if the opaque object is very far away from the screen

ECLIPSE:
An eclipse is the obscuring of light from the sun by either the moon or the earth.
An eclipse occurs when the sun, moon, and earth are in a straight line. There are two types of eclipses namely:
(a) Solar, annular (Eclipses of the sun)
(b) Lunar. (Eclipse of the moon)

a) Solar Eclipse:
Solar eclipse also called eclipse of the sun. It occurs when the moon is between the sun and the earth, such that both umbra and penumbra reaches the earth. The area on earth covered by umbra has total eclipse and the sun cannot be seen **at al**l. The area covered by penumbra has partial eclipse and only part of the sun is seen.

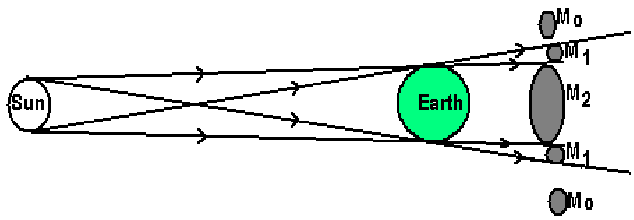


❖ ***Annular Eclipse:***
Annular eclipse of the sun occurs when the sun is very far from the earth and the moon is between the earth and the sun, such that the tip of the umbra is the one that reaches the earth's surface. From one place on the earth, the sun is represented by the appearance of a ring of light.



Note: The distance between the earth and the moon varies slightly since the moon's orbit around the earth is **elliptical.** This explains the variation in the moon's distance around the earth.

b) Lunar Eclipse:
Lunar eclipse is also called eclipse of the moon. Lunar eclipse occurs when the earth is between the sun and the moon. During the eclipse of the moon, the earth's shadow is casted on the moon such that when the moon is at position M_2, total eclipse occurs. In position M_1, partial eclipse occurs and when the moon is in position M_o, no eclipse occurs, but the moon is less bright than usual.

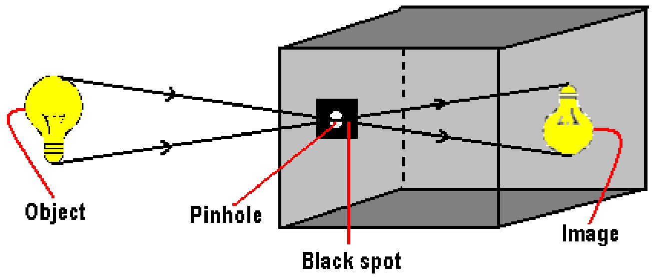


Note: Total eclipse of the moon lasts longer than total eclipse of the sun because for the moon, the earth which is in the middle is larger than the moon for the sun.

Flourescence and phosphorence substance
(i) Fluorescence Substance:
A substance which absorbs energy and immediately release the energy in the form of light e.g. zinc sulphide. The screen of a T.V and C.R.O are made of a fluorescent substance.

(ii) Phosphorescence Substance:
A substance which absorbs the energy falling on it, store it, and when energy stops falling on it, it release energy in the form of light, e.g. calcium sulphide.

THE PIN WHOLE CAMERA



Pin hole camera consists of a closed box with a small hole(pin hole) on face and a screen of tracing paper on the opposite face.

Description of Image Formation:
The image is real and inverted. Each point of the image on the screen will be illuminated only by the light travelling in a straight line from a particular point.

Effect of image formation for pin hole camera if;
(i) Pin hole is enlarged; image become blurred and brighter

Explanation:
The blurring of the image is because the large hole will be the same as a number of pin holes put together, each forming their own image and overlap of these images causes a single blurred image.

Note:
The box is blackened inside to prevent reflection inside a camera. The image comes brighter because of increased quantity of light.

(ii) Moving the object closer to the pin hole: The size of the image increases the but the image becomes less bright.

Explanation:
The image becomes less bright as its size increases because the same amount of light as before spread over large area of the screen.

MAGNIFICATION
Definition:
Magnification is the ratio of image height to object height or image distance to object distance.
Mathematically, magnification is given by:

$$\text{Magnification, } M = \frac{\text{Image distance, } V}{\text{Object distance, } U}$$

OR

$$\text{Magnification, } M = \frac{\text{Image height, } h}{\text{Object height, } H}$$

Larger magnification is obtained when the object is nearer the pin hole and smaller magnification is produced when the object is farther away.

Example: 1

Calculate the height of a building 150m away from a pinhole camera, which produces an image 5 cm high if the distance between the pinhole camera and screen is 10 cm.

Solution

Given; object distance=150 cm
Image height= 5 cm
Image distance= 10 cm
From definition of magnification

$$M = \frac{\text{Image height, } h}{\text{Object height, } H} = \frac{\text{Image distance, } V}{\text{Object distance, } U}$$

$$\frac{h}{H} = \frac{V}{U}$$

$$\frac{5\text{ cm}}{H} = \frac{10\text{ cm}}{150\text{ cm}}$$

$$10H = 5 \times 150$$
$$H = 75\text{ cm}$$

Alternatively, you can first calculate magnification using first equation and then substitute in second equation to obtain object height; i.e.

From

$$M = \frac{\text{Image distance, } V}{\text{Object distance, } U}$$

$$M = \frac{10\text{ cm}}{150\text{ cm}} = \frac{1}{15} \dots.(i)$$

But also;

$$M = \frac{\text{Image height, } h}{\text{Object height, } H}$$

$$M = \frac{5\text{ cm}}{H} \qquad \dots.(ii)$$

Equating (i) and (ii)

$$\frac{5\text{ cm}}{H} = \frac{1}{15}$$
$$H = 5 \times 15$$
$$H = 75\text{ cm}$$

Example: 2

The length of a pinhole camera is 25 cm. An object 2 m, high is placed 10 m from the pinhole. Calculate the height of the image produced and its magnification.

Solution:

Given; Image distance = 25 cm = 0.25 m
Object height = 2 m
Object distance = 10 cm = 0.1 m
Image height=?

From definition of magnification;

$$M = \frac{\text{Image distance, } V}{\text{Object distance, } U}$$

$$M = \frac{10\text{ cm}}{150\text{ cm}}$$
$$M = 2.5$$

$$\frac{h}{H} = \frac{V}{U}$$

$$\frac{h}{2} = \frac{0.25}{0.1}$$

$$0.1h = 2 \times 0.25$$
$$h = 0.5\text{ cm}$$

See UNEB Paper I

1997	2000	2002	2006	2006
Qn.22	Qn. 34	Qn. 27	Qn. 29	Qn.27

1. A girl is 1.6m tall and stands 4m away from the pin hole camera which is 20 m long. Find the:
   i) Image height
   ii) The magnification if the camera is only 10cm long.

2. UNEB 1992 Qn. 1

(a) What is meant by rectilinear propagation of light?
(b) An opaque object is placed in front of a source of light. Draw ray diagrams to show the formation of shadows when;
(i) A point source is used
(ii) An extended source is used

3. . UNEB 1997 Qn. 4

(b) Draw diagrams to show the formation of total and partial solar eclipse.

4. . UNEB1998 Qn.7

(a) Describe an experiment to show that light travels in a straight line.
(b) An object of height 4cm is placed 5cm away from a pin hole camera. The screen is 7cm from the pin hole.
(i) Draw a scale ray diagram to show the formation of an image by a pin hole camera.
(ii) What is the nature of the image?
(iii) Find the magnification.
(iv) Explain what happens to the image if the pin-hole is made larger.

REFLECTION OF LIGHT

Definition:

Reflection is the process by which light energy falling on a body surface bounces off.
The surface from which reflection occurs is called the reflecting surface.

Types of Rays

(i) ***Incident rays****;* is a ray of light from the light source falling onto/striking the reflecting surface

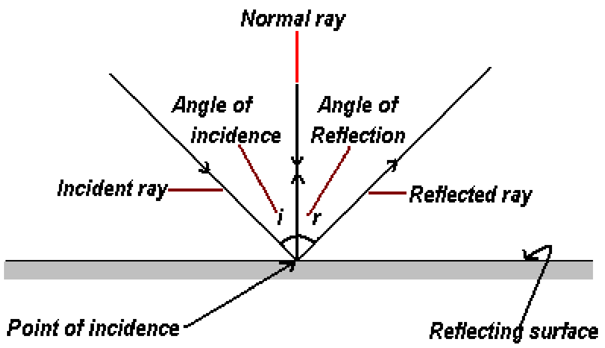
(ii) ***Reflected rays;*** is a ray leaving/bouncing off the reflecting surface at the point of incidence.

Normal: is a line at 90 degrees with the reflecting surface the ray is incident

Types of Angle:

(i) Angle of incidence "**i**"; is the angle between the incident ray and the normal at the point of incidence i.e. it's the angle made by the incident ray with the normal at the point of incidence

(ii) Angle of reflection "**r**"; is the angle between the reflected ray and the normal at the point of incidence i.e. it's the angle made by the reflected ray with the normal at the point of incidence.



✓ Point 0 (point of incidence)
This is the point on the reflecting surface where the incident ray is directed.

✓ Normal (0N)
Is a line drawn from point 0 perpendicular to the reflecting surface.

✓ Incident ray (A0)
Is the path along which light is directed on to the reflecting surface.

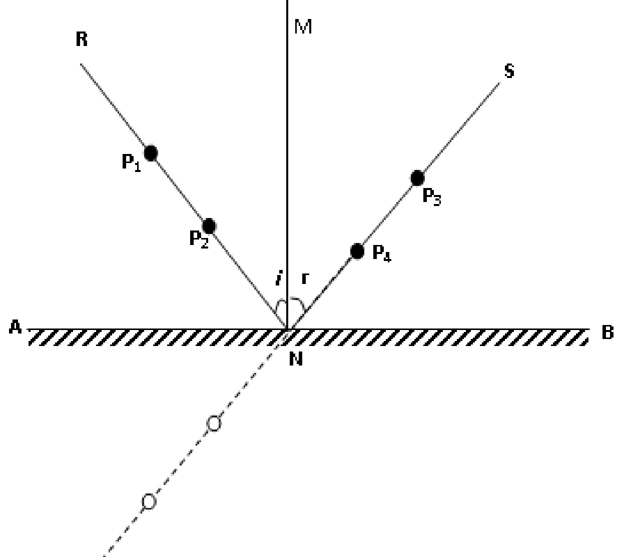
✓ Angle of incidence (i)
This is the angle that the incident ray makes with the normal at the point of incidence.

✓ Reflected (0B)
Is the path along which light incident on a surface is reflected.

✓ Angle of reflection (r)
This is an angle between the reflected ray and the normal at the point of incidence.

The Laws of Reflection
The laws of reflection state that:
i) The incident ray, reflected ray, and normal at the point of incidence all lie in the same plane.
ii) The angle of incidence is equal to the angle of reflection.

Experiment to verify the laws of reflection of light



Procedure:
- ❖ A white sheet of paper is fixed on a soft board and a plane mirror is placed vertically on the paper with its reflecting surface facing the object.
- ❖ The mirror line is traced and the mirror is removed and the line is drawn and labeled AB.
- ❖ A normal MN bisecting the mirror line AB is drawn.
- ❖ A line RN is drawn at an angle θ to the normal. e.g $\theta = 30^0$
- ❖ Pins P_1 and P_2 are fixed along line RN.
- ❖ The mirror is placed back on the board so that its reflecting surface coincides exactly with the mirror line AB.
- ❖ The images of P_1 and P_2 are viewed in the mirror and other pins P_3 and P_4 are fixed such that they are in line with the images of P_1 and P_2.
- ❖ The pins P_3 and P_4 are removed and a line NS is drawn.
- ❖ Angle r is measured and recorded.

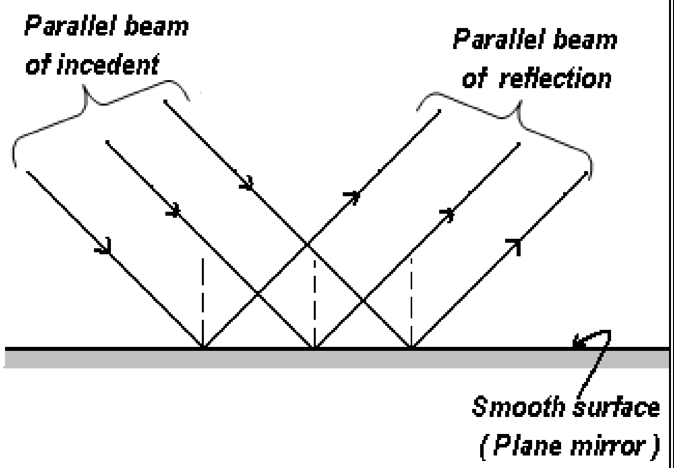
Observation:
- ✓ Angle **i** = angle **r.**
- ✓ The incident ray, the normal and the reflected ray at the point of incidence all in the same plane.

Conclusion: hence verifying the laws of reflection

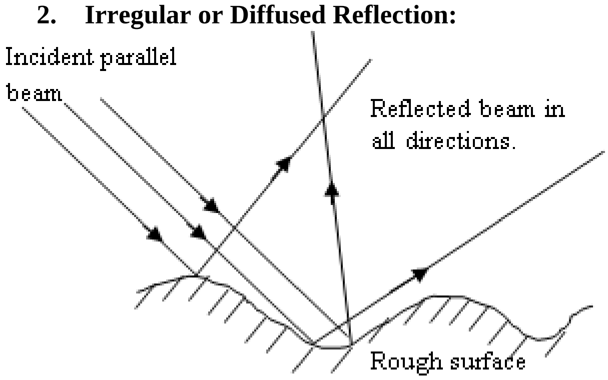
Types of Reflection

1. **Regular Reflection:**

Regular reflection occurs when a parallel incident beam falls on a place smooth surface and it is reflected across a parallel beam. Example of smooth plane surface is a plane mirror.



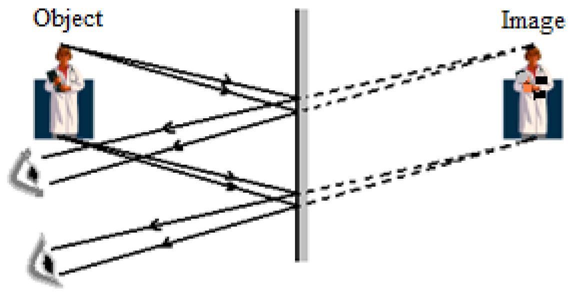
2. **Irregular or Diffused Reflection:**



Diffused reflection occurs when a parallel incident beam falls on a rough surface and the reflected beam is scattered in different directions.

(a) REFLECTION AT PLANE SURFACES:

Image formation by a plane mirror



Characteristics of the image formed

- ✓ Image is of the same size as the Object
- ✓ Laterally inverted
- ✓ Virtual (cannot be formed on the screen)
- ✓ Same distance behind the mirror as the Object is in front of the mirror

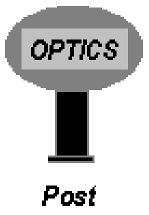
Definition:
Real image: Is the image which is formed by rays that actually intersect and can be formed on the screen.

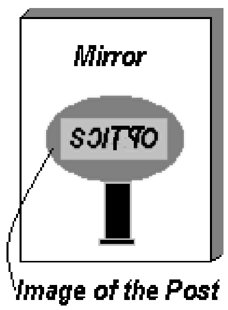
Virtual image: Is the image formed by the apparent intersection of light rays. i.e the rays which have been extended and it cannot be formed on the screen.

Explanation of virtual image in plane mirror:
The image in a plane mirror is virtual in that the rays from a point object are reflected at the mirror and appear to come from the point behind the mirror where the eyes imagine the reflected rays to meet when produced backward.

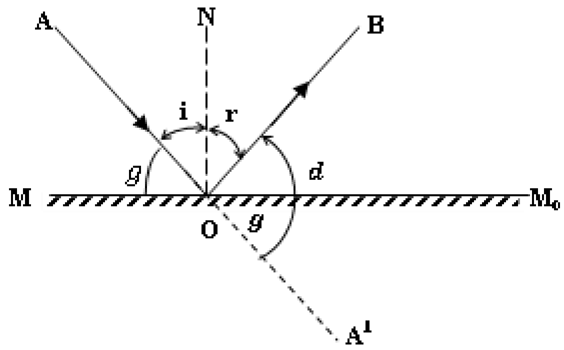
NB: virtual objects and images should be represented by dotted lines.

Lateral Inversion:
In a mirror image, right and left are interchanged and the image is said to be laterally inverted. The effect occurs whenever an image is formed by one reflection.





The glancing angle and the angle of deviation.
Deviation of light at a plane surface



g – **Glancing angle**
The angle between the incident ray and the reflecting surface.

d- **Angle of deviation**
it is the angle between the initial direction of the incident ray (extended incident ray) and the reflected ray.
Angle of Deviation, d;

$d = \text{Angle } A^1OB$

$d = g + \text{Angle } M_0OB$

$d = g + (90 - r)$

But $i = r$ (From the law of reflection).

$d = g + (90 - i)$

But;

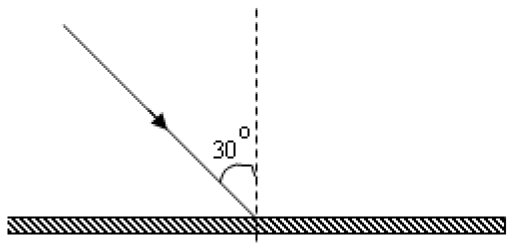
$(90 - i) = g$ (Vertically opposite angles)

$d = g + g$

$d = 2g$

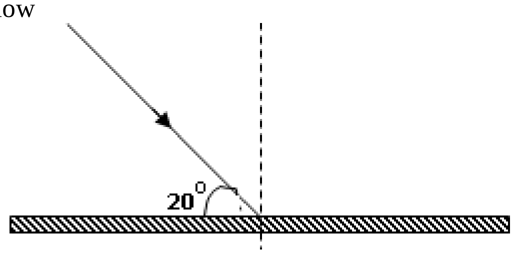
Example

1. A light ray is incident to a smooth surface as shown below



Find the:
- (i) Angle of reflection
- (ii) Glancing angle
- (iii) Angle of deviation

2. A light ray is incident to a smooth surface as shown below



Find the:
(i) Angle of reflection
(ii) Angle of reflection

3. A girl sits 5 m away from a plane mirror. If a table is placed 2 m away from the girl, find the :

(i) Distance between the table and its image.
(ii) Distance between the girl and the tables' image.
(iii) Distance between the table and the girls' image.
(iv) A boy stands 10m away from a plane mirror. What distance should he move towards the plane mirror such that the distance between him and his image is 8m.

INCLINED MIRRORS

Image formed by an inclined mirror at an angle θ

When two mirrors are inclined to each other at an angle θ, the number of images (n) is given by:

$$\mathbf{n = \frac{360}{\theta} - 1}$$

The table below summarizes how one can obtain the number of image formed by 2 mirrors inclined at an angle.

Angle between mirrors θ (°)	$(\frac{360}{\theta})$	Number of image in **n:** $= \frac{360}{\theta} - 1$
90	4	3
60	6	6
45	8	7
30	12	11
15	24	23

Questions

1. Two plane mirrors are inclined at an angle 50^0 to one another find the number of images formed by these mirrors.

$n = \left(\frac{36}{\theta} - 1\right)$

$n = \left(\frac{360}{50} - 1\right) = 7.2 - 1 = 6.2 \approx 6$ images

2. Two plane mirrors are inclined at an angle θ to each other. If the number of image formed between them is 79, find the angle of inclination θ.

Solution

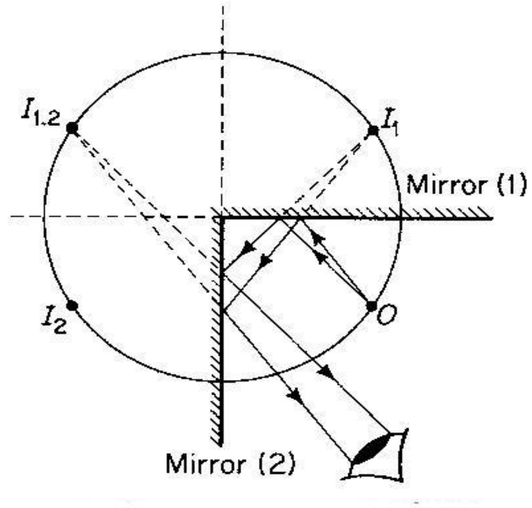
$n = \left(\frac{36}{\theta} - 1\right)$

$79 = \left(\frac{360}{\theta} - 1\right)$

$\theta = 4.5^0$

Find the number of images formed when an object is placed between mirrors inclined at; (i) 90^0 (ii) 60^0 (iii) 120^0

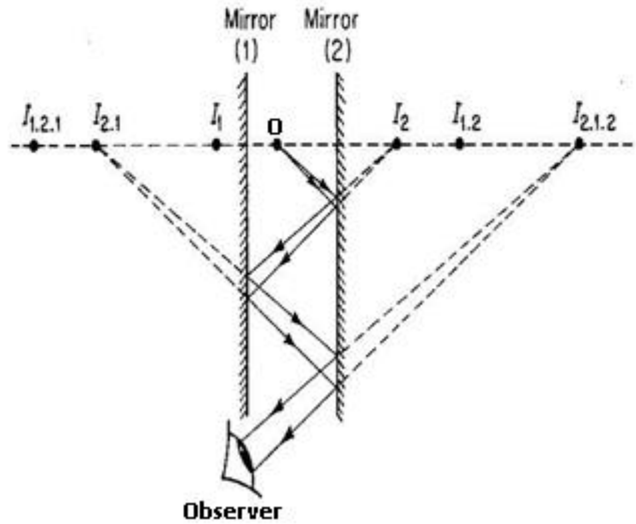
(i) **Image formed in two plane mirrors inclined at 90^0**



When two mirrors are inclined at 90^0 to each other, images are formed by a single reflection in addition to two extra images formed by 2 reflections.

(ii) **Image formed in parallel mirrors**

An infinity number of image is formed on an object placed between two parallel mirrors each image seen in one mirror will act as virtual object to the next mirror.



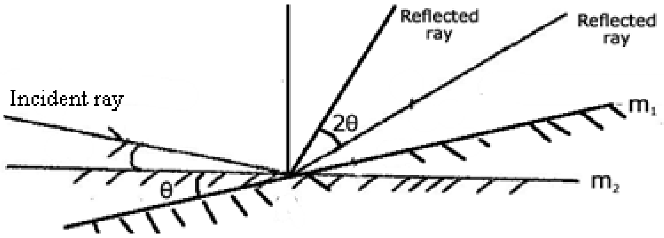
-The object O, gives rise to image I_1, on mirror m_1 and I_2 on m_2 .I_1 acts as virtual object to give an image $I_{(1,2)}$ in mirror m_2 just as I_2 gives an image $I_{(2,1)}$ in mirror m_1. $I_{(1,2)}$ in mirror m $I_{(1,2)}$ gives $I_{(1,2,1)}$ after reflection in m_1 while $I_{(2,1,2)}$ after reflecting in Mirror m_2.

Number of images n = When two mirrors are parallel, the angle θ between them is zero and the number of images formed between them is

N = ($\frac{360}{\theta} - 1$) = 0(infinite)

This shows infinite number of image when two plane mirrors are parallel. The image lies in a straight line through the object and perpendicular to the mirrors.

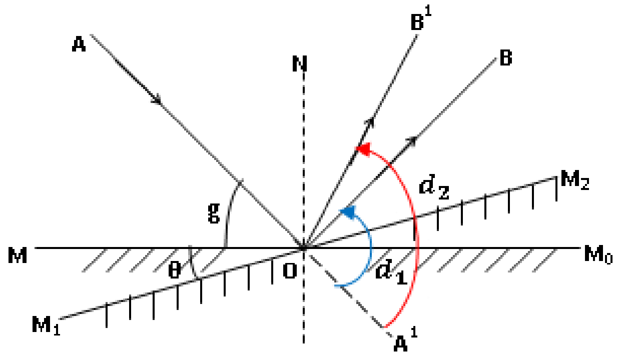
ROTATION OF REFLECTED RAY BY ROTATING THE MIRROR



When a mirror is rotated through any angle, the reflected ray will rotate through an angle 2θ provided the direction of the incident ray remains the same e.g the angle between a fixed ray of light and a mirror is 25^0, if the mirror rotates through 20^o. Find by how many degrees do a reflected ray rotates.

Required angle = 2θ = 2 x 20 = 40^0

N.B the angle through which the reflected ray is rotated does not depend on the angle of incidence but depends on the angle of rotation on the reflecting surface.



Deviation produced by mirror in position MM_0 is twice the glancing angle

d_1 = Angle BO A^1 = 2g … … … … … … … … . . (i)

Deviation produced by mirror in position M_1M_2, is twice the glancing angle

d_2 = Angle $B^1O\ A^1$ = 2(g + θ) … … . . … … . (ii)

Angle of rotation of reflected ray = Angle B^1O B

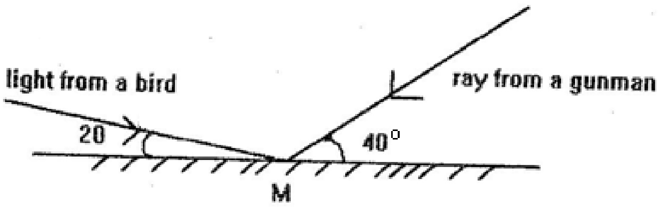
But;

Angle B^1O B = Angle $B^1O\ A^1$ − AngleBO A^1

Angle B^1O B = 2(g + θ) − 2g

Angle B^1O B = 2θ

Questions



An incident ray makes an angle of 20^0 with the plane mirror in position m1 as shown in the diagram

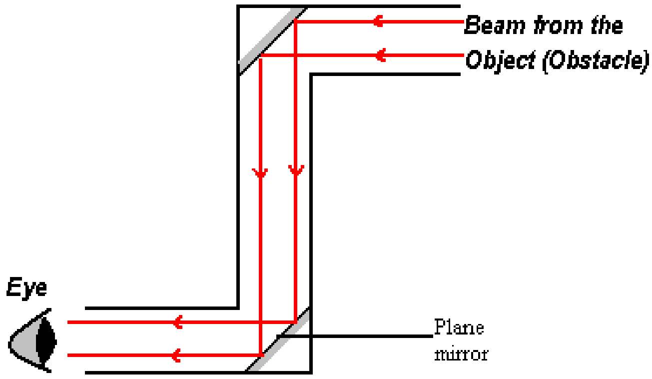
a) What will the angle of reflection be if the mirror is rotated through 6^0 to position m2 while direction of incident ray remains the same?

b) An object is placed 6cm from a plane mirror. If the object is moved further, find the distance between the object and its image.

Application of reflections
Uses of Plane Mirrors

(a) Periscope

This is the instrument used for looking over top obstacles. It is made of 2 plane mirrors inclined at each other at 45^0. It is mainly used in submarines.



The arrangement has two plane mirrors facing each others and fixed at 45^0. Light from a distant object is turned through 900 at each reflection.

(b) Used in pointer instrument to facilitate correct reading of values by preventing errors due to parallax.

(c) They are attached to optical lever such as galvanometer to reflect light falling on the mirror over the galvanometer scale as it rotates.

Used in optical lever instruments to magnify angle of rotation.

(d) Inclined mirrors are used in kaleidoscope for producing different patterns of objects placed between them.

A kaleidoscope consists of two plane mirrors inclined at an angle of 60^0 to each other in a tube.

When one looks through the tube, five images of the same object are seen, which together with the object form a symmetric pattern of six sectors.

(e) Used in small shops and supermarkets, take away and saloons to give a false magnification as a result of multiple reflections.

Exercise See UNEB Paper I

1999 Qn.25	1996 Qn.28	1997 Qn.24	2005 Qn.40	2007 Qn.16

(b) REFLECTION AT CURVED (SPHERICAL) MIRRORS

Curved mirrors are spherical mirrors made by cutting part of the sphere.

Terms used in curved mirrors

Pole, P.
Pole is the mid-point of the actual mirror surface.
Pole is the centre portion of the mirror

Aperture.
This is the width of the mirror. The aperture is the distance between two opposite points on the edge of the mirror.

Centre of Curvature, C.
This is the center of the sphere from which the mirror forms a part.

Radius of Curvature, r.
The radius of curvature is the distance from the pole to the centre of curvature.

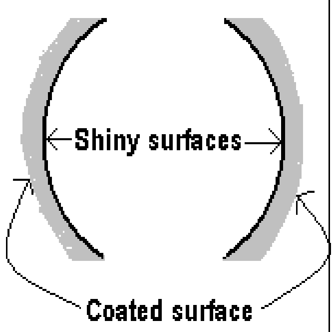
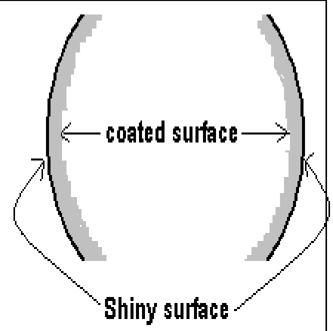
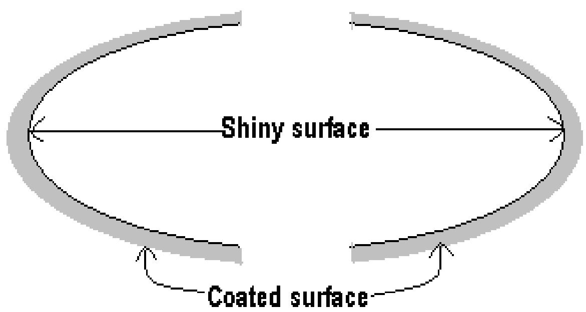
Principal axis.
This is the straight line joining the pole to the centre of curvature.

Focal length, f.
Focal length is the distance from the pole to the principal focus.

Principal focus, F.
Principal focus is half the distance between the centre of curvature and the pole.

Summary for terms used in curved mirrors i.e. Concave mirror.

Types of curved mirrors

(a) Concave mirror	(b) convex mirror
	
(c) Parabolic mirror	
	

(i) CONCAVE MIRROR

A concave mirror is the type of curved mirror in which the reflecting surface is curved inwards.

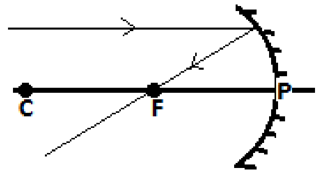
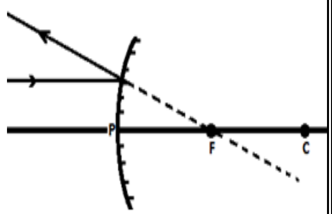
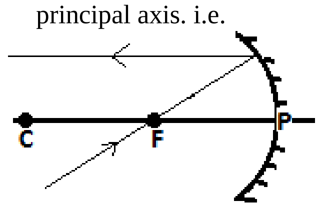
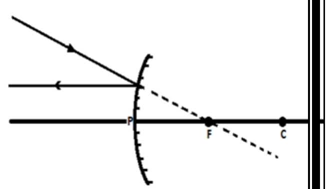
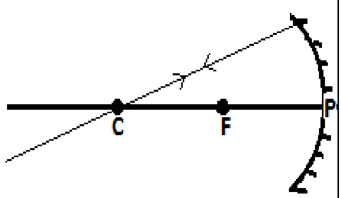
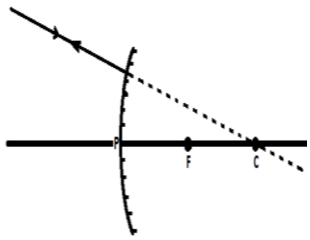
Uses of concave mirror

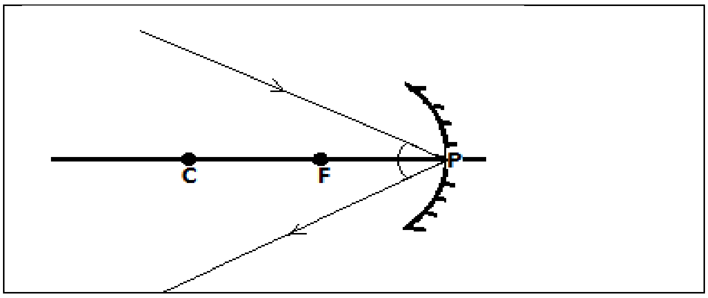
- ✓ Used in astronomical telescopes.
- ✓ Used for shaving because it magnifies the object.
- ✓ Used as solar concentrators.
- ✓ Used by dentists for magnification i.e Dentist mirror.
- ✓ Used in car head lamps , torches

Defect of concave mirror:
When a wide beam of parallel rays fall on a concave mirror of large aperture, not all are brought to a focus at the focal point but instead form a caustic curved.

N.B Caustic curve is an illusory curve that is seen to touch the reflected rays when a wide parallel beam of light falls on a concave mirror.

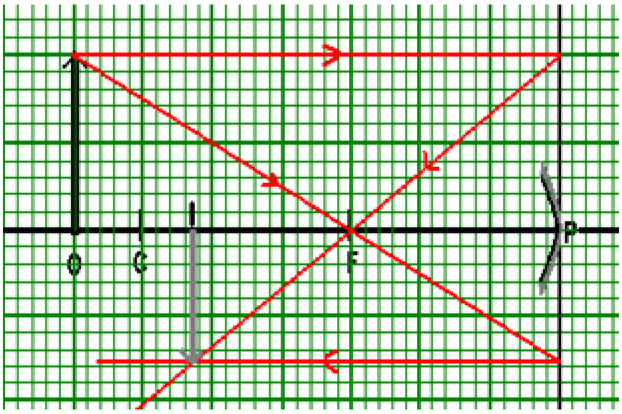
Useful rays used in construction of ray diagrams.

Concave mirror	Convex mirror
1. A ray parallel to the principal axis is reflected through the principal focus, F. i.e. 	A ray parallel to the principal axis is reflected such that it appears to come from the principal focus, F behind the mirror. i.e. 
2. A ray passing through the principal focus, F is reflected parallel to the principal axis. i.e. 	A ray through the principle focus F, behind the mirror is reflected parallel to the principal axis. i.e. 
3. A ray passing though the centre of curvature, C is reflected back along the same path because it is the normal to the surface. i.e. 	A ray which if produced would pass through the centre of curvature is reflected back along the same path. i.e. 
4. A ray striking the pole is reflected so as the incident ray and the reflected ray make the same angle with the principal axis. i.e.	



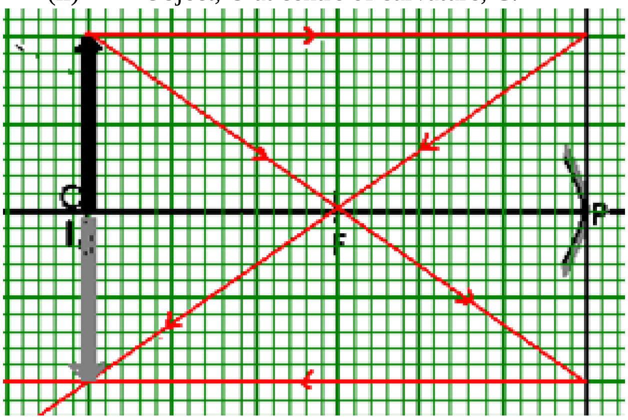
Characteristics of the image, I formed by concave mirror at different positions.

(i) Object, O beyond the centre of curvature, C.



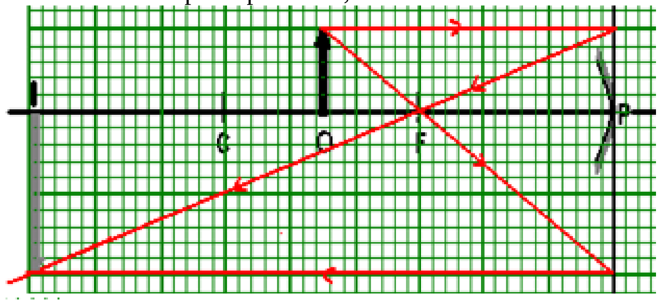
The image, I formed is;
- ❖ Position: Between F and C
- ❖ Nature : Real and Inverted
- ❖ Size : Diminished

(ii) Object, O at centre of curvature, C.



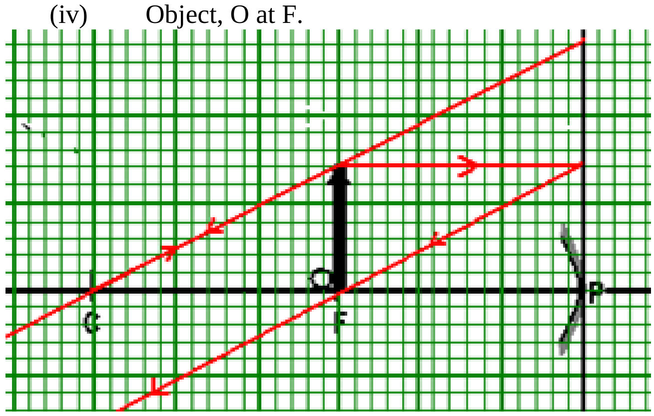
The image, I formed is;
- ❖ Position: At C
- ❖ Nature : Real and Inverted
- ❖ Size : Same size as the object

(iii) Object, O between centre of curvature, C and the principal focus, F



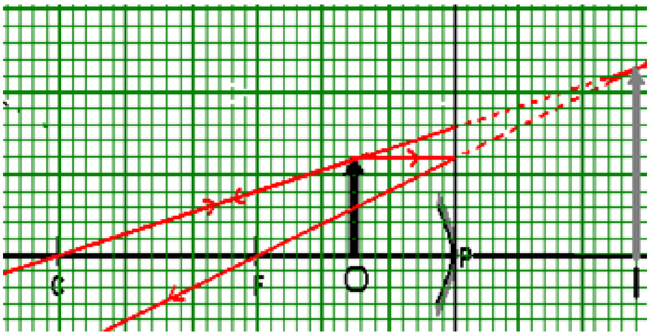
The image, I formed is;
- ❖ Position: Beyond C
- ❖ Nature : Real and Inverted
- ❖ Size : Magnified

(iv) Object, O at F.



The image, I formed is;
- ❖ Position: At infinity
- ❖ Nature : Real and Inverted

(v) Object, O between principal focus, F and pole, P.



The image, I formed is;
- ❖ Position: Behind the mirror
- ❖ Nature : Virtual and Upright (erect)
- ❖ Size : Magnified

NB. A concave mirror can be used as a **magnifying mirror** when the object is placed between the focal point, F and the pole, P to produce an erect image.

(ii) **CONVEX MIRRORS**

Convex mirror is a type of curved mirror in which the reflecting surface curves outward.

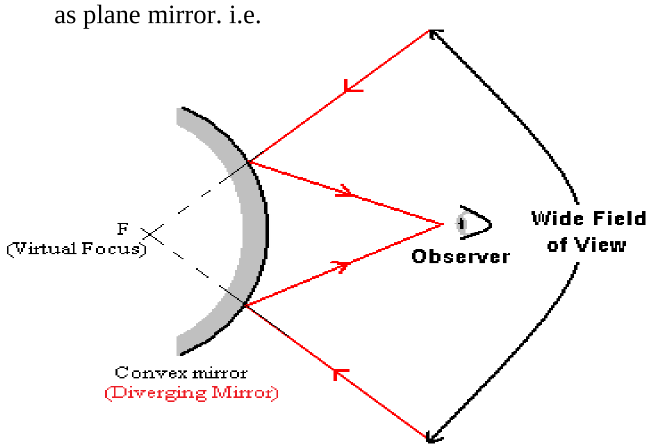
Uses of convex mirror

Convex mirrors are used as;

i) security mirrors in supermarket
ii) driving mirrors

This is **because** a convex mirror;

- ✓ Gives an erect (upright) virtual image of the objects.
- ✓ Provides a wider field of view than other mirrors such as plane mirror. i.e.

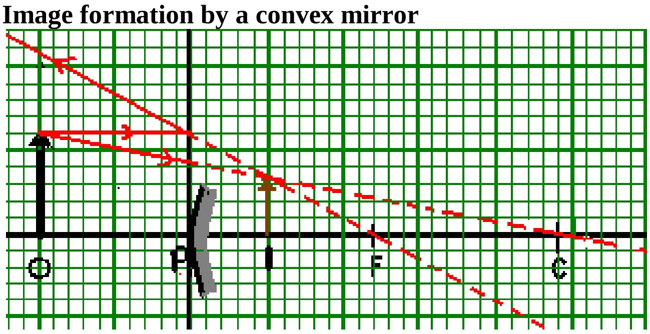


Disadvantage of convex mirrors:

- The image formed is diminished.
- It gives a false impression of the distance of an object

Therefore, convex mirrors give erect diminished images and this makes it difficult for the driver to judge the distance when reversing the vehicle.

Image formation by a convex mirror



Characteristics of the image, I formed by convex mirror.

Irrespective of the position of the object, the images formed in convex mirrors are;

- ❖ Position: Behind the mirror
- ❖ Nature : Virtual and upright (erect)
- ❖ Size : Diminished

NOTE: 1. Magnified images are the images which are larger than the objects.

2. Diminished images are the images which are smaller than the objects.

(iii) **PARABOLIC MIRRORS**

These are used to produce a parallel beam of light in spot light, car head lamps or hand torches.

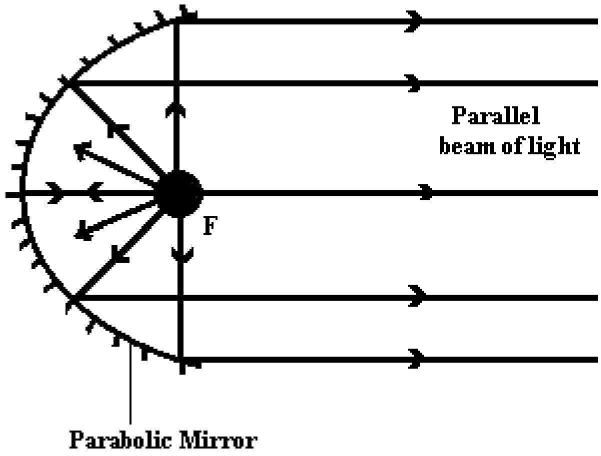
However the parabolic mirror is disadvantageous in that when a wide beam of parallel rays falls on a concave mirror of image aperture; not all rays are brought to a focus at the focal point, instead they form a caustic curve.

Parallel beam from curved mirror

A narrow parallel beam of light may be obtained from a point source light by placing the point source of light at the principal focus of a concave mirror of small aperture.

The image is regarded as being at infinity. If a wide parallel beam is required as from a car head lamp then the section of the mirror must be in the form a **parabola**.

Illustration:



Magnification

Definition:

Magnification is defined as;

- ❖ The number of times the image is larger than the object.
- ❖ The ratio of image size to object size.

Linear or transverse magnification is the ratio of one dimension of the image to a corresponding dimension of the object i.e.

Linear magnification is;

- ❖ The ratio of image distance to object distance.

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{v}{u}$$

- ❖ The ratio of image height to object height.

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{h}{H}$$

Construction of accurate ray diagrams on graph paper

Step 1: On graph paper draw a central horizontal line (which acts as the principal axis) with a perpendicular line to act as the curved mirror.

Step 2: Where distances are given, choose a scale for object size and position.

Step 3: Measure the focal length "f" and radius of curvature "r" from the mirror and mark C and F as centre of curvature and principal focus respectively.

Step 4: Draw two of the principal rays to obtain the position of the image.

Step 5: Measure the position (distance) and the size (height) of the image and multiply by the corresponding scale.

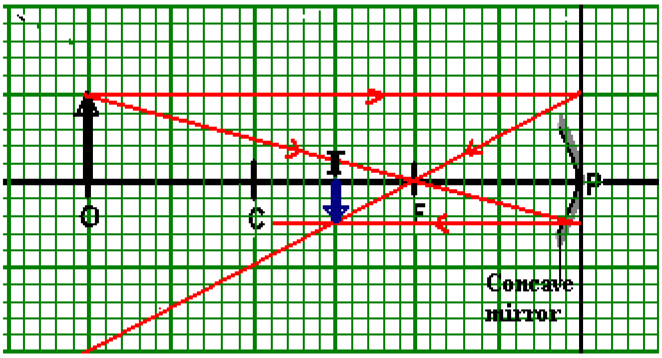
Example 1:

An object of height 10cm is placed at a distance of 60cm from a concave mirror of focal length 20cm. Find by scale drawing the;

(i) Image position.
(ii) Nature of the image formed.
(iii) Magnification of the image formed.

Solution

Axis	Scale	Conversion
Vertical axis	**1 : 10 cm**	❖ $10cm \rightarrow \frac{10}{10} \rightarrow 1cm$
Horizontal axis	**1 : 10 cm**	❖ $60cm \rightarrow \frac{60}{10} \rightarrow 6cm$ ❖ $20cm \rightarrow \frac{20}{10} \rightarrow 2cm$



Position:
The image distance as measured from the scale drawing is 3cm; using the above scale,

$$Image\ distance = (3 \times 10)\ cm = 30\ cm$$

Size:
The height of the image on the scale drawing is 0.5cm; using the scale,

$$Image\ height = (0.5 \times 10)\ cm = 5\ cm$$

Nature:
The image formed is; Real, Inverted and Diminished.

Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{30}{60} = 0.5$$

Or

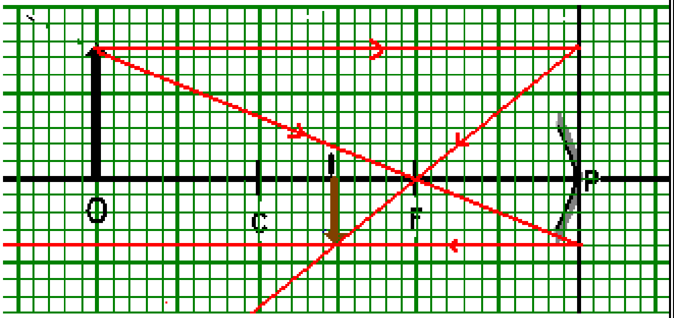
$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{5}{10} = 0.5$$

Example 2:
The focal length of a concave mirror is 4cm. An Object 1.5cm high is placed 12cm in front of the mirror.

(i) Use a ray diagram to locate the position and size of the image on the graph paper.
(ii) Describe the features of the image formed.
(iii) Find the magnification of the image formed.

Solution

Axis	Scale	Conversion
Vertical axis	**1 : 1 cm**	❖ $1.5cm \rightarrow \frac{1.5}{1} \rightarrow 1.5cm$
Horizontal axis	**1 : 2 cm**	❖ $4cm \rightarrow \frac{4}{2} \rightarrow 2cm$ ❖ $12cm \rightarrow \frac{12}{2} \rightarrow 6cm$



(i) Position:
The image distance as measured from the scale drawing is 3cm; using the above scale,

$$Image\ distance = (3 \times 2)\ cm = 6\ cm$$

Size:
The height of the image on the scale drawing is 0.8cm; using the scale,

$$Image\ height = (0.75 \times 1)\ cm = 0.75\ cm$$

(ii) Nature:
The image formed is; Real, Inverted and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{6}{12} = 0.5$$

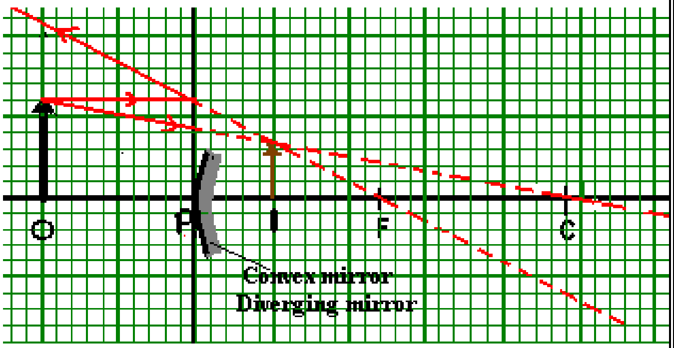
Or

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{0.75}{1.5} = 0.5$$

Example 3:
An object of height 6cm is 10cm in front of a convex mirror of focal length 12cm. Find by graphical method, the size, position and nature of the image.

Solution
Let 5 cm be represented by 1 cm

Axis	Scale	Conversion
Vertical axis	**1 : 5 cm**	❖ $6cm \rightarrow \frac{6}{5} \rightarrow 1.2cm$
Horizontal axis	**1 : 5 cm**	❖ $10cm \rightarrow \frac{10}{5} \rightarrow 2cm$ ❖ $12cm \rightarrow \frac{12}{5} \rightarrow 2.4cm$



(i) Position:
The image distance as measured from the scale drawing is 1cm; using the above scale,

$$Image\ distance = (1 \times 5)\ cm$$

$= 5\ cm$
The image 5.0cm behind the mirror.

Size:
The height of the image on the scale drawing is 0.8cm; using the scale,

$Image\ height = (0.6\ x\ 1)\ cm$
$= 0.6\ cm$

(ii) Nature:
The image formed is; virtual, Inverted and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{5}{10} = 0.5$$

Magnification and the image size of the object.

Magnification, M	Image size, I
When M is greater than 1	The image is magnified i.e. the image is larger than the object
When M is equal to 1	The image size is the same as the object
When M is less than 1	The image is diminished i.e. the image is smaller than the object

THE MIRROR FORMULA
The mirror formula for the concave mirror and convex mirror is given by;

$$\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$$

Where; **u** = object distance from the mirror
v = image distance from the mirror
f = focal length

An image may be formed in front or behind the curved mirror. It is necessary to have a sign convention for the values of **u**, **v** and **f** so as to distinguish between the two cases and obtain the correct answer when substituting into the formula.

Real is positive and virtual is negative sign convention:
According to this sign convention;

- All distances are measured from the pole of the mirror as the origin.
- Distances of real objects and the images are positive.
- Distances of virtual objects and images are negative.
- The principal focus, F of the concave mirror is real hence its focal length, f is positive while a convex mirror has a virtual principle focus, F and so its focal length, f is negative.

Example 1:
An object is placed 20cm in front of a concave mirror of focal length 12cm. Find the nature and position of the image formed.

Solution
u = 20cm; f = 12cm ; v = ?

Using the mirror formula; $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ $\frac{1}{12} = \frac{1}{20} + \frac{1}{v}$ $\frac{1}{12} - \frac{1}{20} = \frac{1}{v}$	$\frac{1}{v} = \frac{5-3}{60} = \frac{2}{60} = \frac{1}{30}$ $\frac{1}{v} = \frac{1}{30}$ $v = 30$ cm A real image was formed 30cm from the mirror on the same side as the object.

Example 2:
Calculate the distance of the image from the concave mirror of focal length 15cm if the object is 20cm from the mirror.
Solution
f = 15cm ; u = 20cm; v = ?

Using the mirror formula; $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ $\frac{1}{15} = \frac{1}{20} + \frac{1}{v}$ $\frac{1}{15} - \frac{1}{20} = \frac{1}{v}$	$\frac{1}{v} = \frac{4-3}{60} = \frac{1}{60}$ $\frac{1}{v} = \frac{1}{60}$ $v = 60$ cm A real image was formed 60cm from the mirror on the same side as the object.

Example 3:
Find the distance of the image from a convex mirror of focal length 10cm if the object is 15cm from the mirror.
Solution
u = 15cm; f = -10cm (for convex mirror); v =?

Using the mirror formula; $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ $\frac{1}{-10} = \frac{1}{15} + \frac{1}{v}$ $\frac{1}{-10} - \frac{1}{15} = \frac{1}{v}$	$\frac{1}{v} = \frac{-3-2}{30} = \frac{-5}{30}$ $\frac{1}{v} = \frac{-1}{6}$ $v = -6$ cm A virtual image was formed 6 cm from the mirror on the opposite side as the object.(i.e behind the convex mirror)

Example 4:
A convex mirror of focal length 18cm produces an image of on its axis 6cm from the mirror. Calculate the position of the object.

Solution
u =?; f = -18cm (for convex mirror); v = -6cm

Using the mirror formula; $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ $\frac{1}{-18} = \frac{1}{u} + \frac{1}{-6}$ $\frac{1}{-18} + \frac{1}{6} = \frac{1}{u}$	$\frac{1}{u} = \frac{-1+3}{18} = \frac{2}{18} = \frac{1}{9}$ $\frac{1}{u} = \frac{1}{9}$ $u = 9$ cm A real object was 9cm in front of the convex mirror.

Exercise

1. Find the distance of the image from the concave mirror of focal length 10cm if the object is 5cm from the mirror.

2. A concave mirror of focal length 15cm has an object placed 25cm from it. Find the position and nature of the image.

3. An object is 32cm in front of a convex mirror of focal length 16cm. Describe the image and give its position.

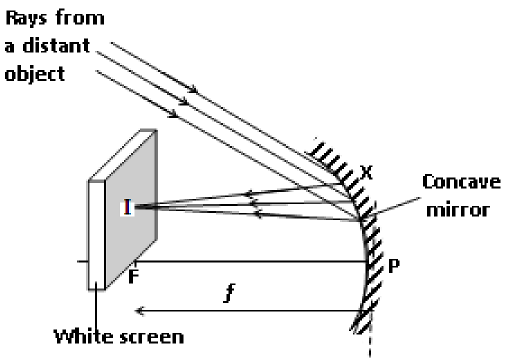
4. When an object is 42cm from a concave mirror, the object and the image are of the same height. What is the focal length of the mirror?

5. An object 5cm high is placed 30cm in front of the concave mirror. The image is 60cm in front of the mirror. Find the;
   (i) Focal length of the mirror.
   (ii) Magnification.
   (iii) Height of the object.

NOTE: Currently, the use of the mirror formula and lens formula is out of the O- level syllabus. Therefore students are encouraged to practice the use of accurate ray diagram (graphical) method to find the position of images and objects or the focal length of the mirror.

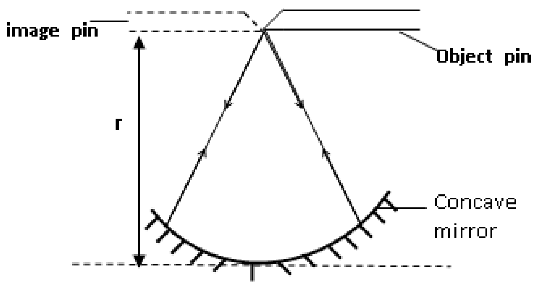
Determining the focal length of Concave mirrors

i) Focusing distant object (Approximate Method)



Light from a distant object such as a tree is focused on the screen.
Distance between the image (screen) and the pole of the mirror are measured using a metre- rule.
It is approximately equal to the focal length .f of the mirror.

ii) **By determining first the radius of curvature. (Self conjugate method) or the no parallax method.**

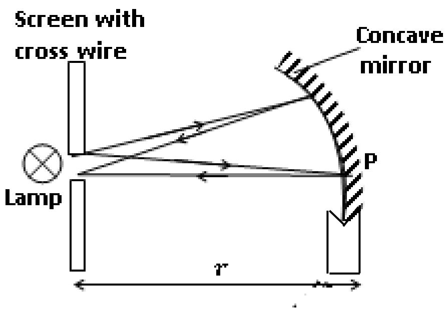


A concave mirror is placed horizontally on a bench. An optical pin is clamped horizontally on a retort stand so that the tip lies along the principal axis of the mirror.

The position of the pin is adjusted until the position is obtained where it coincides with its image and there is no parallax between the two, i.e. there is no relative motion between the object and the image when the observer moves the head from side to side or up and down.
The distance r of the pin from the pole is measured and focal length determined,

$$\boldsymbol{f} = \frac{\boldsymbol{r}}{2}$$

iii) Using an illuminated object at C



Procedures:
The apparatus is set up as shown in the diagram.
A concave mirror is moved to and fro in front of the screen until a sharp image of the cross wire is obtained on the screen.
The distance between the screen and the mirror, r is measured and recorded.
The focal length, f, of the mirror is then determined from;

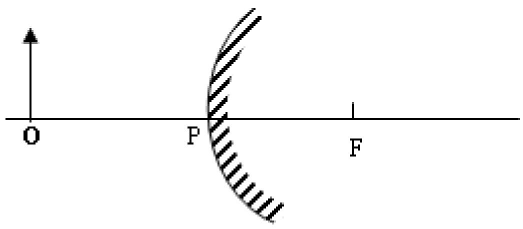
$$\boldsymbol{f} = \frac{\boldsymbol{r}}{2}$$

N.B: .
1. An object coincides with its image when the object is at the centre of curvature of the mirror.
2. The focal length is one half of the distance from the centre of curvature to the mirror.
3. Parallax is the apparent relative movement of two objects due to a movement on the part of the observer.

Exercise: See UNEB Paper I:
1.

2002 Qn.8	2003 Qn.20	2005 Qn.29	2007 Qn.2

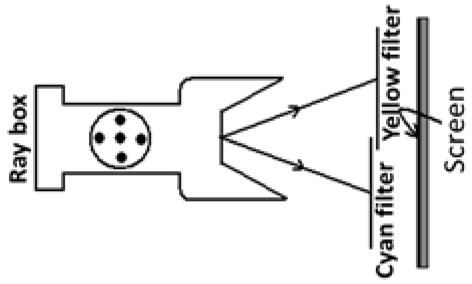
2. UNEB 1995 Qn. 5
(a) The figure below shows an object, O placed in front of a mirror. If F is the principle focus of the mirror. Complete the diagram to show the formation of the image.



(b) State two applications of convex mirrors.

3. UNEB 1997 Paper 2 Qn. 4
(c) An object 10cm high is placed at a distance of 25cm from a convex mirror of focal length 10cm.
(i) Draw a ray diagram to locate the position of the image.

Mixing Coloured Filters and Pigments



When a yellow filter and cyan filter are placed at some distance from a ray box such that half of their portions overlap.

Observation: Green light is seen where white light passes through both filters

Explanation:
For the overlap of yellow and cyan, cyan filters absorb the red
Light and transmit green and blue, but yellow filter absorbs blue light and transmits green and red (which is absorbed by Cyan filter) so only green light is transmitted.

Note: White light is separated into seven colours by a prism because the prism has different refractive index for the different colours of white lights.

Exercise:

1993 Qn.4	**1996 Qn.16**	**2000 Qn.32**	**2001 Qn. 37**	**2003 Qn.**

Section C
UNEB 1994 Qn. .4 PII;
UNEB 1994 Qn. .4 PII;

4. W

4. WAVES

A wave is a disturbance which travels through a medium and transfer energy from one point to another without causing any permanent displacement of the medium itself e.g. water waves, sound waves, waves formed when a string is plucked

CLASSIFICATION AND GENERAL PROPERTIES OF WAVES
A wave is a periodic disturbance which travels with finite velocity through a medium and remains unchanged in type as it travels. Or it is a disturbance which travels through a medium, and transfers energy from one location (point) to another without transferring matter.

Waves may be classified as mechanical or electromagnetic waves.
Mechanical waves: These are waves produced by a vibrating body. They are transmitted by particles of the medium vibrating to and fro.
They require a material medium for their propagation.
These include water waves, sound waves, waves on stretched strings and waves on vibrating springs., e.t.c.

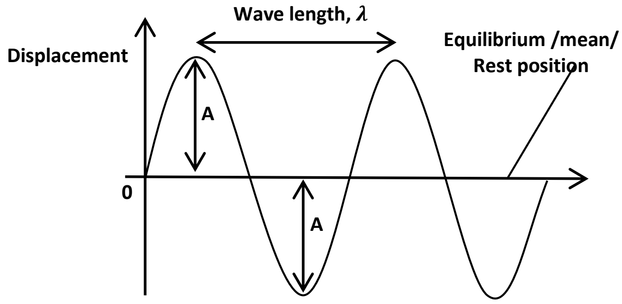
Electromagnetic waves: These are waves produced by a disturbance in form of a varying electric or magnetic fields. These are waves that don't require a material medium for their propagation. Electromagnetic waves travel in a vacuum.
They include radio, infra red, light, Ultraviolet, X-rays, Gamma rays.

If the disturbance of the source of waves is simple harmonic, the displacement in a given time varies with distance from the source as shown below.

WAVE MOTION
When a wave is set up on the medium, the particles of the medium from about a mean position as the wave passes. The vibrations are passed from one particle to the next until the final destination is reached

Generation and Propagation of mechanical waves.
Waves are generated when particles of a transmitting medium at any point are disturbed and start vibrating.
As they vibrate, they cause the neighboring particles to vibrate in turn, hence causing the vibrations to continue from the source to other regions in the transmitting medium.
The disturbance thus spreads the source outwards and it constitutes the wave.

Graphical representation of a wave.



Terms used in describing waves,

Amplitude: This is the greatest displacement of any wave particle from its equilibrium position.

Wave length (λ): Is the distance between two successive particles in a wave profile that are in phase.
It is the distance covered in a complete cycle of a wave.
It is the distance between two successive crests or troughs.
It is the distance between two successive compressions or rare factions.

Crest: It is the maximum displaced point a above the line of 0 (zero) disturbance.

Trough: It is the maximum displaced point below line of zero disturbance.

Wave front. Is a line or surface that joins points of the same phase in a wave travelling through a medium.. OR: It is the imaginary line joining the set of particles that are in the same state of motion (in phase).

Particles are in phase if they are in the same point in their path at the same time and are moving in the same direction.
The direction of travel of the wave is always at right angles to the wave front.

Cycle or Oscillation: is a complete to and fro motion of a wave. It is equivalent to moving from O to B.

Period (T): The time taken for any particle to undergo a complete oscillation. $T = \frac{t}{n}$.
Frequency (f): The number of oscillations per second.
$f = \frac{n}{t}$.

Velocity (v): The distance covered by a wave particle per second in a given direction.

Phase: Is a fraction of a cycle which has elapsed after a particle passing a fixed point.

Relationship between f and T
If a wave completes n cycles in time t, then frequency, f is given by:
Frequency, $f = \frac{n}{t}$……………………………..(i)
Period, $T = \frac{t}{n}$. ....(ii)
Eqn (i) x eqn (ii) gives;

$$fT = \left(\frac{n}{t}\right) \times \left(\frac{t}{n}\right) = 1 \Leftrightarrow f = \frac{1}{T}$$

Relationship between v, λ and f
If a wave of wavelength λ completes n cycles in time t, then the frequency, f is given by;

Each cycle is a wavelength, $\boldsymbol{\lambda}$**:**
Total distance covered in n-cycles = nλ

$$Speed, v = \frac{Distance}{Time} = \frac{n\lambda}{t} = \left(\frac{n}{t}\right)\lambda, \quad But \frac{n}{t} = f$$
$$\Leftrightarrow \quad \boldsymbol{v = f\lambda}$$

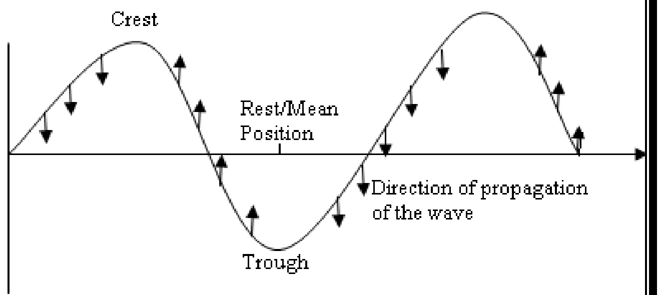
Alternatively,
If a wave covers a distance, λ, the wavelength, then the time taken is T, the period. Hence speed,
$$Speed, v = \frac{\lambda}{T} = \left(\frac{1}{T}\right)\lambda, \quad But, \frac{1}{T} = f$$
$$\Leftrightarrow \quad \boldsymbol{v = f\lambda}$$

Types of waves

There are wo broad types -:
a) progressive waves and
b) stationary waves

PROGRESSIVE WAVES
Is a wave which moves away from its source through a medium and spreads out continuously? There are two kinds of progressive waves namely:
i) Transverse waves
ii) Longitudinal waves

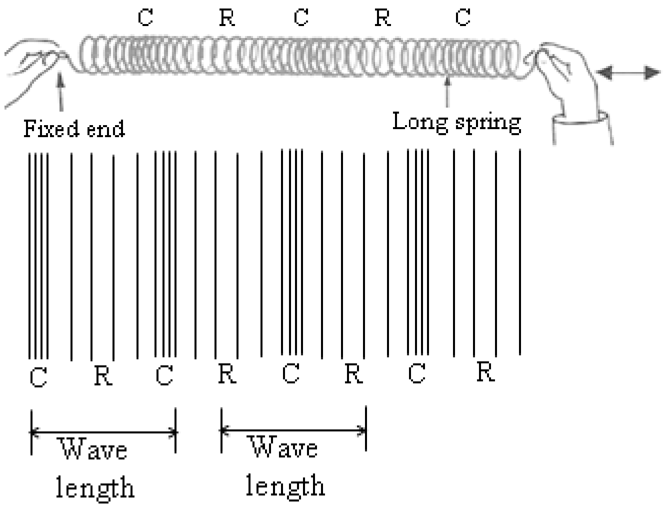
i) Transverse waves
These are waves in which particles vibrate perpendicularly to the direction of propagation of the wave.
Examples
- ✓ water waves,
- ✓ Electromagnetic waves
- ✓ waves formed when a rope is moved up and down.



ii) Longitudinal waves
These are waves in which the particles of media vibrate in the same direction as wave

OR

These are waves in which the particles of the media vibrate parallel to wave motion e.g. sound waves in pipes, waves from a slinky spring.
Longitudinal waves travel by formation of compressions and rare factions. Regions where particles crowd together are called compressions and regions where particles are further apart are called rare factions.



Compression (C) is a region in a longitudinal where the vibrating particles are very close together.
A wave faction (R) Is a region in a longitudinal where the vibrating particles are further apart (distanced).
Wave length; of the longitudinal is the distance between two successive compressions or rare factions.

Differences between longitudinal and transverse waves

Transverse Waves	Longitudinal waves
- Particles vibrate perpendicular to the direction of wave	Particles vibrate parallel to the direction of wave
-Consists of crests & troughs	Consists of compression & refraction
-Can be polarized	Cannot be polarized

1. State two differences between waves and light waves.

Examples

1. A radio station produces waves of wave length 10m. If the wave speed is 3×10^8 m/s, calculate
   (i) Frequency of radio wave.
   (ii) period time, T
   (iii) Number of cycles completed in $10^8\ s$

Solution:

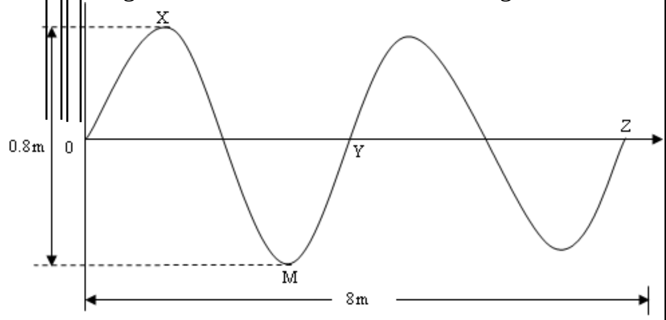
(i) Frequency of radio wave ; λ = 10m, v=3×10^8 m/s $v = f\lambda$ $3\times10^8 = f\times10$ $f = \frac{3\times10^8}{10}$ $f = 3\times10^7$Hz	(ii) Period ,T $\text{Period}, T = \frac{1}{f}$ $T = \frac{1}{3\times10^7}$ $T = 3.3\times10^{-7}$s	(ii) Number of cycles $\text{Frequency}, f = \frac{n}{t}$ $n = ft$ $n = 3\times10^7\times10$ $n = 3\times10^8$cycles

2. The distance between 10 consecutive crests is 36cm. Calculate the velocity of the wave. If the frequency of the wave is $12H_z$.

Solution:

The distance between n-successive crests or troughs is given by; $\mathbf{d = (n-1)\lambda}$	$v = f\lambda$ $v = 12\times0.04$ $v = 0.48\ ms^{-1}$
$\lambda = \frac{d}{n-1}$ $\lambda = \frac{36}{10-1} = \frac{36}{9} = 0.04$m $\lambda = 0.04$ m	

3. The diagram below shows a wave travelling in water.



(a) Name;
   (i) Any two points on the wave which are in phase
   (ii) The points Labeled m and x

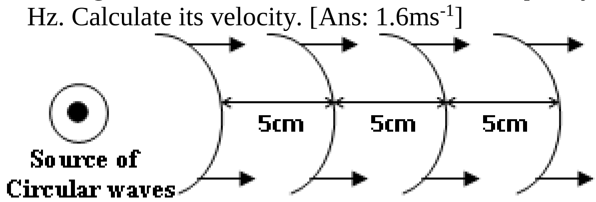
(b) (i) Determine the amplitude of the wave.
   (ii) If the speed of the wave is 8000cm/s. Determine the frequency of the wave.

Questions

1. A vibrator produces waves which travel 35 m in 2 seconds. If the waves produced are 5cm from each other, calculate;

(i) wave velocity $d = 35m, t = 2s$ $v = \frac{d}{t} = \frac{35}{2} = 17.5ms^{-1}$ $v = 17.5ms^{-1}$	(ii) wave frequency $v = f\lambda$ $f = \frac{v}{\lambda} = \frac{17.5}{5} = 3.5$Hz $f = 3.5$Hz

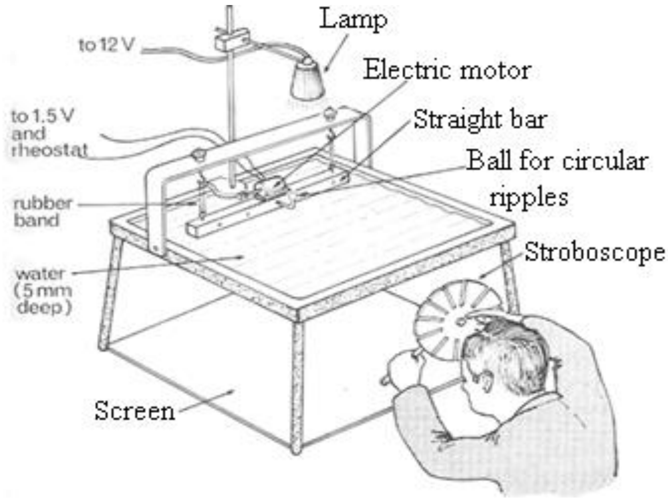
2. The figure below shows circular waves of frequency 32 Hz. Calculate its velocity. [Ans: $1.6ms^{-1}$]



3. A source produces waves which travel a distance of 140cm in 0.08s. If the distance between successive crests is 20cm, find the frequency of the source. [Ans: 87.5Hz].
4. A sound source produces 160 compressions in 10s. The distance between successive compressions is 20m. Calculate the;
   (i) frequency of sound [16HZ]
   (ii) wave speed [$320ms^{-1}$]

5. See **UNEB 1992** Qn. 7

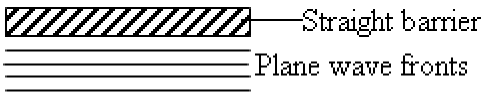
THE RIPPLE TANK



A ripple tank is an instrument used to study water wave properties. It is a shallow glass trough which is transparent. The images of the wave are projected on the screen which is placed below it.
The waves are produced by means of a dipper which is either a strip of a metal or a sphere. The dipper is moved up and down by vibration of a small electric motor attached to it.
The sphere produces circular wave fronts and the metal strip is used to produce plane waves.
A stroboscope helps to make the waves appear stationery and therefore allows the wave to be studied in details.

Straight waves (plane waves): These are produced by dipping a straight edged object e.g. a ruler on the water surface.

Continuous straight waves: These are produced by fixing a straight dipper (horizontal bar) suspended by rubber bands. The whole bar is dipped in water and is made to vibrate by the vibrations generated by an electric motor.



Continuous circular waves: These are produced by attaching small total balls (using rubber bands) to metal bars and using the vibration from an electric motor.
As the bar vibrates, the vibrations cause the dipper to move up and down producing continuous circular waves.

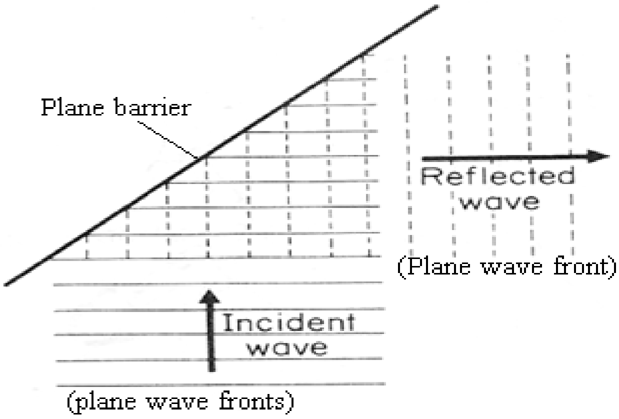
N.B Therefore the speed of the wave in a ripple tank can be reduced by reducing the depth of water in the tank. The effect of reducing the speed of waves is that the wave length of water reduces but frequency does not. The frequency can only be changed by the source of the wave.
Qn: A vibrator in a ripple tank has a period of 0.2 seconds and the distance between 10 successive crests is 38.8cm. Calculate the ;
(i) Wavelength of the wave [4.31cm]
(ii) Velocity of the wave [0.22 ms^{-1}]

WAVE PROPERTIES
The wave produced in a ripple tank can undergo.

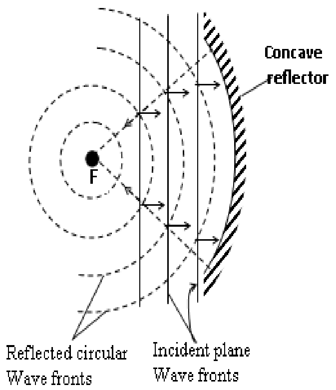
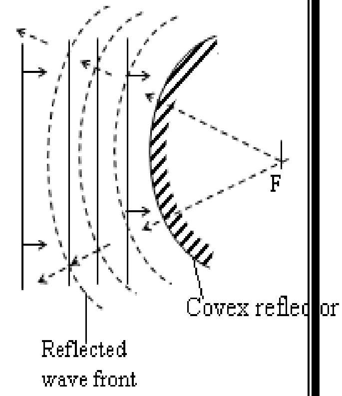
(a) Reflection	(b) Refraction	(c) Diffraction
(d) Interference	(e) Polarization	

(a) REFLECTION OF WAVES
A wave is reflected when a barrier is placed in its path. The shape of the reflected wave depends on the shape of the barrier.
The laws of reflection of waves are similar to the laws of reflection of light.

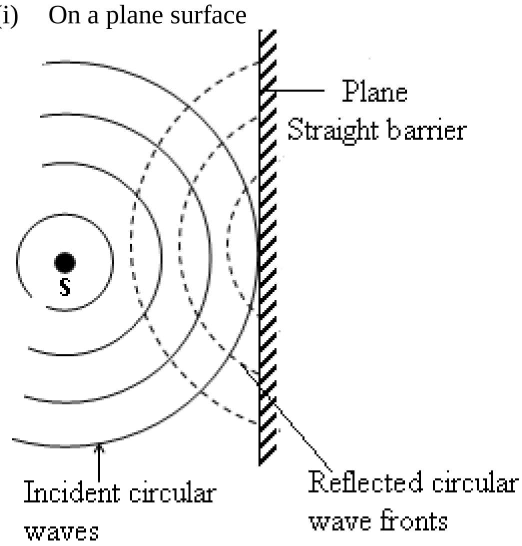
❖ **Reflection of plane wave**
(i) On a plane surface.



(ii) On a curved surface

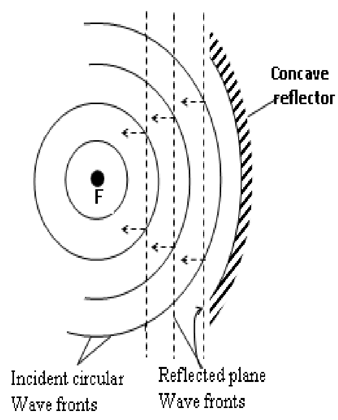
• Concave reflector	• Convex reflector
	

❖ **Reflection of circular waves**
(i) On a plane surface

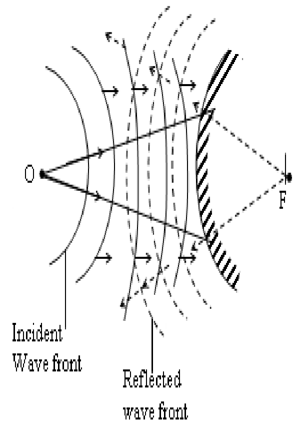


(ii) On a curved surface

- Concave reflector



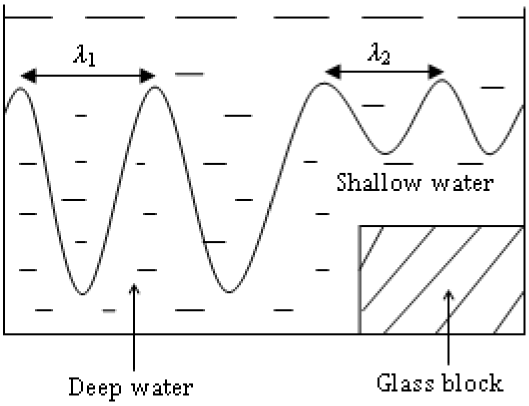
- Convex reflector



Note: During reflection of water waves, the frequency and velocity of the wave do not change.

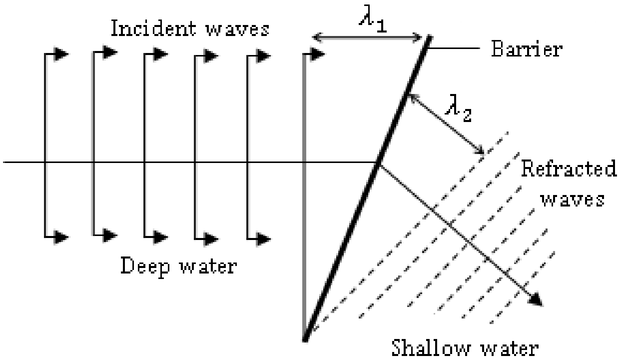
(b) REFRACTION

This is the change of in direction of wave travel as it moves from one medium to another of different depth. It is caused by the change of wave length and velocity of the wave. However, the frequency and the period are not affected.
In a ripple tank, the change in direction is brought about by the change in water depth.



When waves are incident on a shallow water boundary at an angle;

- ✓ Wave length decreases in shallow waters
- ✓ Speed decreases in shallow water
- ✓ Frequency and period remain the same.



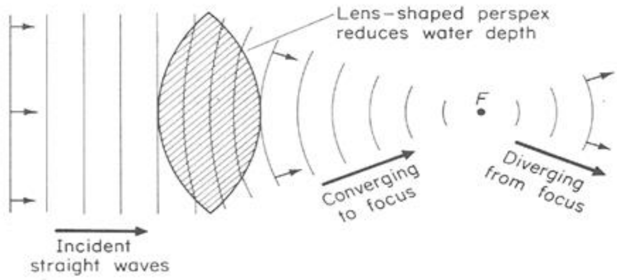
λ_1= wave length in deep water
λ_2 = wave length in shallow water
Note:
(i) $\lambda_1 > \lambda_2$
(ii) $v_1 = f\lambda_1$ and $v_2 = f\lambda_2$
(iii) $v_1 > v_2$; When f – is constant.

Refractive index $n = \frac{\text{velocity in deepwater}}{\text{velocity in shallowwater}}$

Refractive index $n = \frac{v_1}{v_2} = \frac{f\lambda_1}{f\lambda_2}$

Refractive index $n = \frac{\lambda_1}{\lambda_2} = \frac{\text{Wave length in deep water}}{\text{Wave length in shallow water}}$

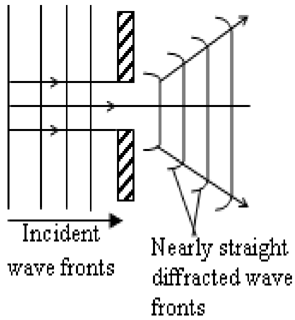
Refraction of plane waves by a convex lens



(c) DIFFRACTION

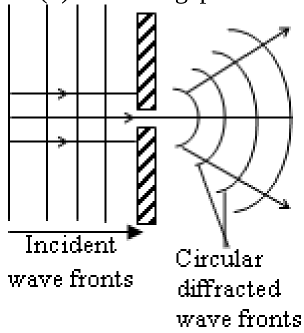
This is the spreading of waves as they pass through holes, round corners or edges of obstacle. It takes place when the diameter of the whole is in the order of wave length of the wave i.e. the smaller the gap the greater the degree of diffraction as shown below.

(a) Wide gap



The ripples emerge straight and curve at the ends.

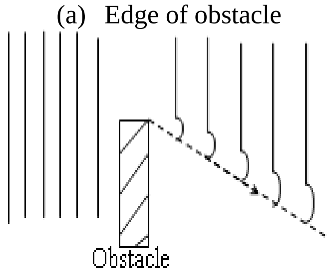
(b) Narrow gap



The ripples emerge in a semi-circular pattern.

-Waves spread out more (i.e greatly diffracted) when the wave length is longer.
-The wave length does not change when waves pass through the slit.
-Diffraction (spreading) increases with decrease in the width of the slit. Wider gaps produce less diffraction.
-When the width of the gap is less than the wave length of the of the incident waves, the emerging waves are circular. At this width, the slit may be considered to act as a separate point source of waves.

(a) Edge of obstacle

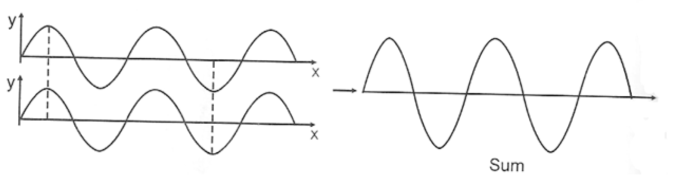


Sound waves are more diffracted than light waves because the wave length of sound is greater than that of light. Therefore sound can be heard in hidden corners.
N.B - When waves undergo diffraction, wave length and velocity remain constant.

(d) INTERFERENCE
This is the super imposition of two identical waves travelling in the same direction to form a single wave with a larger amplitude or smaller amplitude.
The two waves should be in phase (matching).

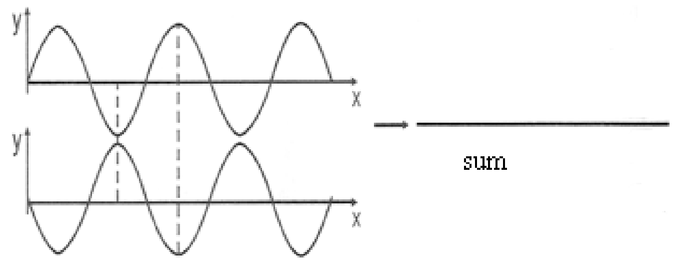
Conditions necessary for producing interference:
1. The two waves must have coherent sources.
2. The two waves must have the same amplitude and the same frequency.
3. The distance between the sources must be very small.

Constructive interference
This constructive interference occurs when a crest from one wave source meets a crest from another source or a trough from one source causing reinforcement of the wave i.e. increased disturbance is obtained.
The resulting amplitude is the sum of the individual amplitudes.
E.g.
$\cap + \cap = \cap$ OR $\cup + \cup = \cup$



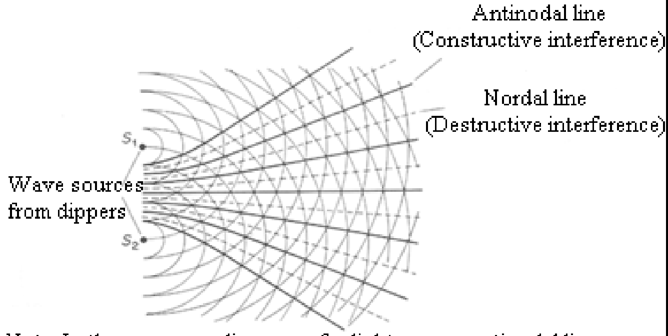
- **For Light,** constructive Interference would give **increased brightness.**
- **For sound,** constructive Interference would give **increased loudness.**

Destructive interference
This occurs when the crest of one wave meets a trough of another wave resulting in wave cancelling i.e.
If waves are out of phase, they cancel each other to give an area of zero resultant. This is called destructive interference.
e.g.
$\cap + \cup =$ ……………………………………………

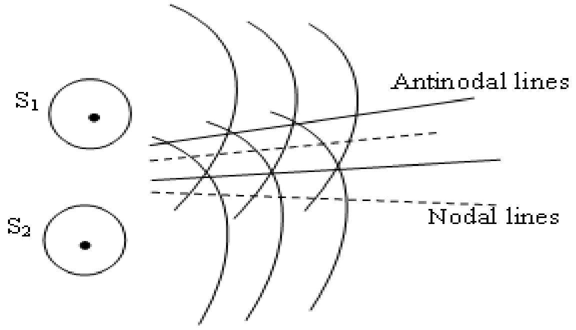


For Light, constructive Interference would give **reduced brightness or darkness.**
For sound, constructive Interference would give **reduced loudness or no sound at all.**

Note:
The interference pattern caused by two sources placed close together – give nodal and antinodal lines that are spread widely. When the two sources are placed far apart, the nodal and anti-nodal lines are closer together making the pattern more difficult to see.



Note: In the corresponding case for light waves, antinodal lines are **bright fringes** and nodal lines are **dark fringes**.



Lines joining points of constructive interference are called **antinodal lines** while these lines joining points of destructive interference are called **nodal lines**.

Trial Questions:
(a) *With the aid of a diagram, describe how an interference patter (Interference fringes) can be produced in a ripple tank.*
(b) *What are the conditions necessary for interference to occur?*

(e) POLARISATION OF WAVES
It only occurs with transverse waves like other transverse waves, water waves can be polarized.
Polarization: is the effect in which vibration are in only a vertical plane.
Differences between water and sound waves;

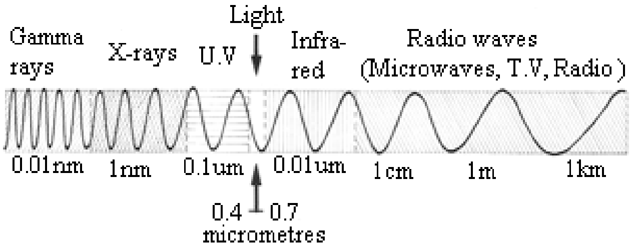
Water waves	Sound waves
-Transverse	Longitudinal
-Low speed	High speed
-Short wave length	Long water length
-Can be polarized	Cannot be polarised
-Possible only in liquid (.e.g water)	Possible in solids, liquids and gases.

State three differences between sound and light waves.

Wave motion 1992 Qn7 1989 Qn30 1990 Qn21	1994 Qn23 1998 Qn23 1998 Qn26 2001 Qn18	1992 Qn1 2006 Qn22 2007Qn35 2007Qn39	2008 Qn31 1989 Qn6 1993 Qn4 2006 Qn5

ELECTRO MAGNETIC WAVES
This is a family of waves which is made by electric and magnetic vibrations of very high frequency.
Electromagnetic waves do not need a material medium for transformation i.e. they can pass through a vacuum.

Spectrum of electromagnetic waves
In decreasing frequency



Properties of electromagnetic waves

- They are transverse waves.
- They can travel through vacuum.
- They travel at a speed of light (3.0×10^8 m/s).
- They can be reflected, refracted, diffracted and undergo interference.
- They posses energy.

Effects of electromagnetic waves on meter

(a) Gamma rays.
- They destroy body tissues if exposed for a long time.
- They harden rubber solutions and lubricate oil to thickness.

(b) X- rays
- Causes curtains to give off electrons.
- Destroys body tissues if exposed for a long time.
- Used in industries to detect leakages in pipes and in hospitals to detect fractures of bones.

(c) Ultra violet
- Causes sun burn
- Causes metals to give off electrons by the process called photoelectric emission.
- Causes blindness.

(d) Visible light
- Enables us to see.
- Changes the apparent color of an object.
- Makes objects appear bent to refraction.

(e) Infrared
- Causes the body temperature of an object to rise.
- It is a source of vitamin D.

(f) Radio waves
- Induces the voltage on a conductor and it enables its presence to be detected.

Wave band	Origin	Source
Gamma rays	Energy changes in modes of atoms	Radioactive substance
X- rays	Electrons hitting a metal target	X – ray tube
Ultra- violet	Fairly high energy changes in atoms	Very hot bodies Electron discharge Through gases especially mercury Vapour
Visible light	Energy changes in electron structure of atoms	Lamps, flames etc
Infrared radiation	Low energy changes in electrons of atoms	All matter over a wide range of temperature from absolute zero onwards.
Radio waves	High frequency Oscillating electric current Very low energy changes in electronic structures of atoms.	Radio transmission aerials.

Red Sun set and Blue sky
Effect of long and short wave lengths.
(i) Long wavelength: Waves of long wavelength are less scattered than waves of short wavelength. This explains why the sun appears red when rising or setting.
Explanation: At sun rise or sun set, the light rays from the sun travel through greater thickness of earth's atmosphere. So the longer wavelength passes through.
(ii) Short wavelength: Waves of short wavelength are highly scattered. This explains why the sky appears blue, since the primary colour, blue has the shortest wavelength in the spectrum.
Note: Beyond the atmosphere, the sky appears black and the astronauts are able to see the stars and the moon.

Electromagnetic waves 1987 Qn30 1989 Qn16	2001 Qn21 2006 Qn31 2007 Qn13

SOUNDS WAVES

Is a form of energy which is produced by vibrating objects e.g. when a tuning fork is struck on a desk and dipped in water, the water is splashed showing that the prongs are vibrating or when a guitar string is struck.

PROPERTIES OF SOUND WAVES
- Cannot travel in a vacuum because there is no metal needed.
- Can cause interference.
- Can be reflected, refracted, diffracted, planes polarized and undergo interference.
- Travels with a speed V= 330m/s in air.

SPECTRUM SOUND WAVES

Frequency	$0H_Z$	$20H_Z$	$20,000H_Z$
Type of sound	Subsonic sound	Audible sound waves	Ultra sonic sound wave.

Subsonic sound waves
These are not audible to human ear because of very low frequency of less than $20H_Z$.

Audible sound waves
These are audible to human ear. This frequency ranges from $20H_Z$- 20 KH_Z.

Ultra sonic sound waves
These are sound waves whose frequencies are above $20H_Z$. They are not audible to human ears. They are audible to whales, Dolphins, bats etc.

Application of ultra sound waves

- They are used by bats to detect obstacles e.g. buildings a head.
- Used in spectacles of blind to detect obstacles.
- Used in radio therapy to detect cracks and faults on welded joints.
- Used in industries to detect rocks in seas using sonar.
- Used to measure the depth of seas and other bodies.

Example: 1

A radio station broad casts at a frequency of 200 kHz and the wave length of its signal is 1500m. Calculate the;

(i) Speed of the radio waves. [3.0×10^8]

(ii) Wave length of another station that broad casts at a frequency of 250 Hz. [$\lambda = 1.2 \times 10^6$ m.]

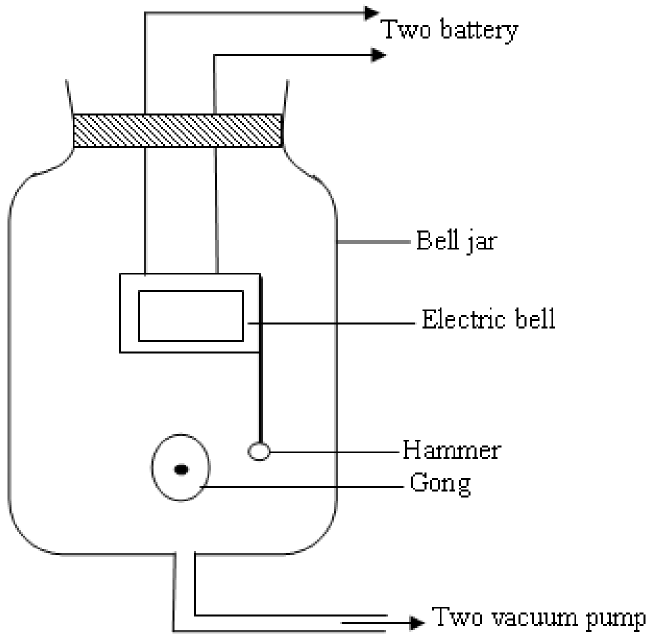
Example: 2

An F.M radio, broad casts at a frequency of 88.8MHz. What is the wave length of the signal? [$\lambda = 3.4$m]

TRANSMISSION OF SOUND.

Sound requires a material medium for its transmission. It travels through liquid, solids and gases, travels better in solids and does not travel through vacuum.

Experiment to show that sounds cannot pass through a vaccum.



Procedures:

- Arrange the apparatus as in the diagram with air, in the jar.
- Switch on the electric bell, the hammer is seen striking the gong and sound is heard.
- Gently withdraw air from the jar by means of a vacuum pump to create a vacuum in the jar.

Observation:

- The sound produced begins to fade until it is heard no more yet the hammer is seen striking the gong.
- Gently allow air back into the jar, as the air returns, the sound is once again heard showing that sound cannot travel through vacuum.

Conclusion:

- Sound waves require a material medium for their transmission.

Note: The moon is sometimes referred to as a silent planet because no transmission of sound can occur due to lack of air (or any material medium).

The speed of sound depends on;

(i) Temperature

Increase in temperature increases the speed of sound i.e. sound travels faster in hot air than in cold air.

(ii) Wind

Speed of sound is increased if sound travels in the same direction as wind.

(iii) Attitude

Sound travels faster on a low altitude and slower on higher altitude.

(iv) Humidity:

The higher the humidity, the higher the speed of sound and velocity.

(v) Density of the medium.

Speed of sound is more in denser medium than in the less dense medium.

Change in pressure of air does not affect speed of sound because the density of air is not affected by change in pressure.

Sound travels fastest in solids than liquids and gases because. In solids the particles in solids are very close together and they produce vibration easily i.e. solids are more dense. Also speed of sound is faster in liquids than in gases.

In solids and liquids, increasing the temperature decreases the speed of sound because solids are denser. Also speed of sound is faster in liquids than in gases.

Some media and the speed of sound

Medium	**Speed of sound (ms^{-1})**
Air	330
Steer	600
Water	1500
Glass	5600

Some explanations

- If a person places his ear near the ground and another person taps along a metal which is some distance away the sound will be heard clearly than when standing since sound travels faster in solids than in gases.

- A sound made by a turning fork, sounds, louder when placed on a table than when held in the hand. This is because a larger mass of air is set in vibration thereby increasing the sound.

Qn. Explain why sound travels faster in solids than in liquids.

- Sound waves of frequency 3.3 KHz travel in air. Find the wavelength (Take speed of sound in air = $330ms^{-1}$)

$$V = f\lambda \Rightarrow \lambda = \frac{V}{f} = \frac{330}{3.3 \times 1000} = \frac{330}{3300} = 0.1m$$

Example:

Two men stand a distance apart besides a long metal rail on a sill day. One man places his ear against the rail while the other gives the rail a sharp knock with a hammer. Two sounds separated by a time interval of 0.5s, are heard by the first man. If the speed of sound in air is $330ms^{-1}$, and that in the metal rail is $5280ms^{-1}$, find the distance between the men.

Solution:

$t_1 - t_2 = 0.5$

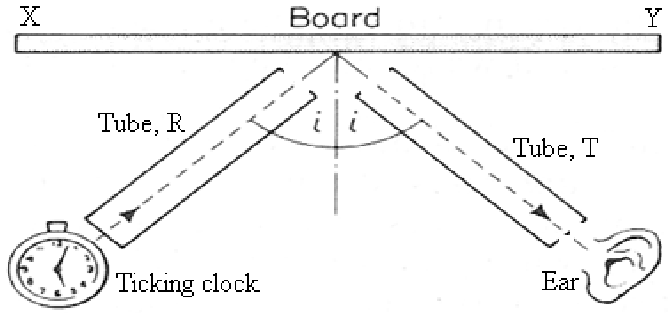
$\frac{x}{330} - \frac{x}{5280} = 0.5$

$x = 176 \text{ m}$

How sound waves travel through air

- Sound waves are produced by the vibration of air particles. As air particles vibrate, the vibration, produce energy which is transferred to the next particles that also vibrate in the same direction as the sound wave.
- The next particle are so made to vibrate and in doing so, they transfer their energy particles which also vibrate.

Experiment to verify the laws of reflection of sound.



XY is a hard plane surface, R is a closed tube and T is an Open tube.

- Put a ticking clock in tube R on a table and make it to face a hard plane surface e.g. a wall.
- Put tube T near your ear and move it on either sides until the ticking sound of the sound is heard loudly.
- Measure angles i and r which are the angles of incidence and reflection respectively.
- From the experiment, sound is heard distinctly due to reflection.
- Angle of incidence (i) and angle of reflection (r) are equal and lie along XY in the same plane.
- This verifies the laws of reflection.

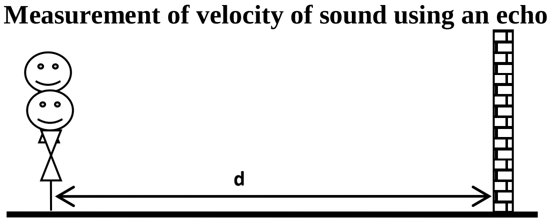
Note: Hard surfaces reflect sound waves while soft surface absorb sound wave.

ECHOES

An echo is a reflected sound. Echoes are produced when sound moves to and fro from a reflecting surface e.g. a cliff wall. The time taken before an echo arrives depends on the distance away from the reflecting surface.

In order for a girl standing at a distance, **d** from a reflecting surface to hear the echo; sound travels a distance of **2d**.

Measurement of velocity of sound using an echo method



- Two experimenters stand at a certain distance **d** from a tall reflecting surface
- One experimenter claps pieces of wood **n times**, while the other starts the stop clock when the first sound is heard and stops it when the last sound is heard.
- The time taken, t for the n claps is recorded and the speed of sound in air is calculated from;

$$\textbf{Speed} = \frac{\textbf{2(distance)}}{\textbf{time}} = \frac{\textbf{2nd}}{\textbf{t}}$$

For an echo; Speed $= \frac{2(\text{distance})}{\text{time}} = \frac{2d}{\left(\frac{t}{n}\right)} = \frac{2nd}{t}$

Where n is the number of claps (or sounds) made.

Example: 1

A girl stands 34m away from a reflecting wall. She makes sound and hears an echo after 0.2 seconds. Find the velocity of sound.

$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$

$V = \frac{2d}{t}$

$V = \frac{2 \times 34}{0.2}$

$V = 340 \text{ ms}^{-1}$

Example: 2

A person standing 99m from a tall building claps his hands and hears an echo after 0.6 seconds. Calculate the velocity of sound in air.

$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$

$V = \frac{2d}{t} = \frac{2 \times 99}{0.6} = 330 \text{ ms}^{-1}$

$V = 330 \text{ ms}^{-1}$

Example: 3

A gun was fired and an echo from a cliff was heard 8 seconds later. If the velocity of sound is 340m/s, how far was the gun from the cliff?

$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$

$V = \frac{2d}{t}$

$340 = \frac{2d}{8}$

$2d = 340 \times 8$

$2d = 2720$

$d = 1360 \text{ m}$

Example: 4

A student is standing between two walls. He hears the first echo after 2 seconds and then another after a further 3 seconds. If the velocity of sound is 330m/s, find the distance between the walls.

$V = \frac{2d_1}{t_1}$ $330 = \frac{2d_1}{2} \Rightarrow 2d_1 = 660$ $d_1 = 330 \text{ m}$	$V = \frac{2d_2}{t_2}$ $330 = \frac{2d_2}{5} \Rightarrow 2d_2 = 1650$ $d_2 = 825 \text{ m}$
$d = d_1 + d_2$ $d = 330 + 825$ $d = 1155\text{m}$	

Example: 5

A man is standing midway between two cliffs. He claps his hands and hears an echo after 3 seconds. Find the distance between the two cliffs.

(Velocity of sound = 330m/s)

$V = \frac{2d_1}{t_1}$ $330 = \frac{2d_1}{3} \Rightarrow 2d_1 = 990$ $d_1 = 495$ m	Since the man is mid way between the cliffs, $d_2 = d_1 = 495$m $d = d_1 + d_2$ $d = 495 + 495$ $d = 990$m

Example: 6

A student made 50 claps in one minute. If the velocity of sound is 330s, find the distance between the student and the wall.

$\text{Speed} = \frac{2n(\text{distance})}{\text{time}}$

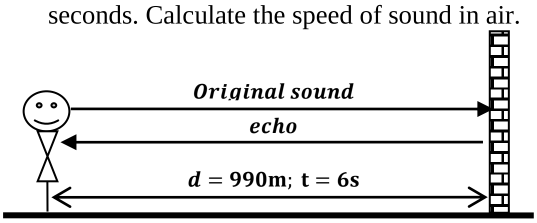
$V = \frac{2nd}{t}$

$330 = \frac{2 \times 50 \times d}{60}$

$100d = 330 \times 60$

$d = 198$

1. A boy stands at a distance of 990m from a tall building and makes a loud sound. He hears the echo after 6 seconds. Calculate the speed of sound in air.



$$V = \frac{2d}{t} = \frac{2 \times 990}{6} = 330ms^{-1}$$

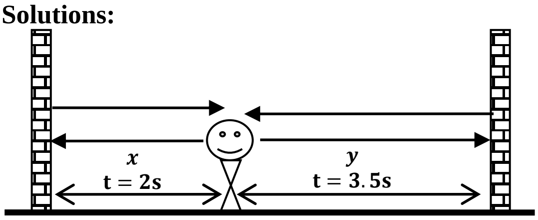
2. A sound wave of frequency 200Hz is produced 300m away from a high wall. If the echo is received after 2 seconds. Find the wave length of sound wave.

$$V = \frac{2d}{t} = \frac{2 \times 300}{2} = 3000ms^{-1}$$

$$f\lambda \Rightarrow \lambda = \frac{v}{f} = \frac{300}{200} = 1.5m$$

3. A man stands between two cliffs and fires a gun. He hears the 1st echo after 2seconds and the second echo after 3 ½ seconds. Calculate the distance between two cliffs and speed of sound in air = 330ms^{-1}.

Solutions:



Case I	**Case II**
$V = \frac{2x}{t_1}$ $330 = \frac{2x}{2} \Rightarrow 2x = 2 \times 330$ $x = 330$ m	$V = \frac{2x}{t_1}$ $330 = \frac{2y}{3.5} \Rightarrow 2y = 3.5 \times 330$ $y = 577.5$ m
$Distance\ between\ the\ cliffs, d = x + y$ $d = x + y$ $d = 330 + 577.7$ $d = 907.5$ m	

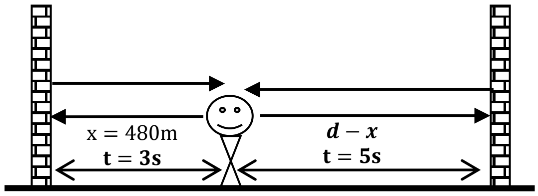
4. A student, standing between two vertical cliffs and 480m from the nearest cliff shouted. She heard the 1st echo after 3 seconds and the second echo 2 seconds later. Calculate;

(i) The velocity of sound in air.

(ii) The distance between the cliff.

Solutions:

Let distance between cliffs = **d**



Case I	**Case II**
$V = \frac{2x}{t_1}$ $V = \frac{2 \times 480}{3} \Rightarrow 3V = 960$ $V = 320\ ms^{-1}$	$V = \frac{2(d - x)}{t_2}$ $320 = \frac{2(d - 480)}{5}$ $2(d - 480) = 5 \times 320$ $d - 480 = 800$ $d = 1280$ m

Questions

1. A boy standing 100m from the foot of a high wall claps his hands and the echo reaches him 0.5s after. Calculate the speed of sound in air.

2. A sound wave is produced 600m away a high wall. If an echo is received after 4 seconds. Find the frequency of sound wave length is 2m.

3. A sound wave of frequency 250Hz is produced 120m away from a high wall. Calculate;

(i) The wavelength of the sound wave

(ii) The time taken for the sound wave to travel to the wall and back to the source and speed of sound in air = 330ms^{-1}.

4. A man standing between two vertical walls and 170m from the nearest wall shouted. He heard the 1st echo after 4s and the 2nd echo 2 seconds later. Find the distance between the walls.

5. A boy standing 150m from a high cliff claps his hands and hears an echo. If the velocity of sound in air is $320ms^{-1}$. Find the time taken for the sound to travel to the wall and back to the source.

6. A man stands at a distance of 340m from a high cliff and produces sound. He hears the sound Again after 2 seconds. Calculate the speed of sound.

7. A child stands between 2 cliffs and makes sound. If it hears the 1^{st} echo after 1.5 seconds and the 2^{nd} echo after 2.0 seconds. Find the distance between the 2 cliffs. (Speed of sound in air = $320ms^{-1}$).

8. A man sees the flash from a gun fired 1020m away and then hears a bang. How long does the bang take to reach him? [Ans: 330x1020 s].

9. The echo sounder on a boat sends down the sea, a pulse and receives its echo 0.3 seconds later. Find the depth of the sea. (speed of sound in water is $1445ms^{-1}$)
[Ans: 216.8m].

10. A girl at A clapped her hands once and a boy at B heard two claps in an interval of 1 second between the two sounds. Find the distance AB. [Ans: 330m].

11. Two people X and Y stand in a straight line at distances of 330m and 660m respectively from a high wall. Find the time interval taken for X to hear the first and second sounds when Y makes a loud sound. [Ans: 2.0 s].

Reverberation
In a large hall where there are many reflecting walls, multiple reflections occur and cause or create an impression that sound lasts for a longer time such that when somebody makes a sound; it appears as if it is prolonged. This is called reverberation.

Definition of Reverberation
Reverberation is the effect of the original sound being prolonged due to multiple reflections.

Advantages of reverberation
In grammar, reverberation is used in producing sound. Complete absence of reverberation makes speeches inaudible.
Disadvantages of reverberation
During speeches, there is a nuisance because the sound becomes unclear.

Prevention of reverberation
The internal surfaces of a hall should be covering the sound absorbing material called acoustic materials.

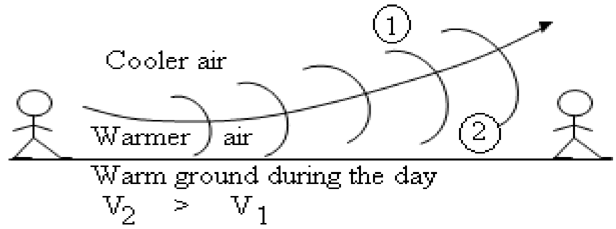
Why echoes are not heard in small rooms?
This is because the distance between the source and reflected sound is so small such that the incident sound mixes up with the reflected sound making it harder for the ear to differentiate between the two.

Questions:
(a) Outline four properties of electromagnetic waves.
(b) Distinguish between:
(i) Sound waves and light waves.
(ii) Sound waves and water waves.

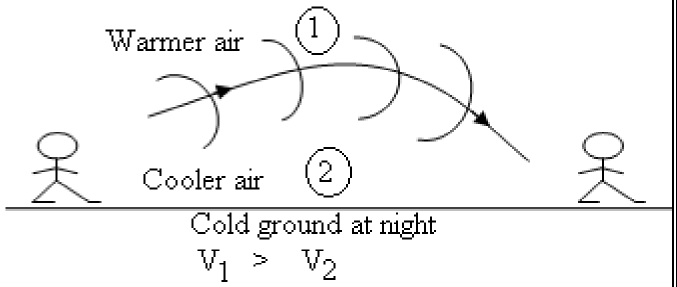
1. A man standing midway between two cliffs makes a sound. He hears the first echo after 3s. Calculate the distance between the two cliffs (Velocity of sound in air = 330m/s)

Refraction of sound waves
Refraction occurs when speed of sound waves changes as it crosses the boundary between two media. The speed of sound in air is affected by temperature.
Sound waves are refracted when they are passed through areas of different temperatures. This explains why it is easy to hear sound waves from distant sources at night than during day.

Refraction of sound during day.



During day, the ground is hot and this makes the layers of air near the ground to be hot while that above the ground is generally cool. The wave fronts from the source are refracted away from the ground.
Refraction of sound during night



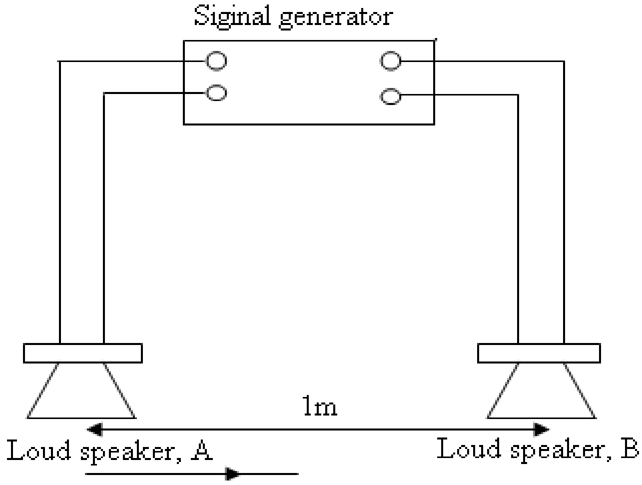
During night, the ground is cool and this makers layers of air near the ground to be cool while above to be warm. The wave fronts from the source are refracted towards the ground making it easier to hear sound waves over long distances.
Diffraction of sound
This refers to the spreading of sound waves around corners or in gaps. When sound waves have wave length similar to the size of the gap. They are diffracted most.
Sound waves easily bend around corners because they have longer wavelength and are easily diffracted.

A person in one room can be heard by another person in the next room because of diffraction of sound waves.
The mouth acts as a gap and the waves from mouth spread and the person is able to hear the sound.
If you are sitting in a room and the door is open, you can hear music from a radio in the next room; the sound waves from the radio pass through the door and spread out into the room you are in.

Note:
Light waves are not easily diffracted because they have short wave length.

Interference of sound
When two sound waves from two different sources overlap, they produce regions of loud sound and regions of quiet sound. The regions of loud sound are said to undergo constructive interference while regions of quiet are said to undergo destructive interference.

An experiment to show interference of sound waves.



Two loud speakers A and B are connected to the same signal generator so that sound waves from each are in phase and are of the same frequency. Interference of waves from A and B occurs
An observer moving in front of the loud along AB hears alternating **loud** and **soft** sound as he moves which corresponds to **constructive** and **destructive** interferences respectively.
With the sound set at a lower frequency (long wave length) the interference pattern becomes widely spread.

Qn. Describe an experiment to show interference of sound waves.

MUSICAL NOTES OR TONES:
A musical note or a tone is a single sound of a a definite pitch and quality made by a musical instrument or voice.

Music: This is an organized sound produced by regular vibrations.

Noise: This is a disorganized sound produced by irregular vibrations.

Characteristics of musical notes
(i) Pitch
This is the loudness or softness of sound. It depends on the frequency of sound produced, the higher the frequency the higher the pitch.

(ii) Loudness
This depends on the amplitude of sound waves and sensitivity of the ear.
- Amplitude; This is the measure of energy transmitted by the wave. The bigger the amplitude, the more energy transmitted by the wave and the louder sounder sound produced.
- Sensitivity of the ear. If the ear is sensitive, then soft sound will be loud enough to be detected and yet it will not be detected by the ear which is insensitive.

(iii) Timber (Quality)
This is the characteristic of a note which allows the ear to distinguish sounds of the same pitch and loudness it depends on the number of overtones produced, the more the number of overtones, the richer and the sweeter the music and therefore the better the quality.

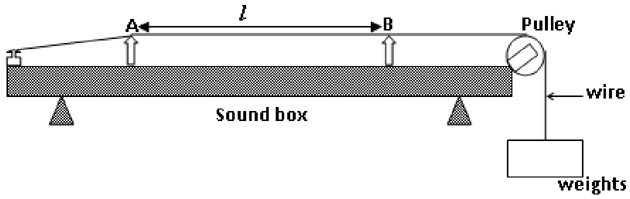
Overtone
This is a sound whose frequency is a multiple of a fundamental frequency of the musical note.

Pure and impure musical notes.
Pure refers to a note without overtones. It is very boring and only produced by a tuning fork.
Impure refers to a note with overtones. It is sweet to the ear and produced by all musical instruments.

Beats
A beat refers to the periodic rise and fall in the amplitude of the resultant note.

VIBRATION IN STRINGS
Many musical instruments use stretched strings to produce sound. A string can be made to vibrate plucking it like in a guitar or in a harp putting it in pianos. Different instruments produce sounds of different qualities even if they are of the same note.

Factors affecting the frequency of the stretched string.



A. =Fixed bridge; B.=Movable bridge

(a) Length
For a given tension of the string, the length of the string is inverse the proportion to the frequency of sound produced. This can be demonstrated by an instrument called sonometer as shown above.
By moving bridgeB, higher frequency can be obtained for a short length AB and lower frequency for a long length. The relation can be expressed as ;
$f \propto \frac{1}{l} \Rightarrow fl = k \Rightarrow \boldsymbol{f_1 l_1 = f_2 l_2}$

(b) Tension
Adding weights or removing them from its ends at load R the tension of the higher sonometer wire. It will be noted that the higher the tension, the higher the frequency of the note produced.

$$f \propto \sqrt{T} \Rightarrow \frac{f}{\sqrt{T}} = k \Rightarrow \frac{\boldsymbol{f_1}}{\boldsymbol{f_2}} = \sqrt{\frac{\boldsymbol{T_1}}{\boldsymbol{T_2}}}$$

(c) Mass per unit length (μ)
Keeping length (l) and tension (t) constant, the frequency of sound produced depends on the mass per unit length of the string. Heavy strings produce low frequency sounds. This is seen in instruments such as guitar, base strings are thicker than solo strings. If the tension and length are kept constant, the frequency of sound is inversely proportional to the mass

of the strings thus a thin short and taut string produces high frequency sound.

$f \propto \frac{1}{\sqrt{\mu}} \Rightarrow f\sqrt{\mu} = k \Rightarrow \boldsymbol{f_1\sqrt{\mu_1} = f_2\sqrt{\mu_2}}$

Where, $\mu = mass\ per\ unit\ length = \frac{mass}{length}$

The three factors can be combined into a single formula to give the expression for frequency of a stretched string (wire) as:

$$\boldsymbol{f = \frac{1}{l}\sqrt{\frac{T}{\mu}}}$$

Where, ***l*** is the length in m, **T** is the tension in N and μ is mass per unit length in kgm^{-1}

Example: 1

A musical note has frequency of $420H_z$ and length (l), if the length of the string is reduced by $\frac{1}{2}$, find the new frequency.

$f_1 l_1 = f_2 l_2$

But, $l_2 = \frac{1}{2}l_1$

$420 \times l_1 = f_2\left(\frac{1}{2}l_1\right)$

$f_2 = 840$ Hz

A stationary wave is a wave formed when two progressive waves of the same frequency and wave length travelling in opposite direction meet producing nodes and antinodes.

Progressive wave is a wave in which energy is transmitted from one place to another and is not stores.

Vibrating strings

The ways in which a string vibrates are called harmonics. The sound is produced when notes are performed at both ends of a stationary wave.

Modes of vibration

The ends of a stretched string are fixed and therefore the ends of the string must be the displacement nodes.

If the string is displaced in the middle, a stationary wave is formed.

Fundamental note:

- Is a note with the lowest audible frequency.
- It is the note produced at the first position of resonance.

Overtones:

- Is a note whose frequency is higher than the fundamental frequency.
-

Uses of overtones:

-Determining the overall quality of sound

-Describing sound systems in pipes or plucked strings.

Harmonics:

- Is a note whose frequency is an integral multiple of the fundamental frequency.

Musical Interval:

- This is the ratio of the frequencies of two notes.

Name of musical note	Tone ratio
Octave tone	2:1
Minor tone	5:4
Major tone	9:8
Semi tone	16:5

Octave:

- This is the span of notes between one pitch and another that it is twice or a half its frequency.

Note: Two notes with fundamental frequencies in a ratio of any power of two (e.g half, twice, four times e.t.c) will sound similar. Because of that, all notes with these kinds of relations can be grouped under the same pitch class.

Note: In calculations involving octave use the formula;

$$\boldsymbol{\frac{f_2}{f_1} = \left(\frac{2}{1}\right)^n}$$

Where, f_2 = Higher frequency

f_1 = Lower frequency

n = Number of octaves above or below f_1

Example: 1

Find the frequency of a note four octave above a note of frequency 20Hz.

Solution: $f_1 = 20Hz, n = 2\ (above);\ f_2 = ?$

$\frac{f_2}{f_1} = \left(\frac{2}{1}\right)^n \Rightarrow \frac{f_2}{20} = \left(\frac{2}{1}\right)^2 \Rightarrow f_2 = 2^2 \times 20 = 80Hz$

Example: 1

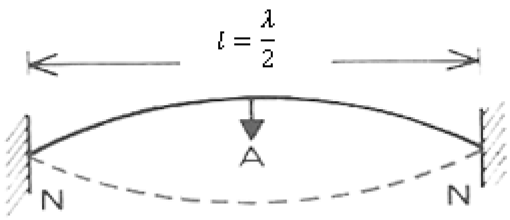
Find the frequency of a note of four octaves below a note of frequency 512Hz.

Solution: $f_2 = 512Hz, n = 4\ (below);\ f_1 = ?$

$\frac{f_2}{f_1} = \left(\frac{2}{1}\right)^n \Rightarrow \frac{512}{f_1} = \left(\frac{2}{1}\right)^4 \Rightarrow f_1 = 2^4 \times 20 = 32Hz$

(i) First Position of resonance (fundamental note)

1st harmonic vibration



The wave formed in this case is the simplest form of vibration and is called the fundamental note .

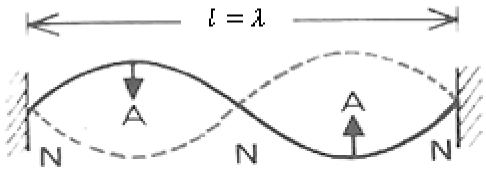
The frequency at which it vibrates is called the fundamental frequency.

If f is the frequency (Fundamental frequency). Then $f_1 = \left(\frac{v}{\lambda}\right)$, But $\lambda = 2l$

$f_1 = \left(\frac{v}{2l}\right)$, Where v is the speed of the wave.

(ii) Second Position of resonance (first Overtone).

When the wave is plucked quarter way from one end, the wave formed is shown below.

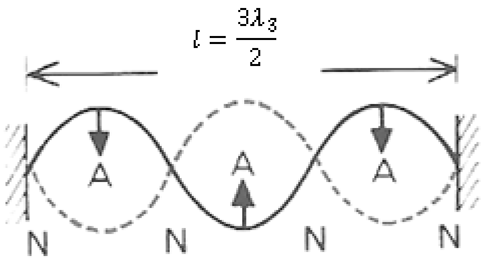


If f_2 is the frequency of the wave, then;

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{l} = \frac{2}{2} \times \frac{v}{l} = 2 \times \left(\frac{v}{2l}\right) = 2f_1$$

Thus, it is also called the **second harmonic.**

(iii) ***Third Position of resonance (2nd overstone)***



$$f_3 = \frac{v}{\lambda_3} = \frac{v}{\left(\frac{2}{3}l\right)} = 3 \times \frac{v}{2l} = 3f_1$$

Thus, it is also called the **third harmonic.**

Therefore in a stretched string all the harmonics are possible and their frequencies are; $f_1, 2f_1, 3f_1, 4f_1$ ..

Thus harmonics obtained from vibrating strings are $f_1, 2f_1, 3f_1$ etc. hence both even and odd harmonics are obtained.

A- Antinodes- these are points that are permanently at rest. No disturbance occurs at these points.

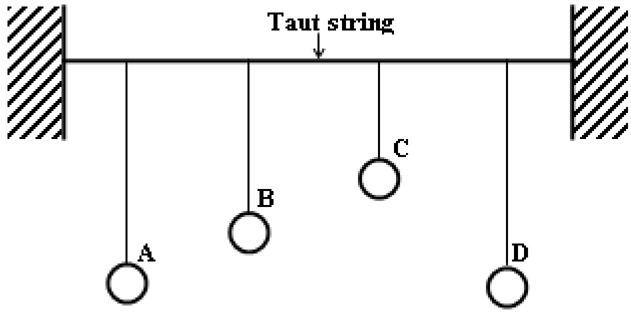
RESONANCE

This is when a body is set into vibrations with its own natural frequency by another nearby body vibrating at the same frequency.

The final amplitude of the resonating system builds up to a much greater value than that of the driving system.

An experiment to demonstrate Resonance using a coupled pendulum and tubes.

Procedures:



Hang four pendulum bobs on the same taut string such that pendulum, A has variable length while B, C and D have different fixed lengths.

Set pendulum A to the same length as D. Make it swing and observe the mode of swinging of the pendulums.

Set pendulum A to the same length as B. Make it swing and observe the mode of swinging of the pendulums.

Observation:

When length of A is equal to length of D, B and C vibrate with smaller amplitudes while D swings with larger amplitudes.

When length of A is equal to length of B, the motion of A will be transferred to B in greater amplitude and B will start to swing with appreciable amplitude while C and D will jiggle a little but they will not swing appreciably.

Common consequences of resonance:

(i) A playground swing can be made to swing high by someone pushing in time with the free swing.
(ii) Soldiers need to break a step when crossing a bridge.
(iii) Vibrations of the sounding box of a violin.
(iv) A column of air in a tube resonates to a particular note.
(v) A diver on a spring board builds up the amplitude of oscillation of the body by bouncing on it at its natural frequency.
(vi) Singers who can produce very high frequency notes can cause wineglasses to break when the notes have the same frequency as the natural frequency of the glass. [Opera singers]

Applications of Resonance:

- In determining the speed of sound in air using a tuning fork and the resonance tube.
- In tuning strings of a musical instrument e.g a guitar and tuning electrical circuits which include indicators.

Dangers of Resonance

- Causes bridges to collapse as soldiers match across them. This can be prevented by stopping the matching.
- Causes buildings to collapse due to earthquake.
- Chimneys can also collapse due to strong resonance.

Vibrations of air in pipes.

(a) When a wave of a particular wave length and frequency is set into a closed pipe, reflection of the wave occurs at the bottom of the pipe. The reflected wave will interfere with the incidence when the length of the wave is adjacent so that a node is reflected at the reflected surface, a standing wave is produced.

The air column is now forced to vibrate at the same frequency as that of the source of the wave which is a natural frequency of the air column.

(a) Closed pipes.

This consist essentially of a metal pipes closed at one end and open at the other.

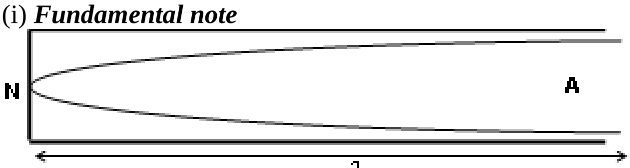
Closed pipes boundary conditions.

At the closed end, there is a displacement node.

At the open end here is displacement antinode.

The allowed oscillation modes or standing wave patterns are:-

(i) ***Fundamental note***



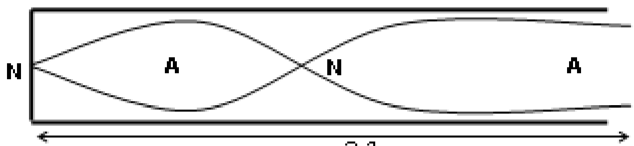
$$l = \frac{\lambda_1}{4}$$

Fundamental frequency, $f_1 = \frac{v}{\lambda_1} = \frac{v}{4l}$ ……………….(i)

Fundamental or lowest audible frequency (f_1)

It is obtained when the simplest stationary wave form is obtained.

(ii) ***First overtone*** (3^{rd}harmonic)

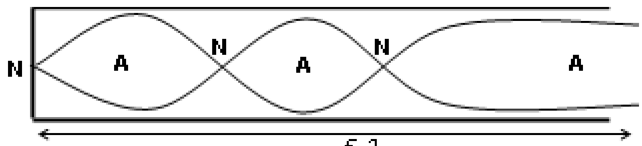


$$l = \frac{3\lambda_1}{4}$$

Frequency of first overtone f_3 is given by;

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{\left(\frac{4l}{3}\right)} = \frac{3v}{4l} = 3\times\left(\frac{v}{4l}\right) = 3f_1$$

(iii) ***Second overtone*** (5^{th}harmonic)



$$l = \frac{5\lambda_3}{4}$$

$$f_3 = \frac{v}{\lambda_3} = \frac{v}{\left(\frac{4l}{5}\right)} = \frac{5v}{4l} = 5f_1$$

The frequencies obtained with a closed pipe are f_1, $3f_1$, $5f_1$, $7f_1$ $9f_1$, etc i.e. only odd harmonics' are obtainable. Because of the presence of only odd harmonics, closed pipes are not as rich as open pipes.

In closed pipes, nodes are formed at closed ends and antinodes at open end.

(b) Open pipes

These are Pipes which are open at both ends.

In open pipes, standing waves resulting into resonance are created when the incident waves are reflected by the air molecules at the other end. Possible ways in which waves travel are shown below:

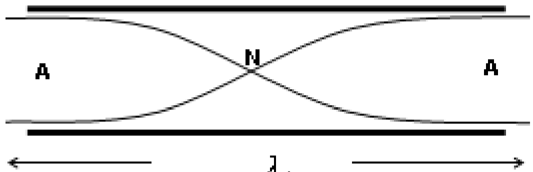
In open pipes, the sound nodes are produced when antinodes are formed at both ends.

Open pipes boundary conditions:

Antinodes are at both ends.

The allowed oscillation modes or standing wave patter are:-

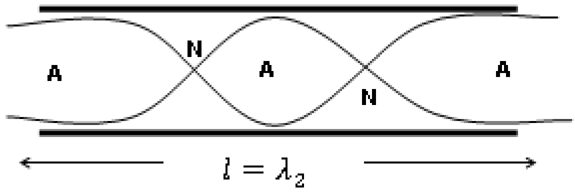
(i) ***Fundamental note.(* 1st harmonic)**



$$l = \frac{\lambda_1}{2}$$

Fundamental frequency; $f_1 = \frac{v}{\lambda_1} = \frac{v}{2l}$

(ii) ***First overtone (second harmonic)***



$$l = \lambda_2$$

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{l} = \frac{2}{2}\times\frac{v}{l} = 2\times\left(\frac{v}{2l}\right)$$

$$f_2 = 2f_1$$

Thus frequencies for notes produced by open pipes are $f_1, 2f_1, 3f_1, 4f_1$..........

So an open pipe can produce both odd and even harmonics.

Therefore, open pipes produce a richer note than that from a similar closed pipe, due to the extra harmonics.

In general;

- For a **closed pipe:** $f_n = n\left(\frac{v}{4l}\right) = nf_1$, Where, **n** = 1, 3, 5, 7………
- For an **open pipe:** ;$f_n = n\left(\frac{v}{2l}\right) = nf_1$, Where, **n** = 1, 2, 3, 4………

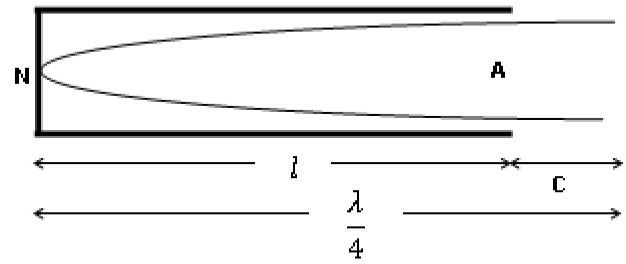
End correction

Then, at the open end of the pipe is free to move and hence the vibration at this end of the sounding pipe extend a little into the air outside.

An antinode of the stationary wave due to any note is in practice a distance, c from the open end. The distance, c is known as the end correction.

For the closed pipe;-

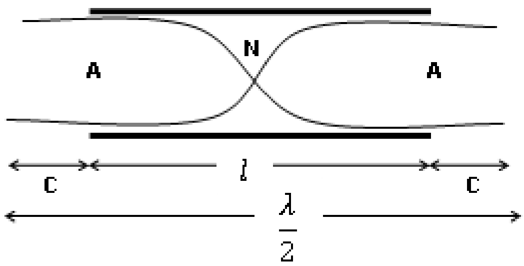
Fundamental mode



$$\frac{\lambda_1}{4} = l + c \Leftrightarrow \lambda_1 = 4(l + c)$$
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{4(l + c)}$$

Fundamental frequency,
$$\boldsymbol{f_1 = \frac{v}{4(l + c)}}$$

For open pipe;-
Fundamental mode,

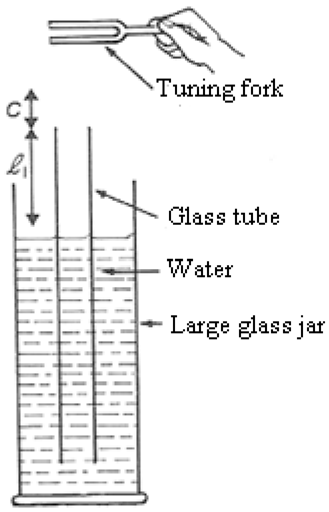


$$\frac{\lambda_1}{2} = l + 2c \Leftrightarrow \lambda_1 = 4(l + 2c)$$
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2(l + 2c)}$$

Fundamental frequency,
$$\boldsymbol{f_1 = \frac{v}{2(l + 2c)}}$$

Open pipes are preferred to closed pipes because they give both odd and even harmonics hence better quality sound.

Determination of velocity of sound in air by Resonance method.



C = End correction, l_1, l_2 = Length of air columns.

- Assemble the apparatus as in the diagram.
- Put a vibrating tuning fork just above the resonance tube.
- Gently lower the resonance tube until the 1st resonance (loud sound) occurs.
- Measure the length l_1 at which it occurs.

l_1 + c = $\frac{1}{4}$ λ…………………………………… (i)

- Raise the resonance tube until the 2nd resonance (loud sound) occurs.
- Measure the length l_2 at which it occurs.

l_2 + c = $\frac{3}{4}$ λ…………………………….......... (ii)

- Subtract equation (i) from (ii) to eliminate c

(l_2 - l_1) + (c-c) = $\frac{3}{4}$λ - $\frac{1}{4}$λ

l_2 - l_1 = $\frac{1}{2}$ λ

2 (l_2 - l_1) = λ

- Hence the speed or velocity of sound in air is determined from the expression. $V = f\lambda$.

$$\boldsymbol{V = 2f(l_2 - l_1)}$$

Example: 1.
In an experiment the velocity of sound in air using a resonance tube, the following results were obtained:

- Length of 1st resonance = 16.1cm
- Length of 2nd resonance = 51.1cm
- Frequency of tuning fork = 480 H_z

(i) .

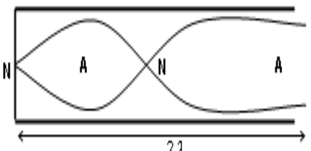
(i) Calculate the wave length of sound produced. $\lambda = 2(l_2 - l_2)$ $\lambda = 2(51.1 - 16.1)$ λ = 70 cm	(ii) The end correction of the resonance tube. $l_1 + C = \frac{1}{4}\lambda$ $16.1 + C = \frac{1}{4} \times 70$ $C = 17.5 - 16.1$ $C = 14$ cm
(iii)The velocity sound in air. $V = 2f(l_2 - l_1)$ $V = 2 \times 480\left(\frac{51.1}{100} - \frac{16.1}{100}\right)$ $V = 336\text{ms}^{-1}$	

Example: 2.
A glass tube open at the top is held vertically and filled with water. A tuning fork vibrating at 264 Hz is held above the table and water is allowed to flow out slowly .The first resonance occurs when the water level is 31.5cm from the top while the 2nd resonance occurs when the water level is 96.3cm from the top. Find the;-

Solution:

(i) Speed of sound in the air column. $V = 2f(l_2 - l_1)$ $V = 2 \times 264\left(\frac{96.3}{100} - \frac{31.5}{100}\right)$ $V = 342.144\text{ms}^{-1}$	(ii) End correction. $\lambda = 2(l_2 - l_2)$ $\lambda = 2\left(\frac{96.3}{100} - \frac{31.5}{100}\right)$ λ = 1.296 m $l_1 + C = \frac{1}{4}\lambda$ $0.315 + C = \frac{1}{4} \times 1.296$ $C = 0.324 - 0.315$ $C = 0.009$ m

Example: 3.
The frequency of the third harmonic in a closed pipe is 280 Hz. Find the length of the air column. (Speed of sound in air = 330ms^{-1})



$l = \frac{3\lambda_1}{4}$

$$\lambda = \frac{4l}{3}$$

From; $v = f\lambda$

$$330 = 280 \times \frac{4l}{3}$$
$$3 \times 330 = 280 \times 4l$$
$$990 = 1120l$$
$$l = 0.884$$

Alternatively;
For a closed pipe, the possible frequencies are;
f_1, $3f_1$, $5f_1$…..; where $f_1 = \begin{pmatrix} frequency\ of\ the \\ fundamental\ note \end{pmatrix}$

But frequency of third harmonic = $3f_1 = 280$Hz**.**

Thus;
$3f_1 = 280$
$f_1 = 93.33\ Hz$

$$f_1 = \frac{v}{4l}$$

$$93.33 = \frac{330}{4l}$$

$4l \times 93.33 = 330$

$l = 0.884$ m

Example : 4.
The frequency of the 4th overtone in an open pipe is 900Hz when the length of the air column is 0.4m. Find the
(i) Frequency of the fundamental note
(ii) Speed of sound in air.

Solution:

(i)Frequency of the fundamental note

For an open pipe, the possible frequencies are;
f_1,, $2f_1$, $3f_1$, $4f_1$, $5f_1$…..; where $f_1 = \begin{pmatrix} \text{frequency of the} \\ \text{fundamental note} \end{pmatrix}$

$$f_1 = \frac{v}{2l}$$

But frequency of 4th overtone = $5f_1 = 900$Hz.

Thus;
$5f_1 = 900$
$f_1 = 180\ Hz$

(ii) Speed of sound in air.

$$f_1 = \frac{v}{2l}$$

$$180 = \frac{v}{2l}$$

$$v = 2 \times 0.4 \times 180$$

$$v = 144\text{ms}^{-1}$$

Exercise:

1. The frequency of the 3rd overtone (4th harmonic) produced by an open pipe is $840H_z$. Given that the velocity of sound in air is 330m/s, calculate;
(i) Length of the people
(ii) Fundamental frequency

2. A pipe closed at one end has a length of 10cm, if the velocity of sound is 340m/s; calculate the frequency of the fundamental note.

3. A tuning fork produces resonance in a tube at a length of 15.0cm and also at a length of 40.0cm. Find the frequency of the tuning fork.

4. (a) A tuning fork of $256H_z$ was used to produce resonance in a closed pipe. The first resonance position was at 22cm and the 2nd resonance position was at 97cm. Find the frequency of sound waves.
(b) An open tube produced harmonics of fundamental frequency $256H_z$, what is the frequency of the 2nd harmonics.

5. A tuning fork of frequency 256 Hz was used to produce resonance in a a tube of length 32.5cm and also in one of length 95.0cm. Calculate the speed of sound in the air column. [320ms^{-1}]

6. A tuning fork of frequency 512Hz is held over a resonance tube of length 80cm. The first position of resonance is 16.3 cm from the top of the tube and the second position of resonance is 49.5cm. Find the speed of sound in air. Why is it better to use a frequency of 512Hz rather than one of 256Hz? [340ms^{-1}]

7. See UNEB

Sound waves 2001 Qn19 1990 Qn40 1995Qn22 2002 Qn17	1989 Qn27 1997 Qn23 1994Qn10 1998 Qn25 2002 Qn25	2006 Qn42 2008 Qn26 1997 Qn26 1999 Qn27	1989 Qn2 1991 Qn14 1991 Qn40 1992 Qn32 1997 Qn33

Progressive and/stationary waves 1988 Qn25 1989 Qn9 1995 Qn21	2000 Qn12 2000 Qn29 2000 Qn30 2002	Qn22 2005 Qn39 2008 Qn31 2008 Qn35 Section B	1990 Qn6 2000 Qn6 2004 Qn7 2008 Qn6