PHYSICS

Physics is a branch of science that deals with the study of matter, energy and their interactions.

Branches of Physics

1. Mechanics: Motion and properties of matter.
2. Heat: A form of energy that causes rise in temperature.
3. Optics: Light and waves.
4. Electricity and Magnetism.
5. Modern Physics: Atomic and Nuclear Physics.

Why we study Physics

- To help students develop an experimental attitude by performing experiments and acquire skills such as observation, measuring, drawing logical conclusions.
- To understand scientific theories, principles and concepts
- To prepare students for further studies in Physics.
- To understand the applicability of Physics in other disciplines like security, medicine, engineering, e.t.c and improve the world's technology.

1 MECHANICS AND PROPERTIES OF MATTER

1:1. MEASUREMENTS:

Physics is concerned with measurement of physical quantities and classifying them into groups according to their nature.
To measure is to find the value of a physical quantity using a scientific instrument with a standard scale.

Physical Quantities

A physical quantity is a physical property that can accurately be measured.

Types of Physical Quantities

There are two types of Physical Quantities namely;

(i) Fundamental Quantities or Basic Quantities
(ii) Derived Quantities

1:1:1. FUNDAMENTAL QUANTITIES OR BASIC QUANTITIES

These are quantities from which all other quantities are obtained. They are seven in total and these are:

Fundamental Quantities	S.I unit	Symbol
1. Length	**Metre**	**M**
2. Mass	**Kilogrm**	**Kg**
3. Time	**Second**	**S**
4. Thermodynamic Temperatur	Kelvin	K
5. Electric current	Ampere	A
6. Amount of a substance	Mole	Mol.
7. Luminous Intensity	Candela	Cd

Note: *In mechanics, we use only three fundamental quantities; i.e* ***length, mass and time***.

1:1:1:1. LENGTH:

Length is the distance between any two points.
It can also be defined as the distance covered by matter. It is a measurement of the extent of something from end to end.

The S.I unit of length is **a metre (m).**
Other units of length include; Miles, kilometer, Hectometre, Decametre, Decimetre, Centimetre, etc.

CONVERSIONS

Example: 1

Convert the following as instructed:
(i) 16.4mm to metres
(ii) 20m to centimetres
(iii) 0.092km to metres
(iv) 250cm to metres

Solution

(i) 16.4mm to metres

km	Hm	Dm	**M**	dm	cm	**mm**
			1	0	0	0

1m =	1000mm
x =	16.4mm

$1000x = 16.4 \times 1m$
$1000x = 16.4$
$\frac{\cancel{1000}x}{\cancel{1000}} = \frac{16.4}{1000}$
$x = 0.0164m$
Thus 16.4mm = 0.0164 m

(ii) 20m to centimetres

Solution

20m to centimetres

Km	Hm	Dm	**M**	dm	**Cm**	Mm
			1	0	0	

1m =	100cm
20m =	X

$1 \times x = 20 \times 100cm$
$x = 2000\ cm$
Thus 20m = 2000 cm

(iii) 0.092km to metres

Solution

0.092km to metres

Km	Hm	Dm	**M**	dm	cm	Mm
1	0	0	0			

1km =	1000m
0.092km =	X

$x = 0.092 \times 1000m$
$x = 92\ m$
$x = 92\ m$
Thus 0.092km = 92 m

(iv) 250cm to metres

Solution

250cm to metres

Km	Hm	Dm	**m**	Dm	**cm**	mm					
			1	0	0						

1m =	100cm
x =	250cm

$100 \times x = 250 \times 1m$

$\frac{\cancel{100}x}{\cancel{100}} = \frac{250}{100}$

$x = 2.5cm$

Thus 250cm = 2.5m

Instruments Used in measuring length

(i) **Tape-measure:** (Accurately measures length greater than 1metre:$l > 1m$). E g length of a foot ball field, length of a plot of land etc.

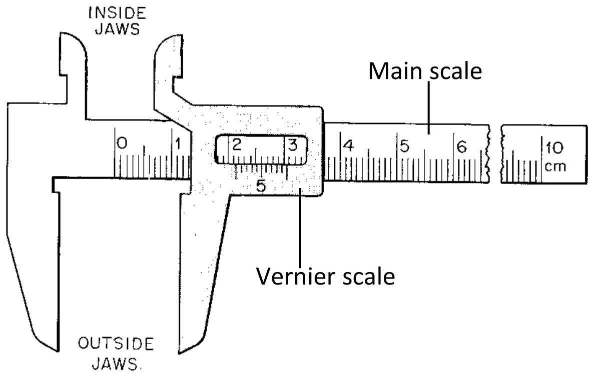
(ii) **Metre-rule :**(Accurately measures length greater than 12 centimetres but less than 1metre:$12cm < l < 1m$). Eg length of a desk, breadth of a window, etc.

A metre rule gives readings in cm to 1dp.

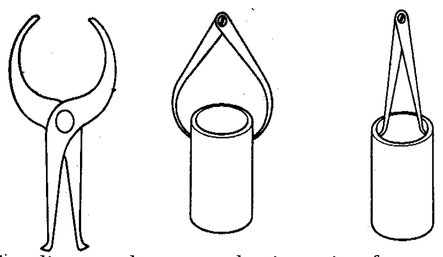
(iii) **Vernier calipers or Slide calipers :**

Accurately measures length greater than 1cm but less than 12 cm:2.5cm $< l <$ 12 cm. E.g Internal and External diameters of test tubes and beakers, breadth of a metre rule. etc.

A vernier caliper gives readings in cm to 2dp.

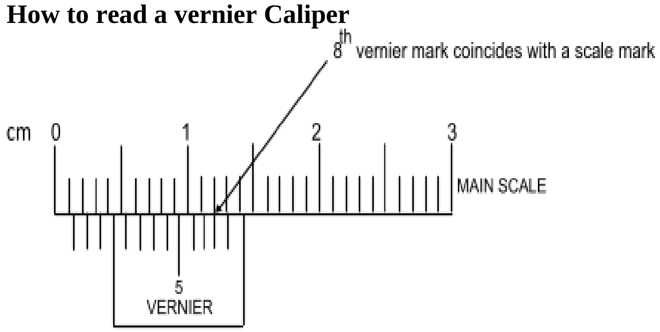


Engineer calipers



The distance between the jaws is after wards measured on an ordinary scale like a metre-rule.

How to read a vernier Caliper

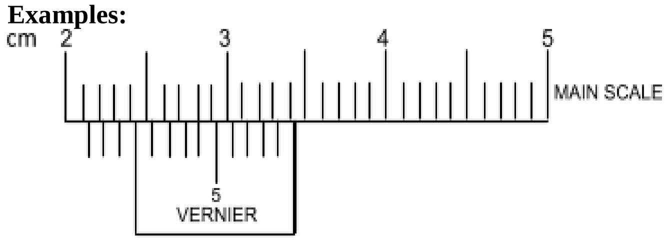


- The main scale is in centimeters, 1cm has 10 divisions each division is $\frac{1}{10}$ cm = 0.1cm.
- Vernier scale, each division is $\frac{1}{100}$ cm = 0.01cm.

Reading of vernier calipers,

1. Record the reading on the main scale to two places in cm.
2. Look along the Vernier scale carefully until you see division on it which coincides with the main scale, this gives the second decimal place.

Examples:

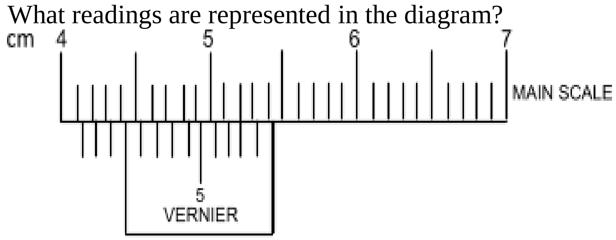


Main scale = 2.40cm

Vernier scale = 0.04cm

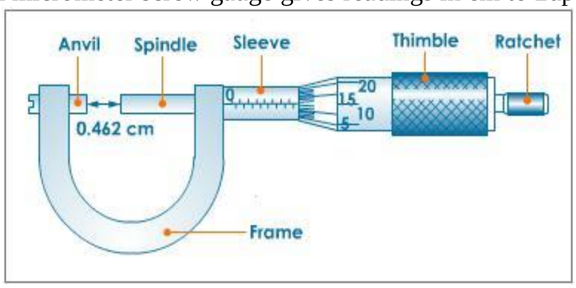
Final reading = 2.44cm

What readings are represented in the diagram?



(iv) **Micrometer screw gauge:** (Accurately measures length less than 1centimetre: $1mm < l < 25mm$). Eg Diameter of wires, Diameter of ball beairings and pendulum bob, etc.

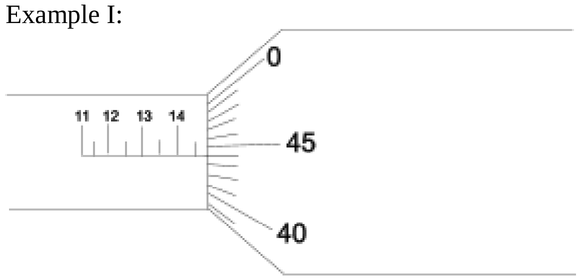
A micrometer screw gauge gives readings in cm to 2dp.



For each turn the spindle moves through 0.5mm.The fraction of each turn is indicated on the thimble. This has a scale of 50 divisions on the thimble and represents $\frac{1}{50}$ of half a millimeter i.e. $\frac{1}{10} \times 0.5$ mm = 0.01mm.

The sleeve-reading gives units to the 1st two decimal places and the thimble gives 2nd decimal place.

Example I:

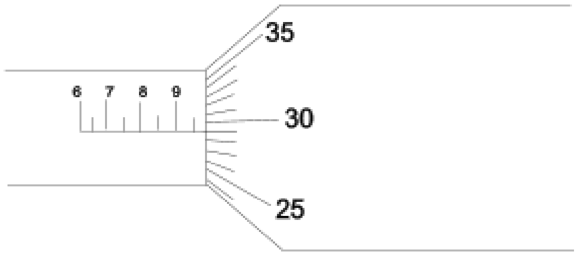


Sleeve scale reading = 14.50mm

Thimble scale reading = 0.44mm

= 14.94mm

Example II:



Sleeve scale reading = 9.5 00mm
Thimble scale reading = 0.29mm
= 9.79mm

Precautions taken when using a micrometer screw gauge

- The faces of the anvil and the spindle must be cleaned to remove dust so as to get accurate readings.
- The reading must be checked.

1:1:1:2: MASS:

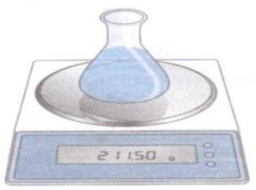
Mass is the quantity of matter in a substance.

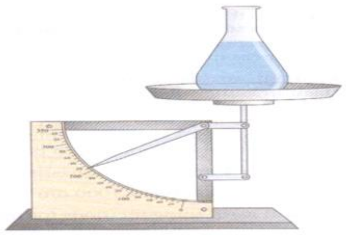
The S.I unit of mass is **a kilogram (kg).**

Other units of mass include: Tonnes (1tonne = 1000kg), Hectogram (Hg), Decagram (Dg), Gram (g), Decigram (dg), Centigram (cg), Milligram (mg), etc.

Instruments Used in measuring Mass

(i) weighing beam balance (ii) Digital beam balance (iii) Top arm beam balance	(iv) Lever arm beam balance (v) Tripple beam balance





Conversions

Example 1:

Convert the following as instructed:

(i) 100grams to kilograms
(ii) 2kg to dg
(iii) 40mg to kg
(iv) 20.55g to cg

Solution

(i) 100grams to kilograms

Kg	Hg	Dg	**G**	Dg	Cg	Mg
1	0	0	0			

1kg	=	1000g
x	=	100g

$1000 \times x = 100 \times 1kg$

$$\frac{\cancel{1000}x}{\cancel{1000}} = \frac{100}{1000}$$

$\underline{x = 0.1kg}$

Thus 100grams = 0.1kg

(ii) 2kg to dg

Solution

2kg to dg

Kg	Hg	Dg	G	**dg**	Cg	mg
1	0	0	0	0		

1kg	=	10,000dg
2kg	=	X

$1 \times x = 2 \times 10000dg$

$\underline{x = 20{,}000dg}$

Thus 2 kilograms = 20000dg

(iii) 40mg to kg

Solution

40mg to kg

Kg	Hg	Dg	G	dg	Cg	**mg**
1	0	0	0	0	0	0

1kg	=	1000000mg
x	=	40mg

$1000000 \times x = 40 \times 1kg$

$$\frac{\cancel{1000000}x}{\cancel{1000000}} = \frac{40}{1000000}$$

$\underline{x = 0.00004kg}$

Thus 40miligrams = 0.0000kg

(iv) 20.55g to cg

Solution

20.55g to cg

Kg	Hg	Dg	**g**	dg	**Cg**	mg
			1	0	0	

1g	=	100cg
20.55g	=	X

$1 \times x = 20.55 \times 100cg$

$\underline{x = 2055cg}$

Thus 20.55grams = 2055cg

1:1:1:3: TIME:

Time is the interval between two events.

The S.I unit of time is **a second (s).**

Other units of time include Minute (1min = 60s), Hour (1hr=60min), Day (1day=24hrs), Week (7 days), fortnight (2weeks), Month (1month=30days), Year (1yr=12months), decade, century, and a millennium.

Instruments Used in measuring Time

- Stop clock
- stop watch
- Half life of a radioactive substance eg Carbon – 14
- Shadows

1:1:2. DERIVED QUANTITIES

These are quantities which can be expressed in terms of the fundamental quantities. Besides the seven fundamental quantities, the rest of the Physical quantities' are derived quantities. Their S.I units are also called **Derived units**.

Examples of Derived Physical quantities include:

Derived Quantities	**S.I unit**	**Symbol**
1. Area	squaremetre	m^2
2. Volume	cubicmetres	m^3
3. Density	kilogram per cubicmetre	kgm^{-3}
4. Speed and Velocity	metres per second	ms^{-1}
5. Pressure	newton per square metre (or pascal)	Nm^{-2} (or Pa)
6. Force and weight	Newton	N
E.t.c		

1:1:2:1. AREA:

Area is ameasure of the size of a surface.

The S.I unit is a squaremetre **(m^2).**

Other units of area include: $cm^2, mm^2, km^2\ e.t.c$

Example 1:

Convert the following as instructed

(i) 15 mm^2 to cm^2

(ii) 20 m^2 to mm^2

(iii) 16.4 mm^2 to m^2

Solution

(i) $15\ mm^2\ to\ cm^2$

Km	Hm	Dm	M	dm	**Cm**	**Mm**
					1	0

1cm	=	10mm
(1cm)^2	**=**	**(10mm)^2**
1cm^2	=	100mm^2
x	=	15 mm^2

$100 \times x = 15 \times 1cm^2$

$x = 0.15cm^2$

Thus 15 mm^2 =0.15cm^2

(ii) $20\ m^2\ to\ mm^2$

km	Hm	Dm	**M**	dm	Cm	**Mm**
			1	0	0	0

1m	=	1000mm
(1m)^2	**=**	**(1000mm)^2**
1m^2	=	1000000mm^2
20 m^2	=	X

$1 \times \mathrm{x} = 20 \times 1000000\mathrm{mm}^2$

$\mathrm{x} = 20{,}000{,}000\mathrm{mm}^2$

Thus 20 m^2 =20,000,000mm^2 or $\mathbf{2.0 \times 10^7 mm^2}$

Solution

(iii) 16.4 $mm^2\ to\ m^2$

Km	Hm	Dm	**M**	dm	Cm	**Mm**
			1	0	0	0

1m	=	1000mm
(1m)^2	**=**	**(1000mm)^2**
1m^2	=	1000000mm^2
x	=	16.4 mm^2

$1000000 \times \mathrm{x} = 16.4 \times 1\mathrm{m}^2$

$$\frac{\cancel{1000000}\mathrm{x}}{\cancel{1000000}} = \frac{16.4}{1000000}$$

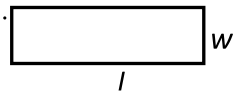
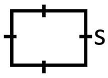
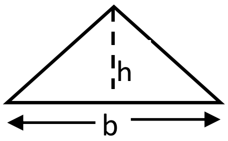
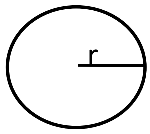
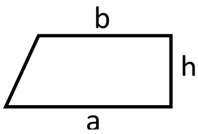
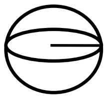
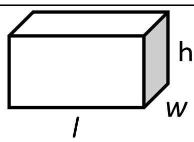
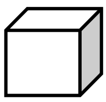
$\mathrm{x} = 0.0000164\mathrm{m}^2$

Thus 20 m^2 = 0.0000164m^2 or $\mathbf{1.64 \times 10^{-5} m^2}$

Types of areas

(i) Cross-sectional area

(ii) Surface area

Figure	Name	Formula for Area
1. 	Rectangle	$A = lw$
2. 	Square (All sides are equal)	$A = S^2$
3. 	Triangle	$A = \frac{1}{2}bh$
4. 	Circle	$A = \pi r^2$
5. 	Trapezium (2 parallel un equal sides)	$A = \frac{1}{2}h(a+b)$
6. 	Sphere	$S.A = 4\pi r^2$
7. 	Cuboid	$S.A = 2(lw) + 2(wh) + 2(lh)$
8. 	Cube (All faces are equal)	$S.A = 6S^2$

1:1:2:2. VOLUME:

Volume is the space occupied by matter.

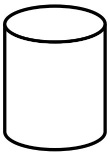
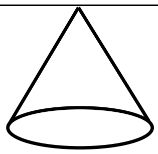
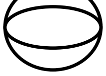
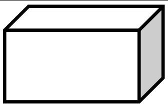
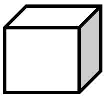
The S.I unit of volume is cubic metre **(m^3).**

Other units of volume include: $cm^3, mm^3, km^3, millilitre(ml), litre(l).e.t.c$

Instruments for measuring Volume include:

- Measuring cylinder
- Volumetric flask
- Burette
- Pipette

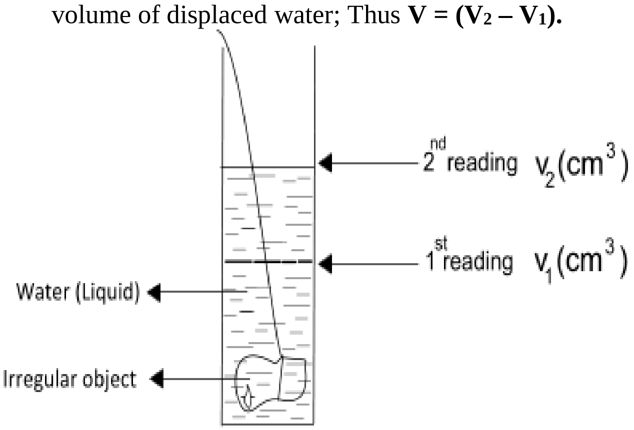
Volume of regular objects

Figure	Name	Formula for Volume
1. 	Cylinder	$V = \pi r^2 h$
 2.	Circular cone	$V = \frac{1}{3}(\pi r^2)h$
3. 	Sphere	$V = \frac{4}{3}\pi r^3$
4. 	Cuboid	$V = lwh$
5. 	Cube (All faces are equal)	$V = S^3$

Experiment to determine the volume of an irregular object

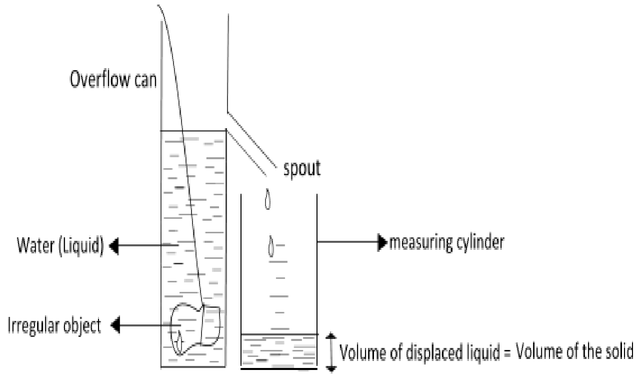
The volume of an irregular object can be obtained by the **Displacement method.**

- Pour water into a measuring cylinder up to a certain level. Record the volume of water (V_1).
- Tie a thread on the irregular object and gently lower it into the water in the measuring cylinder. Note the new volume of water in the cylinder (V_2).
- The Volume of the irregular object is then equal to the volume of displaced water; Thus **V = (V₂ – V₁).**



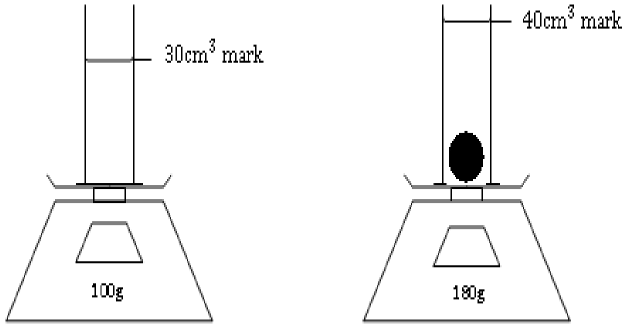
OR

- Pour water in an over flow can up to the level of the spout. Place a measuring cylinder just below the spout.
- Tie a thread around the irregular object and gently lower it into the overflow can.
- Note the volume of water, **V** that collects in the measuring cylinder. It is equal to the volume of the irregular object.



Question:

A measuring cylinder containing some water stands on a scale pan. A solid ball is lowered into the water. The water level rises from the 30cm³ mark to 40cm³ mark. The scale reading increases from 100g to 180g.



What is the density of the material of the ball?

A. 2.0 gcm^{-3}. B. 4.5 gcm^{-3}.
B. 8.0 gcm^{-3}. D. 18 gcm^{-3}.

Example 1:

Convert the following as instructed

(i) $250\ cm^3\ to\ m^3$ $(iii) 0.032 km^3\ to\ m^3$
(ii) $500 ml\ to\ m^3$ $(iv) 10{,}000\ litres\ to\ m^3$

Solution

(i) $250\ cm^3\ to\ m^3$

Km	Hm	Dm	**m**	dm	**Cm**	mm
			1	0	0	

1m	=	100cm
(1m)³	=	**(100cm)³**
1m³	=	1000000cm³
x	=	250cm³

$1000000 \times x = 250 \times 1m^3$

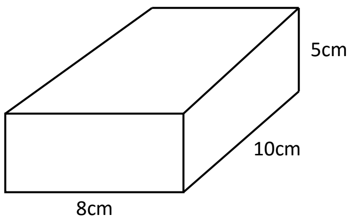
$\frac{\cancel{1000000}x}{\cancel{1000000}} = \frac{250}{1000000}$

$x = 0.00025\ m^3$

Thus 250 cm^3 = $0.00025 m^3$ *or* $\mathbf{2.5 \times 10^{-4} m^3}$

Example 2:

Use the match box below to answer questions that follow.



Find the volume
(i) in cm^3 **[$400cm^3$]**
(ii) in m^3 [**$0.0004m^3$**]

Exercise:
1. A cuboid has dimensions 2cm by 10cm. Find its width in metre if it occupies a volume of $80cm^3$. [**0.04m]**

2. (a) Find the volume of water in a cylinder of water radius 7cm if its height is 10cm.[**$1540cm^3$]**
(b) The volume of the cylinder was $120m^3$.When a stone was lowered in the cylinder filled with water the volume increased to $15cm^3$. Find the height of the cylinder of radius 7cm. [**0.078 cm**]

3. A Perspex box has 10cm square base and contains water to a height of 10cm. A piece of rock of mass 600g is lowered gently into the water and the level rises to 12cm. Find the;
(i) Volume of water displaced by the rock.
(ii) volume of the rock in $\boldsymbol{cm^3}$ and $\boldsymbol{m^3}$
(iii) density of the rock in $\boldsymbol{gcm^{-3}}$ and $\boldsymbol{kgm^{-3}}$

1:1:3. SCIENTIFIC NOTATION AND SIGNIFICANT FIGURES.

Scientific notation or Standard form

- A number is in scientific form, when it is written as a vnumber between 1 and 9 which is multiplied by a power of 10. i.e when it is written in the form $\mathbf{A \times 10^n}$.

Where$1 \leq \mathrm{A} < 10$; i.e A lies between 1 and 10 with 1 inclusive but 10 exclusive. **n** is an integer (….-2,-1,0,1,2…).

- Scientific notation is used for writing down very large and very small measurements.

Example:
(i) 598,000,000m = 5.98×10^8 m
(ii) 0.00000087m = 8.7×10^{-7} m
(iii) 60220m = 6.022×10^4 m

Questions:
Convert the following to scientific form.
(a) 0.048 = 4.8×10^{-2}
(b) $\frac{3}{4}$ = 0.75 = 7.5×10^{-1}
(c) 1000 = 1.0×10^3
(d) 8.72 = 8.72×10^0
(e) $\frac{1}{8}$ = 0.125 = 1.25×10^{-1}

Significant figures

- **Decimal Places**

The number of decimal places (dp) is the number of digits to the right end of a decimal point. E.g. the number 3.6420 is given to 4dp.Thus 3.6420 ≈ 3.642(3dp), 3.6420 ≈ 3.64(2dp), 3.6420 ≈ 3.6(1dp), 3 .6420 ≈ 4 (0dp).

- **Significant Figures**

a) None zero digits (1, 2, 3, 4, 5, 6, 7, 8 and 9) are significant figures.
b) Zeros

Leading zeros (i.e. zeros at the left end of a number) i.e zeros before the first significant figure; are not significant figures e.g. 0.000456 (3s.f), 0.017 (2s.f).

Tapped zeros; zeros between significant figures i.e. zeros between non zero digits are significant figures e.g. 6.0037 (5s.f), 0.0100034 (6 s.f).

Trailing zeros (zeros at the right end of a number);
(i) Trailing after a decimal point: These are significant figures. E.g 2.00 (3s.f), 0.0020 (2s.f), 0.0120700 (6s.f)
Normally these values are obtained by using an instrument.

(ii) Trailing before a decimal point: These are NOT significant figures. E.g 20 (1s.f), 2400 (2s.f), 580100 (4s.f)
Normally these values are obtained as a result of rounding off certain numbers to the nearest tens, fifties, hundreds, thousands, ten thousands e.t.c.
For example, if a number 348 is rounded off to 1 s.f, we get 300 and if it`s rounded off to 2 s.f we get 350. The trailing zeros in these approximations (i.e. 300 and 350) are due to rounding off and therefore are not significant.

Questions
Write the following to the stated significant figures
a) 28.8 to 3 s.f b) $\frac{2}{7}$ to 2 s.f c) 4.027 $\times 10^{-2}$ to 3 s.f

Prefix and Surfix	Symbol	Exponent
Tera	T	10^{12}
Giga	G	10^9
Mega	M	10^6
Kilo	K	10^3
Hecto	H	10^2
Deca	D	10^1
Metre		$\mathbf{10^0}$
Deci	d	10^{-1}
Centi	c	10^{-2}
Mili	m	10^{-3}
Micro	μ	10^{-6}
Nano	n	10^{-9}
Pico	p	10^{-12}
Fermto	F	10^{-15}
Atto	A	10^{-18}

Example:

Value	Scientific form	Prefix used
3000W	3×10^3W	3kW
4900 000J	4.9×10^6J	4.9MJ
0.00526m	5.26×10^{-3}m	5.26mm
0.00000125g	1.25×10^{-6}g	1.25μg

1:2. DENSITY AND RELATIVE DENSITY

1:2:1. DENSITY

Density is the mass per unit volume:

$$\text{Density} = \frac{\text{mass}}{\text{volume}}$$

The SI unit is kg/m^3 or kgm^{-3} other units are g/l or gcm^{-3}

Note: the density of pure water is $1000kgm^{-3}$ or $1gcm^{-3}$

Changing gcm^{-3} to kgm^{-3}

$1gcm^{-3} = 1000kgm^{-3}$

So when changing gcm^{-3} to kgm^{-3} simply multiplies by 1000

Example:

Express 0.8 gcm^{-3} in kgm^{-3}

$1gcm^{-3}$=	**$1000kgm^{-3}$**
0.8 =	x

$x = 0.8 \times 1000kgm^{-3}$

$\underline{x = 800km^{-3}}$

Thus $0.8gcm^{-3} = 800kgm^{-3}$

1:1:2:3:1. Simple density Measurements

When the mass "M" and volume "V" of a substance are known; then the density is obtained from:

$$Density, \rho = \frac{\boldsymbol{m}}{\boldsymbol{V}}$$

(a) *For a Regularly shaped solid*

- The mass of the solid is measured on a beam balance
- The volume of the solid is obtained by measuring the sides of the solid using a ruler, veneer calipers or micrometer screw gauge.
- The density is then got from the formula.

$$\text{Density of solid} = \frac{\text{mass of solid}}{\text{volume of solid}}$$

(b) *For an irregularly – shaped solid*

- The solid is weighed using a beam balance to obtain its mass.
- The volume of the solid is obtained by displacement methods; using a displacement can. The volume of displaced water is equal to the volume of the solid.
- The density is then got from the formula.

$$\text{Density of solid} = \frac{\text{mass of solid}}{\text{volume of solid}}$$

NOTE:

1. For a floating object. Tie a sinker on the floating object and gently dip it water. Get the volume of the water displaced, $\mathbf{V_1}$.
   Then dip the sinker alone in the water and again get the volume of water displaced, $\mathbf{V_2}$.
   The volume of the floating object, V = $\mathbf{V_1 - V_2}$

2. For a pin or a ball bearing.

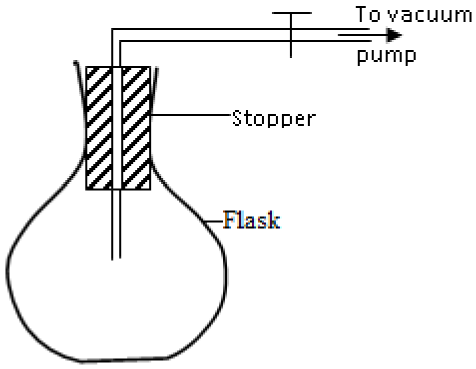
(c) *For liquids*

- The volume of the liquid is measured using a measuring cylinder and the volume, V is noted.
- An empty measuring cylinder is weighed on a beam balance and its mass, M_o is noted.
- A liquid is added to it and it is weighed again using the beam balance;

$$\begin{pmatrix} Mass \\ of\ liquid \end{pmatrix} = \begin{pmatrix} mass\ of \\ empty \\ cylinder \end{pmatrix} - \begin{pmatrix} mass\ of \\ cylinder \\ with\ liquid. \end{pmatrix}$$

$$\text{Density of liquid} = \frac{\text{mass of liquid}}{\text{volume of liquid}}$$

(d) *Air*



(i) Measuring of mass

A round-bottomed flask is weighed using a beam balance when full of air and after removing the air using a vacuum pump. Then

(ii) Measuring of volume

The volume of air is found by filling the flask with water and pouring it into a measuring cylinder. Then volume of air = volume of water transferred into the measuring cylinder.

$$\text{Density of air} = \frac{\text{mass of air}}{\text{volume of air}}$$

Precautions taken

-The flask should be dried

-The atmospheric pressure and temperature should be noted.

-The air should be dry

Factors that affect Density

(i) **Temperature**

When the temperature of a substance is increased, it expands hence increasing its volume. The density then decreases.

When the temperature of a substance is reduced, it contracts hence reducing its volume. The density then increases.

(ii) **Pressure**

Pressure only affects the density of gases.

When the pressure of a given mass of a gas is increased, the gas molecules become squeezed and occupy a smaller volume. This increases the density of the gas.

When the pressure of a given mass of a gas is reduced, the gas molecules become occupy a larger volume. This decreases the density of the gas.

Uses of density

It is used to: -Identify materials for construction

-Test the purity of a substance

-Choose the light gases to fill balloons

Example 1:

A Perspex box has a10cm square base containing water to a height of10 cm. A piece of rock of mass 600g is lowered into the water and the level rises to 12 cm.

(a) What is the volume of water displaced by the rock?

$V = L \times w \times h$
$= 10 \times 10 \times (12-10)$
$= 200\ cm^3$

(b) What is the volume of the rock?

Volume of rock = volume of water displaced
= $200cm^3$

Alternatively,
Volume of water before adding the rock

$V_1 = L \times W \times H$
$= (10cm \times 10cm \times 10cm)$
$= 1000cm^3$

Volume of water after adding the rock

$V_2 = L \times W \times H$
$= (10 \times 10 \times 12)\ cm^3$
$= 1200cm^3$

Volume of water displaced

$V = V_2 - V$
$= (1200 - 1000)\ cm^3$
$= 200cm^3$

(c) Calculate the density of the rock

$$\text{Density} = \frac{\text{mass}}{\text{volume}} = \frac{600\ g}{200cm^3} = 3gcm^{-3}$$

Example 2:

(ii) The mass of $24.4cm^3$ of mercury is 332g. Find the density of mercury.**(=13.6 gcm^{-3})**
(iii) An 800g solid measures 10cm by 5cm by 4cm. Determine its density.**(= 4 gcm^{-3})**
(iv) A glass stopper of volume $16cm^3$ weighs 40g. Calculate its density in : (i) gcm^{-3} .**(=2.5 gcm^{-3})**
(ii) kgm^{-3}. **(=2500kgm^{-3})**
(v) The density of copper is $8.9gcm^{-3}$. What is the mass of $100cm^3$ of copper? .**(=890 g)**
(vi) When a piece of irregular stone of mass200g is lowered in a measuring cylinder, the initial and final volumes were $500cm^3$ and $600cm^3$ respectively. Calculate the density of the stone.**(=2gcm^{-3})**
(vii) An empty beaker weighs 120g in air and 180g when filled with 75cm3 of methylated spirit. Find the density of methylated spirit. **(=0.8gcm^{-3})**
(viii) What is the mass of 1.5litres of water? **(= 1.5kg)**

2. The oil level in a burette is $25cm^3$.50 drops of oil fall from a burette. If the volume of one drop is $0.1cm^3$.What is the final oil level in the burette. [**$30cm^3$**]

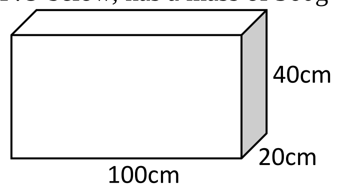
3. A measuring cylinder has water level of 13cm.What will be the new water level if 1.6g of a metallic block of density $0.8g/cm^3$ is added.

4. A perspex box having 6cm square base contains water to a height of 10cm.

(a) Find the volume of water in the box [$360cm^3$]

(b) A stone of mass 120g is lowered into the box and the level of water rises to 13cm.
(i) Find the new volume of water? [$468cm^3$]
(ii) Find the volume of the stone? [108 cm^3]
(iii) Find the density of the stone. [$\frac{2}{5}$ g/cm^3]

5. A steel C.P.U below, has a mass of 560g



Find its density (i) in g/cm^3 (ii) in kg/m^3

6. 200g of liquid Y of density $4gcm^{-3}$. Calculate the density of the mixture.

7. Liquids X and Yare mixed to form a solution. If the density of X is $0.8gcm^{-3}$ and volume is $100cm^3$, density of Y $1.5cm^{-3}$ and its volume is $300m^3$.Find the;
(i) mass of liquid X [80g]
(ii) mass of liquid Y [450g]
(iii) Density of a mixture [$1.325gcm^{-3}$]

7. In an experiment to determine the density of a pin, 100pins are gently lowered into a measuring cylinder containing $12cm^3$ of water. The water in the cylinder rose to $98cm^3$. Find the;
(i) volume of a pin.
(ii) density of the pin in kgm^{-3}

1:2:2. DENSITY OF MIXTURES

Suppose two substances are mixed as follows:

Substance	Mass	Volume	Density
X	M_X	V_X	$D_X = \frac{M_X}{V_X}$
Y	M_Y	V_Y	$D_Y = \frac{M_Y}{V_Y}$

$$\textbf{Density of mixture} = \frac{\textbf{mass of mixture}}{\textbf{Volume of mixture}}$$

$$\text{Density of mixture} = \frac{M_X + M_Y}{V_X + V_Y}$$

Example: 1

$100cm^3$ of fresh water of mass100g is mixed with 100 cm^3 of sea water of mass103g. Calculate the density of the mixture.

<u>Solution</u>

$$\text{Density of mixture} = \frac{\text{mass of mixture}}{\text{Volume of mixture}}$$

Density of mixture

$$= \frac{\text{mass of fresh water} + \text{mass of sea water}}{\text{Vol. of fresh water} + \text{Volume of sea water}}$$

$$\text{Density of mixture} = \frac{100 + 103}{100 + 100}$$

$$= \frac{203}{200}$$

<u>Density of mixture = 1.015 gcm^{-3}</u>

Example 2:

Liquid Y of volume $0.40m^3$ and density $90.0kgm^{-3}$ is mixed with liquid X of volume$0.35m^3$ and density $800kgm^{-3}$. Calculate the density of the mixture.

Solution

$\text{mass of Y} = \text{Volume of Y} \times \text{Density of Y}$

$\text{mass of Y} = 0.40 \times 90.0$

$\text{mass of Y} = 360\text{kg}$

$\text{mass of X} = \text{Volume of X} \times \text{Density of X}$

$\text{mass of Y} = 0.35 \times 800$

$\text{mass of Y} = 280\text{kg}$

.Then:

$$\text{Density of mixture} = \frac{\text{mass of mixture}}{\text{Volume of mixture}}$$

$$\text{Density of mixture} = \frac{\text{mass of liquid Y} + \text{mass of liquid X}}{\text{Volume ofliquid Y} + \text{Volume of liquid X}}$$

$$\text{Density of mixture} = \frac{360 + 280}{0.40 + 0.35}$$

$$= \frac{640\text{kg}}{0.75\text{m}^3}$$

$\underline{\text{Density of mixture} = 853.33\text{kgm}^{-3}}$

Exercise:

1. An alloy is formed by adding 500g of element P of density $5gcm^{-3}$ to $400cm^3$ of element Q of density $4gcm^{-3}$. Calculate the density of the alloy.[$4.2gcm^{-3}$]

2. $500cm^3$ of liquid X of density $2gcm^{-3}$ is combined with 200 g of liquid Y of density $4gcm^{-3}$. Calculate the density of the mixture.

3. Liquid M of density $0.5gcm^{-3}$ is mixed with liquid N in equal volumes. If the mixture has a density of $0.8gcm^{-3}$, Find the density of liquid N.

4. $3cm^{-3}$of water was mixed with $5cm^{-3}$ of milk of density $1500kgm^{-3}$. Find the density of the mixture. [$1312.5kgm^{-3}$]

5. Liquid A of volume $400cm^3$ and density $800kgm^{-3}$ is mixed with liquid B of volume $600cm^3$ and density $1120kgm^{-3}$. Calculate the density of the mixture.

1:2:3. RELATIVE DENSITY (R.D)

Relative density is defined as the ratio of the density of a substance to the density of an equal volume of water.

$$\text{Relative Density} = \frac{\text{Density of substance}}{\text{Density of equal volume of water}}$$

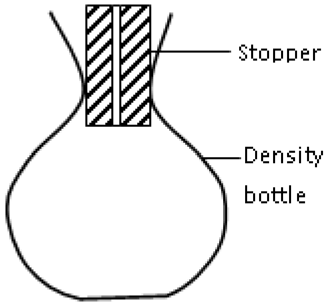
Note: Density of pure water $=1gcm^{-3} = 1000kgm^{-3}$ since density = mass / Volume, Then:

$$\text{Relative Density} = \frac{\text{mass of substance}}{\text{mass of equal volume of water}}$$

$$\text{Relative Density} = \frac{\text{weight of substance}}{\text{weight of equal volume of water}}$$

Note: Relative density has no units.

Experiment: ***To determine the Relative density of a liquid using a density bottle.***



The bottle contains exactly the same volume when the liquid level is at the hole.

- mass of empty bottle M_0

A dry density bottle with a stopper is weighed when empty using a balance.

- Mass of bottle filled with the liquid M_2

A dry density bottle with a stopper is weighed when filled with the liquid using a balance.

- Mass of bottle filled with water M_1

After removing the liquid and rinsing out the density bottle with water, the density bottle is filled with water and weighed again.

- The measurements are recorded as below:

Mass of empty: $= m_0$

Mass of bottle full of water: $= m_1$

Mass of bottle full of liquid: $= m_2$

Mass of liquid: $= m_2 - m_0$

Mass of water: $= m_1 - m_0$

- Relative Density of a liquid $= \frac{m_2 - m_0}{m_1 - m_0}$

Note: The advantage of using a density bottle in measuring the relative density of a solid is that it is accurate compared to other methods.

Measurement of relative density of a solid

- This can be found by weighing the solid in air and when fully immersed in water.
- The solid immersed in water displaces an amount of water equal to its volume. The relative density is then calculated using;
- Relative density $= \frac{\text{Weight in air}}{\text{Weight in water}} = \frac{W_a}{W_a - W_w}$

Example 1

A density bottle was used to measure the density of mercury. The following measurements were taken:

- Mass of empty bottle = 20g
- Mass of bottle full of mercury = 360g
- Mass of bottle full of water = 45g

Calculate the;

a. Relative density of mercury
b. Density of mercury

Solution

(i)	(ii)
$\text{R.D} = \frac{m_2 - m_0}{m_1 - m_0}$ $\text{R.D} = \frac{360 - 20}{45 - 20}$ $\text{R.D} = \frac{340}{25}$ $\underline{\text{R.D} = 13.6}$	$\text{R.D} = \frac{\text{Density mercury}}{\text{Density of water}}$ $13.6 = \frac{\rho}{1000}$ $\rho = 13.6 \times 1000$ $\underline{\rho = 13600kgm^{-3}}$

Example: 2
A density bottle has mass 75g when empty, 95g when full of water and 99g when full of a liquid. Calculate the:
(i) Relative density of the liquid.
(ii) density of the liquid

Solution

$m_E = 75g; m_L = 99g; m_W = 95g$	
(i) $R.D = \frac{m_L - m_E}{m_W - m_E}$ $R.D = \frac{99-75}{95-75}$ $R.D = \frac{24}{20}$ $\underline{R.D = 1.2}$	(ii) $R.D = \frac{\text{Density of liquid}}{\text{Density of water}}$ $1.2 = \frac{\rho}{1000}$ $\rho = 1.2 \times 1000$ $\underline{\underline{\rho = 1200kgm^{-3}}}$

Exercise:
1. A bottle full of water has a mass of 45g, when full of ethanol, its massis36g. If the empty bottle weighs 20g, calculate the density of ethanol.

2. Density bottle has a mass of 70g when empty, 90g when full of water and 94g when full of liquid.
Find the relative density of the liquid and its density.

3. An empty 60-litre petrol tank weighs10kg. What will be its mass when full of petrol of relative density 0.72?

4. A density bottle was used to measure the relative density of a liquid and the following results were obtained.
Mass of empty bottle : =30g
Mass of bottle full of water : =130g
Mass of bottle full of liquid : =110g
Calculate the density of the liquid. **($=0.8gcm^{-3}$)**

5. An empty density bottle is 46.00g. When fully filled with water, it weighs 96.00g. It weighs 86.00g when full of an unknown liquid. Find the density of the liquid. **($=0.8gcm^{-3}$)**
6. A piece of aluminum weighs 80N in air and 50.37N when completely immersed in water. Calculate the relative density of aluminum. **(=2.7)**

7. Two solid cubes have the same mass but their surface areas are in the ratio of 1 : 16. What is the ratio of their densities?
A. 1 : 2 B. 4 : 1
C. 64 : 1 D. 1 : 64

9. A metal cuboid of dimensions 3 cm by 2 cm by 1 cm and 8.9 g cm^{-3} is completely immersed in a liquid of density 0.8 g cm-3. The mass of the liquid displaced is.
A. 53.4 g. C. 29.1 g.
B. 7.5 g. D. 4.8 g.

10. $0.002m^3$ of a liquid of density $800kgm^{-3}$ is mixed with $0.003m^3$ of another liquid of density $1200kgm^{-3}$. What is the density of the mixture?
A. 1,000 kgm^{-3} B. 4,000 kgm^{-3}
C. 2,500 kgm^{-3} D. 1,040 kgm^{-3}

11. A bottle weighs 160 g when empty, 760 g when filled with water, and 1 kg when filled with a certain liquid. Calculate the volume of the liquid in bottle.
A: 160 cm^3 B: 600 cm^3
C: 760 cm^3 D: 1000 cm^3

12. What mass of lead has the same volume as 1600 kg of petrol? {Density of lead = 11400 kg m^{-3}, Density of petrol = 800 kg m^{-3}}
A. 22 800 kg C. 1600 kg
B. C. 11400 kg D. 800 kg

13. A metal cuboid of dimensions 3 cm by 2 cm by 1 cm and 8.9 g cm-3 is completely immersed in a liquid of density 0.8 g cm-3. The mass of the liquid displaced is
A. 53.4 g. B. 29.1 g.
B. C. 7.5 g. D. 4.8 g.

14. A tank 2m tall and base area of $2.5m^2$ is filled to the brim with a liquid, which weighs 40000N. Calculate, the density of the liquid in kg/m^3.
A. $\frac{4000}{2\times2.5\times10}$ C. $\frac{4000}{2\times2.5\times10}$

B. $\frac{40000}{2\times2.5\times10}$ D.$\frac{40000}{2\times25}$

1:3. SCALARS AND VECTORS

Physical quantities can be divided into two types namely:
i) Scalar quantity ii) Vector quantity

<u>A scalar quantity is physical quantity which has magnitude only.</u>
Examples: Mass, volume, time, temperature distance, pressure etc.

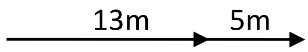
<u>A vector quantity is a physical quantity which has both magnitude and direction.</u>
Examples: Velocity, acceleration, force, momentum displacement, Electric and magnetic field intensities.

Resultant Vector
<u>A resultant vector is a single vector which produces the same effect on an object as two or more vectors acting on the same body.</u>
Moving from O to B along OB is the same as moving through OA followed by AB. This shows that a single vector OB produces the same effect as adding; $\overrightarrow{OB} = \overrightarrow{OA} + \overrightarrow{AB}$

In general the resultant force is calculated by adding all the force. But when the forces are in opposite direction the resultant force is calculated by subtracting.

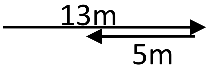
Addition and subtraction of vectors
The addition of vector takes place so long as the directions are the same though the magnitude may differ.
The subtraction occurs when the directions are opposite.

Example 1:
A goat moves 13m west and continue moving west ward 5m. Find the resultant displacement of the got .



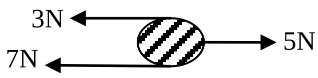
S_H =13+5
=18m in the western direction

Example 2:
Move 13m west and the move 5m east



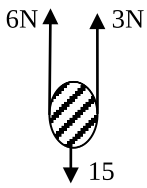
S_H =13-5
=8m in the western direction

Example 3:
Three force of 3, 5N and 7N act on an object A as shown. Find single vector which can produce the same effect.



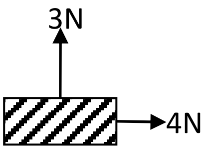
$F_H = (3+7) - 5$
=5N towards the East

Example 4
Three force of 3, 5N and 7N act on an object A as shown. Find single vector which can produce the same effect.



F_V =15- (6+3)
= 6N towards the South

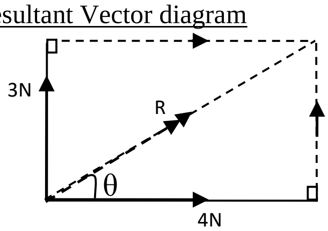
Example 5
Two force of 3 and 4N act on an object as shown. Find single force which can produce the same effect as the two forces above.



Solution:

<table>
<tr>
<td>$F_H = 4N \rightarrow$

$F_V = 3N \uparrow$

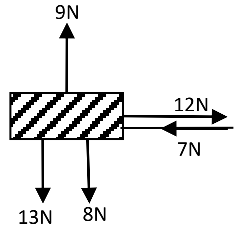
<u>Resultant Vector diagram</u>


<u>Magnitude of the resultant force</u>
Using the Pythogras theorem;
$(\mathbf{Hypotenuse})^2 = (\mathbf{Base})^2 + (\mathbf{Height})^2$
$(R)^2 = (b)^2 + (h)^2$
$R^2 = 4^2 + 3^2$
$R^2 = 25$
$R = \pm\sqrt{25}$</td>
<td><u>Direction of the resultant force</u>
From the Vector diagram;
$\tan\theta = \frac{\text{Height}}{\text{Base}}$
$\tan\theta = \frac{3}{4}$
$\theta = \tan^{-1}\left(\frac{3}{4}\right)$
$\underline{\underline{\theta = 36.9^0}}$

∴The direction of the resultant force is 36.9^0above the horizontal (or above the 4N force)</td>
</tr>
</table>

$R = \pm 5N$ <u>∴The magnitude of the resultant force is 5N</u>	

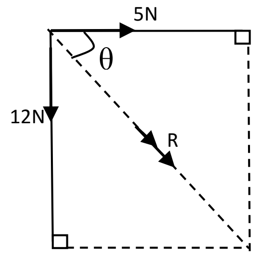
Example 6
The figure below shows five forces acting on a 2.5kg mass.



Calculate the;
(i) resultant force on the mass
(ii) direction of the resultant force
(iii) acceleration of the mass

Solution
(i) $F_H = (12 - 7)N = 5N \rightarrow$
$F_V = \{(13+8)N - 9N\} = 12N \downarrow$

- ❖ Resultant Vector diagram



- ❖ The magnitude of the resultant force

Using the Pythogras theorem;
$(\mathbf{Hypotenuse})^2 = (\mathbf{Base})^2 + (\mathbf{Height})^2$
$(R)^2 = (b)^2 + (h)^2$
$R^2 = 5^2 + 12^2$
$R^2 = 169$
$R = \pm\sqrt{169}$
$R = \pm 13N$
<u>∴The magnitude of the resultant force is 13N</u>

(ii)
- ❖ Direction of the resultant force

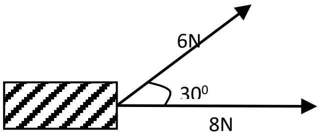
From the Vector diagram;
$\tan\theta = \frac{\text{Height}}{\text{Base}}$
$\tan\theta = \frac{12}{5}$
$\theta = \tan^{-1}\left(\frac{12}{5}\right)$
$\theta = 67.4^0$
∴The direction of the resultant force is 67.4^0below the horizontal (or below the 4N force)

(iii)
- ❖ Acceleration of the mass

From $F = ma$
$13 = 2.5a$
$\frac{13}{2.5} = \frac{2.5}{2.5}a$
$= a$
$\underline{\underline{\therefore \quad a = 0.48 \quad ms^{-2}}}$

Example 7

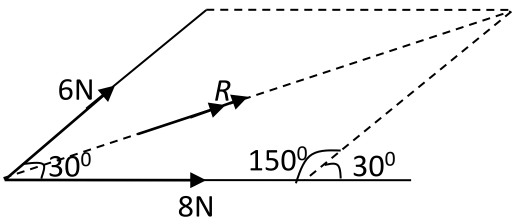
Two forces 6N and 8N act on 2kg body as shown. Calculate (i) the resultant force (ii) the acceleration



Methode I: Using Graphical Method.
Procdures

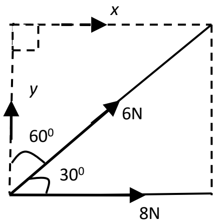
- Choose a scale for the axes
- Draw the vectors at the given angle
- Complete the Parallelogram of vectors.
- Measure the length R of the diagonal
- Multiply R by the scale to get the resultant Vector.

Method II: Using the Cosine Rule.



$a^2 = b^2 + c^2 - 2bc\cos\theta$
$R^2 = 8^2 + 6^2 - 2(8)(6)\cos 150$
$R^2 = 64 + 36 - 104\cos 150$
$R^2 = 100 - 104\cos 150$
$R^2 = 190.07$
$R = \pm 13.8$ N

Method III: By Resolving the Forces Horizontally and Vertically.



From the diagram;

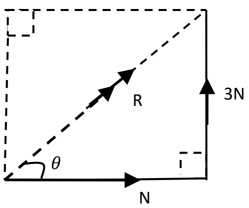
$\sin 60 = \dfrac{x}{6}$

$x = 6\sin 60 = 6 \times 0.8666 = $ N

$\cos 60 = \dfrac{y}{6}$

$y = 6\cos 60 = 6 \times 0.5 = 3$N

Then;
$F_V = y = 3$N
$F_H = x + 8 = $ N



Using the Pythogras theorem;

$(\textbf{Hypotenuse})^2 = (\textbf{Óase})^2 + (\textbf{Height})^2$
$(R)^2 = (b)^2 + (h)^2$
$R^2 = 5^2 + 3^2$
$R^2 = 169$
$R = \pm\sqrt{169}$
$R = \pm 13$N

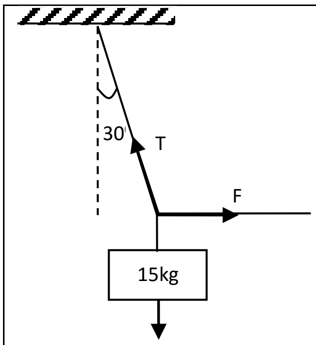
<u>∴The magnitude of the resultant force is 13N</u>

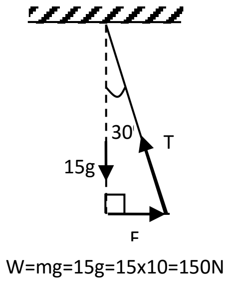
Example 8

A mass of 15kg is suspended using a string. The string is then pulled by a horizontal force F such that the string makes an angle of 30^0 with the down ward vertical. Calculate the;

(i) Tension in the string.
(ii) Horizontal force F.

Solution:





The three forces are in equilibrium
Step 1: forming a closed triangle
Step 2: resolving Vertically;

$\cos 30 = \frac{150}{T} \Leftrightarrow T\cos 30 = 150 \Leftrightarrow T = \frac{150}{\cos 30} = 173.21\text{N}$

Step 3: Resolving Horizontally

$\text{Tan } 30 = \dfrac{F}{150} \Leftrightarrow 150\tan 30 = F \Leftrightarrow F = 86.6\text{N}$

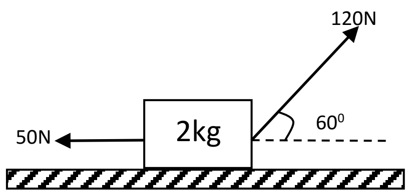
OR

$\sin 30 = \dfrac{F}{T} \Leftrightarrow T\sin 30 = F \Leftrightarrow F = 173\sin 30 = 86.6\text{N}$

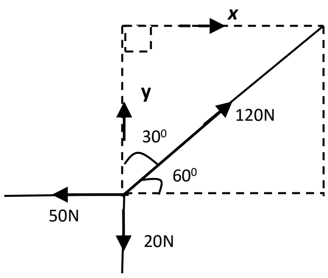
Example 9

A block of mass 2kg is pulled along a rough horizontal ground by a force of 120N, with the help of a string, which makes an angle of 60^0 with the horizontal. If the friction between the block and the ground is 50N, calculate the;

(i) Resultant force on the block.
(ii) Acceleration of the block.



Solution



From the diagram;

$\sin 30 = \dfrac{x}{120}$

$x = 120 \sin 30 = 120 \times 0.5 = 60\text{N}$

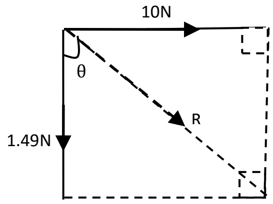
$\cos 30 = \dfrac{y}{120}$

$y = 120 \cos 30 = 120 \times 0.8666 = 18.51\text{N}$

Then;

$F_V = 18.51 + (-20) = -1.49$ N

$F_H = 60 + (-50) = 10$ N



Using the Pythogras theorem;

$(\textbf{Hypotenuse})^2 = (\textbf{Base})^2 + (\textbf{Height})^2$

$(R)^2 = (b)^2 + (h)^2$

$R^2 = 10^2 + 1.49^2$

$R^2 = 102.2201$

$R = \pm\sqrt{102.2201}$

$R = 10.11\text{N}$

∴The magnitude of the resultant force is 10.11N

1:3:1. FORCES

A force is that which changes a body's state of rest or uniform motion in a straight line.

Or

-It is that which makes a body to accelerate.

-It is a push or a pull on a body.

Force is a vector quantity.

The S.I unit is a newton, N.

Types of forces

There various types

Gravitational force, weight, friction, upthrust force, electrostatic force, elastic force, magnetic force, Centripetal force, centrifugal force, Tensional force, compression force, shear force etc.

Gravitational force

The earth is surrounded by gravitational field which exerts a force on anybody in the field.

The strength of the gravitational field is the force acting on a unit mass in the earth's field. Experimental measurements show that on a unit mass on the earth's surface, a mass of 1kg experiences a force of 0.9 N i.e. its weight is 9.8N so the earth's field strength "g" =9.8N/kg =10N/kg

1kg =10N

g = 10N/kg = 10m/s

Free fall is a vertical motion whose acceleration is due to gravity "g" = 10m/s^2. The gravitational force is towards the centre of the earth and its magnitude on the body of mass "m" is given by **mg**.

1:3:1:1WEIGHT

Weight of a body is the force of gravity on the body. or The gravitational force acting on a body. **Or**

Is the force a body exerts on anything which freely supports it in the gravitational field.

Weight of body = mass of body "m" (kg) x acceleration due to gravity, g. **W = mg**

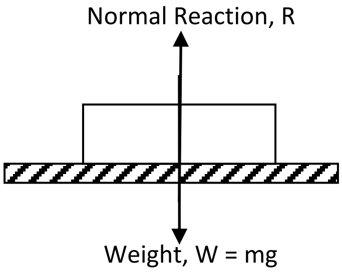
The S.I unit of weight is a newton "N" Weight of a body varies from place to place or from planet to planet.

Why weight of a body varies

Weight of a body varies because of the following reasons:

i) The shape of the earth is not a perfect sphere. so at the equator the value of acceleration due to gravity is less than that at the pole. This makes the weight of the body to be less at the equator and greater at the poles.

ii) Planets have different accelerations due to gravity. A body resting on the surface experience a reaction force R from the surface which supports it.



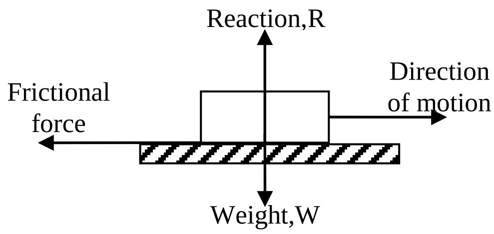
Differences between Mass and weight

Mass	Weight
i) S.I unit is kg	SI unit is N
ii) Is a scalar quantity	Is a vector quantity
iii) Is constant at all places	Varies from place to place
iv) Is a measure of quantity of matter in a body	Is force of gravity acting on a body.

1:3:1:2. FRICTION

Friction is the force which opposes motion.

It acts in the opposite direction to that of the force causing motion.



Types of friction

These are:

a) Static friction b) Sliding or dynamic friction

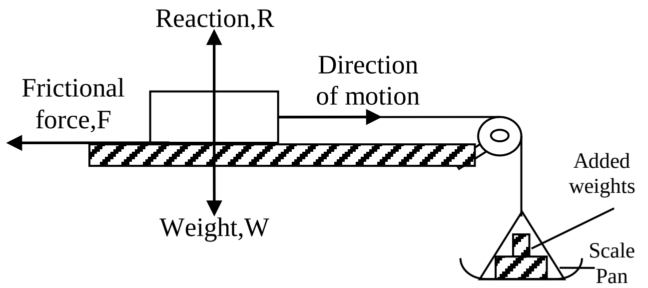
c) Viscosity

a) **Static Friction**:

Is friction which opposes motion between two surfaces in contact at rest.

- It prevents motion.

Experiment for measurement of static friction

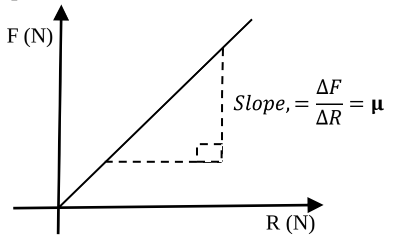


i) Adding weight on pan
Know weights are added to the scale pan until the block moves with a uniform velocity.

ii) The above will occur when weight of scale pan + weights on the pan (loads) = maximum friction, F. This maximum friction is called limiting friction.

iii) Repeating
The procedure is repeated by increasing weight of the block "W" and obtaining the corresponding "F"

iv) Plotting a graph
A graph of F against W (= normal reaction "R") is plotted .and its slope = coefficient of static friction **μ..**



$$\begin{pmatrix}\text{Frictional} \\ \text{force, F}\end{pmatrix} = \begin{pmatrix}\text{coefficient} \\ \text{of friction, }\mu\end{pmatrix} \times \begin{pmatrix}\text{Normal} \\ \text{Reaction, R}\end{pmatrix}$$
$$F = \mu R$$

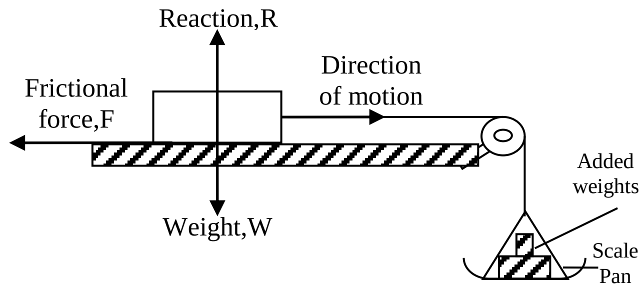
Thus Coefficient of static friction μ is the ratio of limiting frictional force F to the normal reaction R. i.e $\mu = \frac{F}{R}$
Note: Coefficient of friction μ has no units.

Example
Calculate the static friction when a body of mass 6kg rests on a surface; given that coefficient of friction of surface is 0.5.
Given: m= 6kg; $\mu = 0.5$; g = 10ms^{-2}
From; Frictional force, $F = \mu R$
But $R = W = mg$
$= 6(10)$
R $= 60N$

Then From; $F = \mu R$
$F = 0.5(60)$
$F = 30N$

b) Sliding or kinetic or dynamic friction:
Is friction which opposes relative motion between two surfaces in contact and in motion.
It is the force which opposes the motion of one surface moving with uniform velocity over another surface.
- ❖ It slows down motion.

Experiment for measurement of static friction

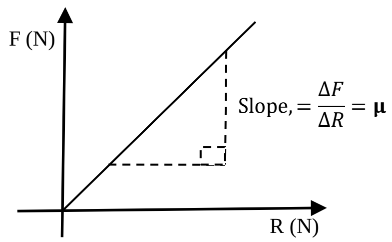


i) Adding weight on pan
Known weights are added to the scale pan and **a small push is given** each time until the block move with a uniform velocity.

ii) The above will occur when weight of scale pan + weights on the pan (loads) = maximum friction, F. This maximum friction is called limiting friction.

iii) Repeating
The procedure is repeated by increasing weight of the block "W" and obtaining the corresponding frictional force F'.

iv) Plotting a graph
A graph of "F" against R is plotted and its slope = coefficient of sliding friction **μ.**.



c) Viscosity:
Is the opposition to the relative motion between layers of a fluid.

Advantages of friction
i) It enables bodies to come to rest
ii) It enables bodies to move without sliding
iii) It helps in writing
iv) It helps in making fire

Disadvantages of friction
i) causes unnecessary heat
ii) reduces the efficiency of machines
iii) Causes things like tyres, soles of shoes to wear out.
iv) Causes parts of machines to break.
v) Causes un necessary noise

Reduction of friction
i) Lubrication using oil or grease
ii) Using ball bearings or rollers

Laws of friction
-The limiting does not depend on the surface area in contact but depends on the nature of the face contact.
-Frictional force is not affected by velocity with which a body moves for sliding friction.

-Friction always opposes motion
-Limiting friction is proportional to normal reaction which is equal and opposite to the weight of the body.
-Friction always increases from zero to maximum value called limiting friction.

Exercise

1. Two forces of 7N and 9N act perpendicularly on a body of mass 2kg. Find the acceleration of the body.

2. A man starts from point A and walks a distance of 20m due north and then 15m due east. Find his new position relative to A.

3. A parachutist falling with a constant velocity of 16 ms^{-1} is blown by wind horizontally at 12 ms^{-1}.
(i) Find the resultant velocity of the parachutist.
(ii) If the parachutist jumps from a height of 500m directly above a ground target, find the horizontal distance by which the parachutist will miss the target on landing.

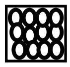
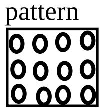
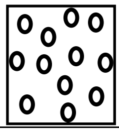
4.

UNEB 1999 Qn. 7 UNEB 2003 Qn. 2 , 27, 41 UNEB 2005 Qn. 12 UNEB 1998 Qn. 2, Qn 18 and Qn. 1 Section B UNEB 2007 Qn. 1, 3 and Qn11	UNEB 1987 Qn. 23 UNEB 1988 Qn. 23 UNEB 1991 Qn. 24 UNEB 1992 Qn. 34
Friction: UNEB 1997 Qn. 1, 27, and Qn. 1 Section B UNEB 1994 Qn.	

1:4. PARTICULATE NATURE OF MATTER

MATTER:
Matter is anything that occupies space and has weight.

States of matter:
There are three states of matter namely:
- Solids → e.g stone, ice, e.t.c
- Liquids → e.g water, paraffin, e.t.c
- Gases → e.g oxygen, nitrogen, e.t.c

Property	**Solids**	**Liquids**	**Gases**
1. Arrangement of molecules.	Closely packed in regular pattern called lattice 	Fairly closely packed in regular pattern 	Far apart from each other. 
2.Intermolecular forces.	Strong	Weak	Very weak
3. Motion of the molecules.	Vibrate within fixed position	Vibrate with greater amplitude	Move randomly throughout the container, at greater speed
4.Shape	Have definite shape	No definite shape. Take shape of container	No definite shape.
5.Rate of diffusion	Very low in some solids	Low	High
6.Compressibility	Incompressible	Incompressible	Compressible

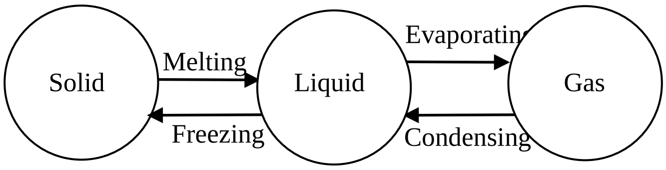
Note:
- Solids and liquids are incompressible, meaning that their volumes cannot be reduced by squeezing them.
- Gases are compressible because of the large spaces between their molecules.

Change of state
- Heating of matter

When a solid is heated, it changes to a liquid at constant temperature called melting point. The process is called melting or fusion.
When the liquid formed is heated further, the liquid changes to vapour at constant temperature called boiling point. The process is called boiling or evaporation.

- Cooling of matter

When a gas or vapour is cooled, it condenses to a liquid at constant temperature called freezing point. The process is called condensation or liquefying.
When the liquid formed is cooled further, it changes to a solid at constant temperature called freezing point. The process is called freezing or solidifying.



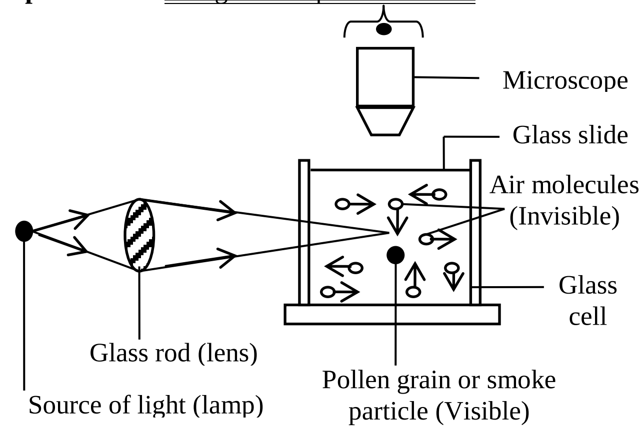
Kinetic Theory of matter
The kinetic theory of matter states that:
- ❖ Matter is made up of small particles called molecules or atoms that are in a state of constant random motion.
- ❖ The speed of motion of the particles is directly proportional to the temperature.

The kinetic theory of matter can be proved by using:
(i) Brownian motion
(ii) Diffusion

BROWNIAN MOTION
Brownian motion is the constant random (or haphazard) movement of tiny particles in fluids.

Experiment to demonstrate Brownian motion
Experiment 1: Using Pollen grains.
- ❖ When pollen grains molecules are dropped in water or suspended in water and observed through a microscope,
- ❖ The molecules will be seen making irregular movements in random directions.
- ❖ This shows that particles of matter are ever in a state of constant random motion.

Experiment 2: Using Smoke particles in air.



- ❖ Smoke is placed in a glass cell and the glass cell illuminated with light from one side.
- ❖ The smoke particles are then observed from above using a microscope.

Observation:
- ❖ White specks of smoke particles will be seen moving in a constant random motion.
- ❖ This shows that particles of matter are ever in a state of constant random motion.

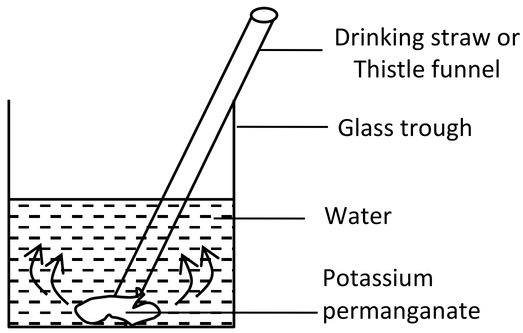
Explanation:
The constant random motion is due to un even collision (or bombardment) of the invisible air molecules with the visible pollen grains or smoke particles.

Factors that affect Brownian motion
(i) Temperature
- ❖ When the temperature of the smoke cell is increased, smoke particles are seen moving faster and when it is reduced, they are seen moving slowly.
- ❖ Increase in temperature increases the kinetic energy of the molecules, hence they move faster than before.
- ❖ Decrease in temperature decreases the kinetic energy of the molecules, hence they move slowly.

(ii) Size and density of the particles
- ❖ When the size of the particles is increased, Brownian motion is reduced and when the size of particles is reduced, Brownian motion increases.

DIFFUSION
Diffusion is the spreading (or flow) of molecules a substance from a region of high concentration to a region of low concentration.

Diffusion in liquids:
Experiment to show diffusion in liquids



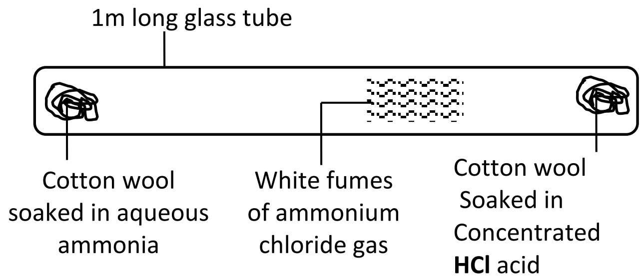
Procedures:

- ❖ Water is placed in a clean glass trough
- ❖ A crystal of potassium permanganate is then introduced at the bottom using a drinking straw.

Observation:
- ❖ The purple crystal of potassium permanganate dissolves and spreads throughout the water forming a purple solution.

Conclusion:
- ❖ This means that potassium permanganate has diffused through the water in the glass trough.

Diffusion in gasses:
Experiment to show diffusion in gases



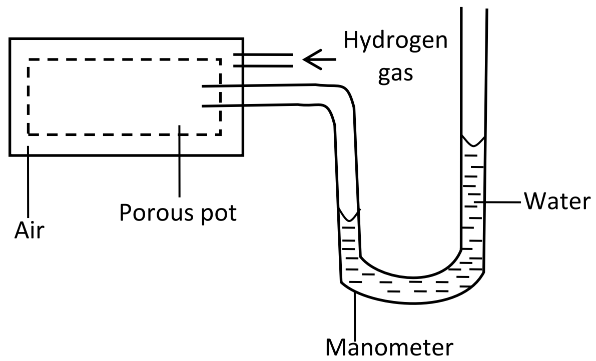
Procedures:
- ❖ Cotton wool soaked in aqueous ammonia is placed at one end and another cotton wool soaked in concentrated hydrochloric acid is placed at the other end of a glass tube of about 1m long.

Observation:
- ❖ White fumes of ammonium chloride forms inside the tube near the end with cotton wool soaked in **HCl** acid.

Conclusion:
- ❖ This means that:
  - (i) The gases have diffused through the air in the tube.
  - (ii) Ammonia diffuses faster than Hydrogen chloride.

Note: Alternatively;
An air molecule tube is inverted over brown nitrogen dioxide molecules tube.
Observation: the brown colour spreads into the upper tube at the same time the air molecules spread into the lower tube.

Experiment II: to show diffusion in gases



- ❖ Connect a water manometer to a porous pot containing air.
- ❖ Pass hydrogen into the air enclosed in the porous material as shown in the diagram above.
- ❖ The water level in the left arm of the manometer falls while that in the right arm rises.
- ❖ The hydrogen molecules diffuse through the porous material into the air. This increases the pressure in the porous pot, which then acts on the water surface in the left arm of the manometer, thus pushing the water level down wards.

Factors that determine the rate of diffusion

(i) Size of diffusing molecules
Smaller molecules diffuse faster than larger molecules. This is because larger molecules occupy large space than small ones.

(ii) Temperature
The rate of diffusion is directly proportional to temperature.

(iii) Pressure
The rate of diffusion is directly proportional to pressure.
This is because at a higher pressure, gas molecules are squeezed, move faster and collide frequently than at low pressure.

(iv) Molecular weight
Lighter molecules diffuse faster than massive molecules.
The speed of diffusion in a gas depends on the speed of molecules in that; lighter molecules diffuse at greater rate e.g. the rate of diffusion of hydrogen gas is faster than that of carbon dioxide because the molecules of hydrogen move at a higher speed since they are lighter than the molecules of carbon dioxide.

PROPERTIES OF MATTER

(a) MOLECULAR PROPERTIES OF MATTER

Molecular properties of matter are based on the behavior of the molecules. These are observed in the following;
- (i) Diffusion
- (ii) Molecular forces
- (iii) Capillarity
- (iv) Surface tension
- (v) Elasticity

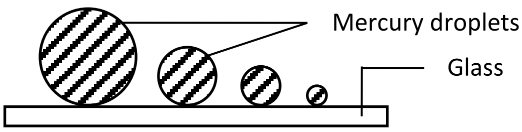
Molecular forces:
Intermolecular forces are forces of attraction or repulsion between molecules of matter. The molecules may be of the same substance or of different substance.
Types of molecular forces

❖ Cohesion (or Cohesive) force
Cohesion is the force of attraction between molecules of the same kind or same substance.
E.g Forces between water molecules themselves, forces between mercury molecules themselves e.t.c.

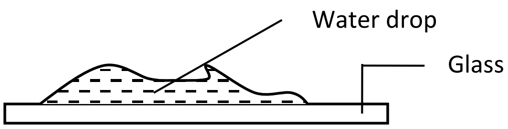
❖ Adhesion (or Adhesive) force
Adhesion is the force of attraction between molecules of different kinds or different substances.
E.g Forces between water molecules and glass molecules, forces between mercury molecules and glass molecules, forces between water molecules and mercury molecules, e.t.c.

NOTE: The magnitude of the cohesion and adhesion forces determines the:
- Shape of liquid meniscus in contact with a solid
- Ability of the liquid to wet a substance
- Rise or fall in a capillary tube.

When cohesion is greater than adhesion forces, e.g mercury and glass, then the liquid;
- (i) Does not wet glass
- (ii) Forms spherical balls when spilled on a glass surface
- (iii) Depresses in a capillary tube
- (iv) Meniscus curves downwards.



When adhesion is greater than cohesion forces, e.g water and glass, then the liquid;
- (i) Wets glass
- (ii) Spreads when spilled on a glass surface
- (iii) Rises in a capillary tube
- (iv) Meniscus curves upwards

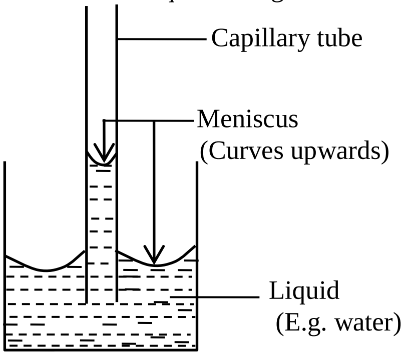


Water spreads on the glass surface due to greater adhesion forces between glass and water molecules than the cohesion forces between water molecules themselves hence wetting the glass.

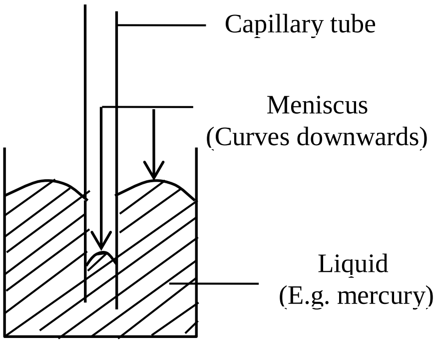
CAPILLARITY:

Capillarity is the elevation (or rise) or depression (or fall) of a liquid a narrow porous medium e.g tube.
Capillary action depends on cohesion and adhesion forces.

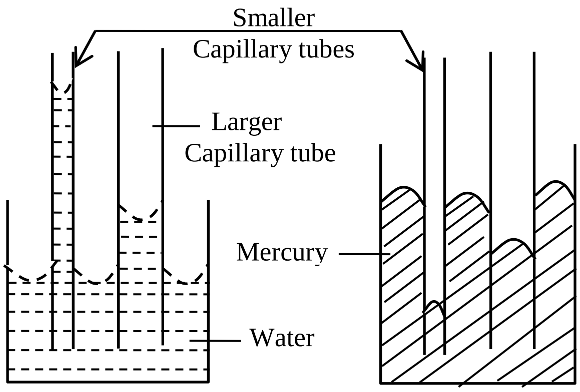
(i) When adhesion is greater than cohesion forces, e.g water and glass, then :
- the liquid rises in the capillary tube
- the meniscus curves upwards (concave);
- The liquid wets glass



(ii) When cohesion is greater than adhesion forces, e.g mercury and glass, then the :
- liquid falls (or depresses) in the capillary tube
- the meniscus curves downwards (convex);
- the liquid forms spherical balls when spilled on a surface
- does not wet glass



Effect of size or diameter of the capillary tube on capillarity



- Water rises higher in a capillary tube of smaller diameter than the one of a larger diameter.
- Mercury depresses deeper in a capillary tube of smaller diameter than the one of a larger diameter.

Uses of capillarity
- It helps paraffin (fuel) to rise up in wicks of stoves and lamps.
- It helps water to move up tree-trunks to the leaves
- It helps blotting papers to absorb liquids

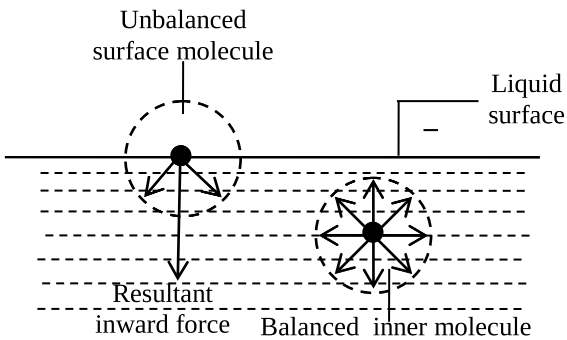
NOTE:
- ❖ All the above uses are possible because of greater adhesion forces than cohesion forces between molecules of the two substances. (i.e Fuel and wick, water and tree-trunk, liquid and blotting paper respectively). Thus, the wet part of the solid goes on increasing upwards.
- ❖ Damp proof material e.g polythene is put in the foundation course of a building to stop capillary action. This is because bricks, plaster and mortar are porous, so water can rise up through the narrow pores and weaken the wall.

SURFACE TENSION:

Surface tension is the force acting normally on a one-metre length of a line drawn on the surface of a liquid. Its S.I unit is Nm^{-1} .
Surface tension enables the surface of a liquid to behave like a stretched elastic skin (or membrane).
It is due to cohesion forces between the liquid molecules.

Surface tension is the force on the liquid surface that causes it to behave as if it is covered with a thin elastic membrane.

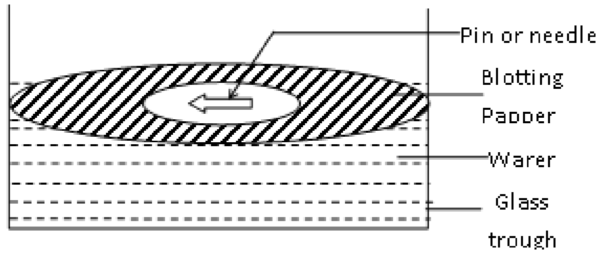
Molecular explanation of surface tension:



According to Kinetic theory surface tension is explain as follow:-

Molecules on the surface experience a net down word force on them and surface of the liquid thus tends to contract and acquire a state of tension.
- ❖ A molecule inside the surface of the liquid is surrounded by equal number of molecules on all sides. The intermolecular forces between it and the surrounding molecules is zero.
- ❖ A molecule on the surface has very few molecules on the upper side compared to those bellow the liquid surface.
- ❖ Thus if this molecule is displaced upwards, a resultant attractive force due to the large number of molecules bellow the liquid surface has to be overcome.
- ❖ This force is trying to pull the molecule out of the surface into the bulk. It is trying to make the surface smaller, hence surface tension.

Experiment to demonstrate existence of Surface tension



Procedures:
- ❖ A clean beaker is filled with water.
- ❖ A blotting paper is placed on the surface of the water.
- ❖ A pin or needle is gently placed on the blotting papper and observed.

Observation:
- ❖ After some few minutes, the blotting paper absorbs water and sinks to the bottom.
- ❖ The needle remains floating on the water surface.

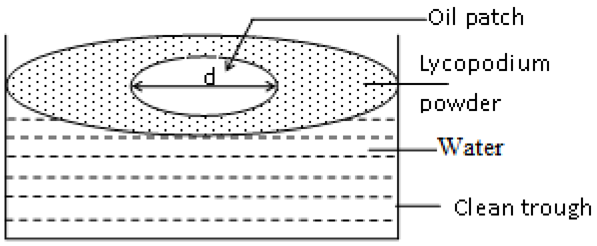
Conclusion:
- ❖ The needle is held by surface tension.

Effects of surface tension
(i) A needle (pin) floats on water surface.
(ii) Tents keep water, umbrellas and raincoats keep water off due to surface tension.
(iii) Insects e.g pond skater can walk across a water surface.
(iv) Water drops from a tap form spherical shapes. This is because; a free falling drop will take the shape that has the least (minimum) area.

Factors affecting surface tension
(i) Temperature: Increase in temperature (or heating a liquid) weakens or reduces surface tension.
(ii) Impurities: Impurities such as detergents, soap solution, alcohol e.t.c reduce surface tension.

Estimating the thickness (or Size) of an oil molecule:
A drop of oil is able to spread into a thin film of a large area when placed on a clean water surface. This is because the end of the oil molecule has greater adhesion forces than cohesion forces for neighboring molecules.
The size of an oil molecule is too small to be accurately measured. Its approximate size can only be estimated using an experiment.

Experiment to estimate the size of an oil molecule
.



- ❖ Fill a clean trough with clean water and sprinkle lycopodium powder on the surface of the water.
- ❖ Drop a known volume, V_o of the oil onto the water surface covered with lycopodium powder.
- ❖ The oil spreads forming a cylindrical oil film with a circular patch, whose diameter ''**d**'' is measured.
- ❖ The thickness or size of the oil film is estimated from:

$$\textbf{Thickness of oil drop; } t = \frac{\textbf{Volume of oil drop}}{\textbf{Area of oil patch}}$$

$$t = \frac{V_{oil\ drop}}{A_{patch}}$$

NOTE:
It is a common procedure to;
- ✓ Dissolve a known volume of a solute (e.g cooking oil or oleic acid) $\mathbf{V_1}$ in a known volume of a solvent (e.g Petroleum, alcohol or ether) $\mathbf{V_2}$ to form a solute-solvent solution.
- ✓ Then a known volume, $\mathbf{V_3}$ of the solute-solvent solution is dropped onto the water surface covered with lycopodium powder.
- ✓ The solvent in the drop either dissolves in water or evaporates and the solute (oil) spreads forming a cylindrical oil film with a circular patch, whose diameter ''**d**'' is measured.
- ✓ The thickness or size of the oil film is estimated from:

$$\textbf{Volume of cylindrical film} = \begin{pmatrix}\textbf{Volume of oil in the} \\ \textbf{spherical drop}\end{pmatrix}$$

Area of Patch × Thickness (t) = Volume of oil

$$\textbf{Thickness of oil drop; } t = \frac{\textbf{Volume of oil drop}}{\textbf{Area of oil patch}}$$

However, the volume of the oil in the solution which forms the oil film is calculated as follows:

$\mathbf{(V_1+V_2)}$ of solution =(contains)	$\mathbf{(V_1)}$ of solute or oil
$\mathbf{(V_3)}$ of solution dropped =(contains)	**V** (volume of oil in drop)

$$(V_1 + V_2) \times V = V_3 \times V_1$$

$$V = \frac{V_1 V_3}{(V_1 + V_2)}$$

$$\textbf{Volume of oil in drop}, V = \frac{V_1 V_3}{(V_1 + V_2)}$$

Assumption
(i) All the solvent has evaporated or dissolved in water.
(ii) The oil patch is circular.
(ii) The oil film or molecule formed is cylindrical.
(iii) The oil film formed is one molecule thick. (i.e the spaces between the molecules in the oil film are assumed to be negligible).
(iii) The oil drop is spherical.
(iv) Volume of cylindrical film=Volume of oil in spherical drop

NOTE:
The water surface should be sprinkled with lycopodium powder so that:
(i) The film becomes stationary.
(ii) A clear circular patch for measuring diameter is formed.

Example 1:
A solution is made by dissolving $1cm^3$ of cooking oil in $1999cm^3$ of methanol. When $0.004\ cm^3$ of the solution is dropped on the surface of water, an oil film of diameter 12cm is obtained.
(i) Calculate the volume of cooking oil in the film.
(ii) Estimate the thickness of a molecule of cooking oil.

(iii) State any two assumptions made in (i) above.

Solution:

Volume of solute or oil, **(V_1)** = $1cm^3$

Volume of solvent (methanol), **(V_2)** = $1999cm^3$

Volume of solution dropped, **(V_3)** = $0.004cm^3$

Volume of solute or oil, in **V_3** = **V**

$$\text{Volume of oil in drop}, V = \frac{V_1V_3}{(V_1+V_2)} = \frac{1\times(0.004)}{(1+1999)}$$

$$V = \frac{0.004}{(2000)}$$

Volume of oil in drop , $V = 0.000002 \text{ cm}^3$

Alternatively:

Volumes	
Volume of Solution	**Volume of Oil**
2000 cm^3	1 cm^3
0.004 cm^3	V
$2000V = 1 \times 0.004$ $V = 0.000002 \text{ cm}^3$	

Area of oil patch, $= \pi R^2$

$= \pi(\frac{12}{2})^2$

$= 3.14 \times 36$

Area of oil patch, $A = 113.097cm^2$

$$\text{Thickness of oil drop; } t = \frac{\text{Volume of oil drop}}{\text{Area of oil patch}}$$

$$t = \frac{0.000002}{113.097}$$

Thickness of oil drop; t = 1.76×10^{-8} cm

Example 2:

In an oil film, experiment to estimate the size of a molecule $0.005cm^3$ of oleic acid was dropped on lycopodium powder on a water surface. The mean diameter of the acid was 5cm. Calculate the thickness of a molecule of oleic acid.

Solution:

Volume of solute or oleic acid, **(V_1) =** $0.005cm^3$

Volume of oil in drop , $V = 0.005 \text{ cm}^3$

Area of oil patch, $= \pi R^2$

$= \pi(\frac{5}{2})^2$

$= 3.14 \times 6.25$

Area of oil patch, A= $19.63cm^2$

Then, from $A \times t = V$

$$\text{Thickness of oil drop; } t = \frac{\text{Volume of oil drop(V)}}{\text{Area of oil patch(A)}}$$

$$t = \frac{0.005}{19.63}$$

Thickness of oil drop; t = 2.55×10^{-4} cm

Example 3:

An oil drop of volume $1x10^{-9}$ m^3 spreads on a water surface to form a patch of area $5x10^{-2}$ m^2. If the patch is one molecule thick, find the approximate number of molecules in the drop.

Solution:

Volume of oil in drop , $V = 1x10^{-9} \text{ m}^3$

Area of oil patch, $A = \pi R^2$

$A = 5 \times 10^{-2} m^2$

Then, from $A \times t = V$

$(5 \times 10^{-2} m^2) \times t = 1x10^{-9} \text{ m}^3$

$$t = \frac{1x10^{-9} \text{ m}^3}{5\times10^{-2} m^2}$$

$t = 2 \times 10^{-8}$ m

NOTE: Remember the oil drop is spherical thus its radius, r is equal to half the thickness, $\frac{t}{2}$ of the oil film.

Thus the radius of the spherical oil drop, r is given by;,

$r = \frac{t}{2} = \frac{2\times10^{-8}}{2} = 1\times10^{-8}$ m

If n is the number of molecules in the oil drop, then

$$n\left(\text{volume of sphere of radius, } \frac{t}{2}\right) = (\text{volume of oil drop})$$

$$n\left(\frac{4}{3}\pi r^3\right) = 1x10^{-9}$$

$$n\left\{\frac{4}{3} \times 3.14 \times (1 \times 10^{-8})^3\right\} = 1x10^{-9}$$

$$n(4.189 \times 10^{-24}) = 1x10^{-9}$$

$$n = \frac{1 \text{ x } 10^{-9}}{4.189\times10^{-24}}$$

$n = 2.39 \text{ x } 10^{14}$ molecules.

Exercise

1. In an experiment to estimate the size of an oil molecule, a volume of $0.12cm^3$ was placed on a clean surface and spread into a patch of area $0.0006cm^2$. Calculate the size of the oil molecule. (Ans:t =200 cm).

2. When 0.002 cm^3 of oil was dropped on the surface of water, an oil film of diameter 6.0cm was formed. Calculate the thickness of the film.
(Ans:t =7.08×10^{-5} cm).

3. The volume of 100 drops of certain oil is $1.0cm^3$. One such drop was placed on a water surface and it spread into a circular patch of average diameter 50cm. What is the size of the oil molecule?
(Ans:t =5.09×10^{-6} cm).

4. If $1.8x10^{-4}cm^3$ oil spreads to form a patch of area 150 cm^2. Determine the thickness of the patch.
(Ans: t =1.2×10^{-6} cm).

5. A drop of oil of diameter 0.5mm becomes a circular film of oil of diameter 30cm.
   (i) Find the thickness of the oil film.
   (Ans:t =9.2×10^{-10} m).

   (ii) Calculate the number of molecules in the oil drop. (Ans:n =1.6×10^{17} molecules).

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

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

$$e = l_n - l_o.$$

It is also important to note that;

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

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.

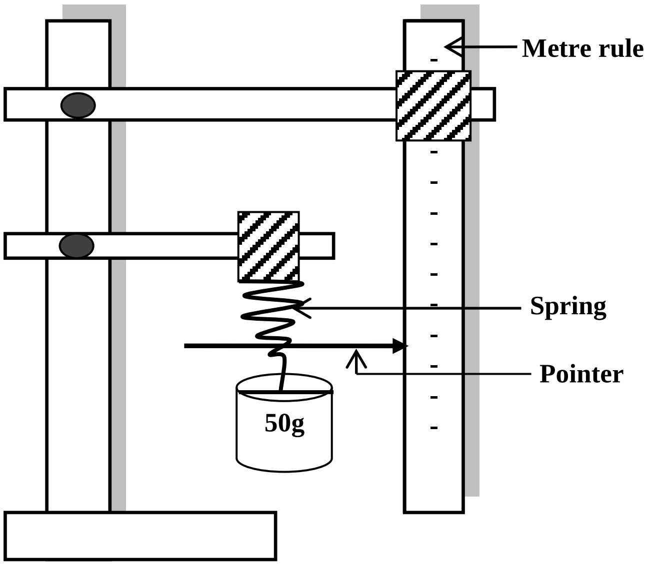
2. A force of 500N extends a wire by 2mm. If the force is reduced by a half, what will be the new length of the wire, if the original length is 10cm.

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

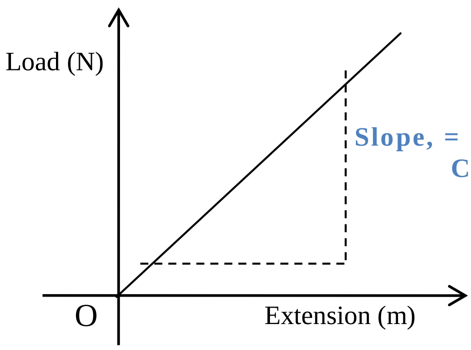
Experiment to verify Hook's law.



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

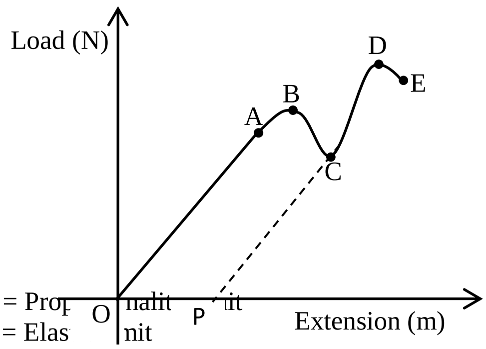
Load(N)	l_n (m)	e(m)
-	-	-
-	-	-

- 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=$6.67Nm^{-2}$

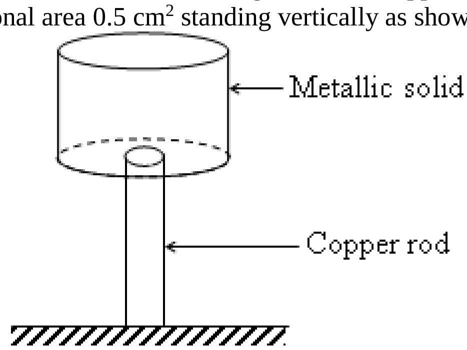
Example 4:
Calculate the tensile stress when a force of 25N acts on a wire of cross sectional area $5m^2$.

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. $9.0\times10^{2}Nm^{-2}$ B. $9.0\times10^{5}Nm^{-2}$
C. $9.0\times10^{6}Nm^{-2}$ D. $9.0\times10^{8}Nm^{-2}$

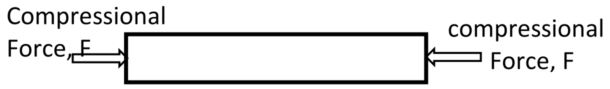
CRYSTALS:
Crystals have hard, flat sides and straight edges. Crystals of the same substance have the same shape. This will be observed when salt crystals grow as water evaporates from the salt solution on glass slide as seen through a microscope.

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.

Tensile, shear and compression force.

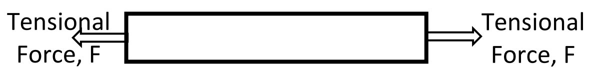
(i) Compression force

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.



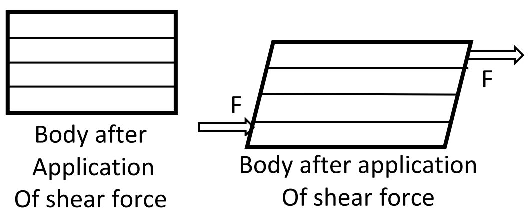
Differences between tensile and compression force.

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) Metals:

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) Alloys:

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

❖ Steel alloys. 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) Stony materials

❖ 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.

Properties of concrete which makes it a suitable building material
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.

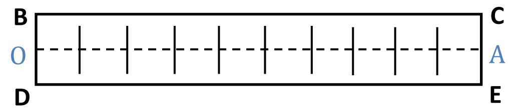
Thin sheets of wood are glued together to form a laminate (plywood) which is stronger than solid wood of the same thickness.

BEAMS AND STRUCTURES

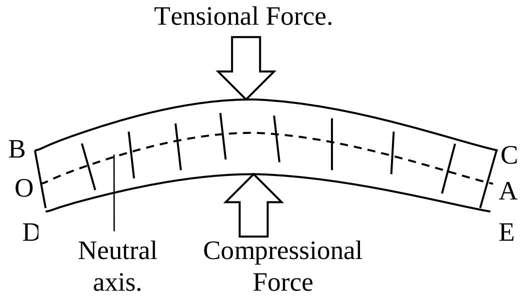
A beam is a large and long straight piece of materials with uniform cross-sectional area.

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,

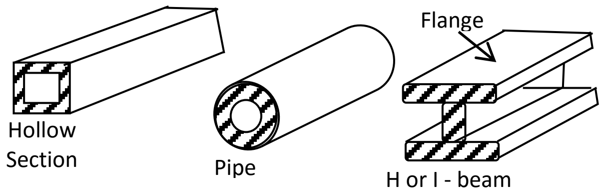


The lines above OA move further apart. Showing that the above parts are in tension.

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.

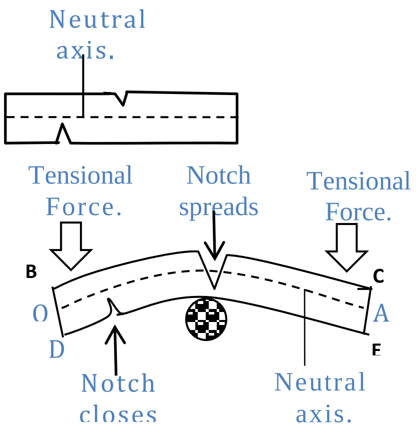
Because they are beams that have had material removed from the neutral plane, so can with stand compression and tensile forces due to loading.

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 <u>notch</u> 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) <u>For concrete and cement mortar;</u>
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.

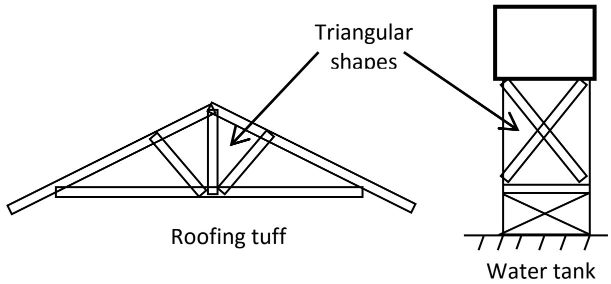
This is advantageous in that as well as resisting tension forces they keep the concrete in concrete in compression even if the whole structure is not.

(b) <u>For glass:</u>
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 <u>thermal toughening.</u>
iii) By reinforcing glass with transparent polythene.

(c) <u>For wood;</u>
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.



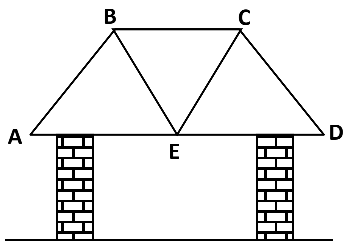
Struts and Ties
In any structure, there are parts, which are under action of tensional forces and others under action of compressional forces.

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.

<u>Properties of ties:</u>
- ✓ 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.

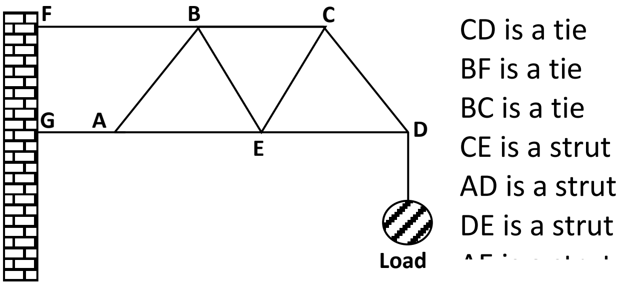
<u>Properties of struts:</u>
- ✓ It is under compression
- ✓ When removed, the point it joins move closer to each other.
- ✓ It cannot be replaced by a rope or strong string.



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.



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.

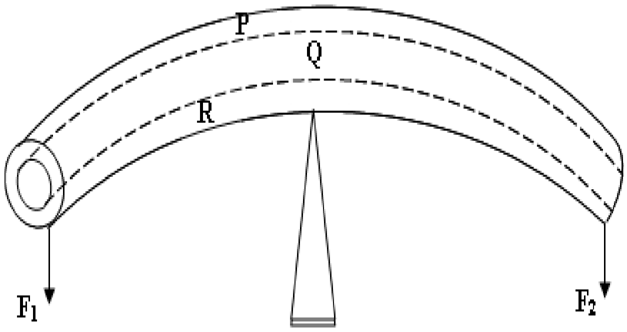
When CE is removed, the load moves down wards and part BCD will be straight due to the load. Thus, point C moves nearer to E meaning that girder CE is a strut. Similarly, girders BE and AB are struts.

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

1:5. TURNING EFFECT OF FORCE

Moment of a force is also called the measure of the turning effect of a force.

<u>**Moment of a force** is a product of a force and the perpendicular distance of the line of action of the force from the fulcrum (pivot).</u>

$$\begin{pmatrix}\text{Moment of}\\ \text{a force}\end{pmatrix} = \text{Force} \times \begin{pmatrix}\text{Perpendicular distance of}\\ \text{the line of action of the}\\ \text{force from the pivot}\end{pmatrix}$$

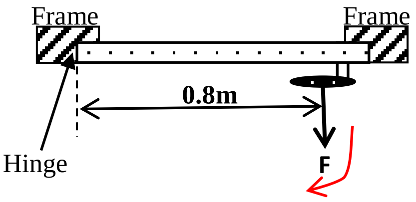
SI unit of moment is a newton meter (Nm). Moment of a force is a vector quantity.

Examples of the turning effects of a force;

- Opening or closing a door
- Children playing on a see-saw
- Bending of the fore arm of a hand

Example;1

A force of 12N is applied to open a door handle, which is 0.8m from the hinges of the door. Calculate the moment of the force produced.



Solution

<u>Taking moments about the Hinge;</u>

$Moment\ of\ Force\ = Force, F \times Perp. distance$

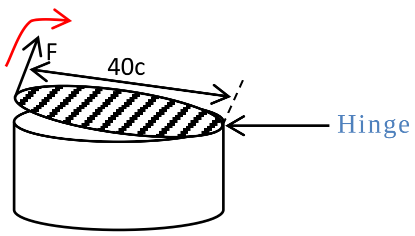
$Clockwise\ moment = 12 \times 0.8$

$\underline{Clockwise\ moment = 9.6Nm}$

Example;2

The moment of a force is 4Nm in the clockwise direction when the lid of a tin is opened. Calculate the vertical force applied, if the perpendicular distance from the hinges is 40cm.

Solution



<u>Taking moments about the Hinge;</u>

$\text{Moment of Force} = \text{Force, F} \times \text{Perp. distance}$

$$4 = \text{F} \times 0.4$$

$$\text{F} = \frac{4}{0.4}\text{N}$$

$$\text{F} = 10\text{N}$$

<u>Thus the vertical force applied is 10N</u>

From above, it can be noted that:

- ❖ The greater turning effect of a force occurs when the force acts on an object at a right angle.
- ❖ It is easier to close the door by pushing it at a point as far away from the hinges as possible. Because the force applied can easily balance with the reaction at the hinges.

Factors affecting moments

The moment of the force depends on the:-

i) magnitude of a force

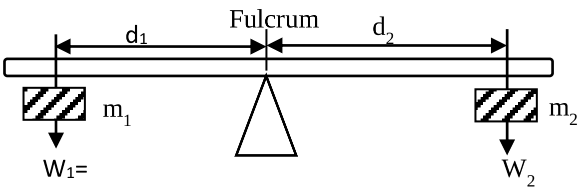
ii) Perpendicular distance from the turning point (fulcrum).

Law or principle of moments

This states that when body is in a state of equilibrium the sum of clockwise moments about any point is equal to the sum anticlockwise moments about the same point.

$$\begin{pmatrix}\textbf{Sum of clockwise}\\ \textbf{moments}\end{pmatrix} = \begin{pmatrix}\textbf{Sum of anticlockwise}\\ \textbf{moments}\end{pmatrix}$$

Experiment to verify the principle of moments.



The metre rule is balanced horizontally on a knife-edge and its centre of gravity, G noted.

Un equal masses m_1 and m_2 are hung from cotton loops on either sides of the rule.

The distances of the masses are then adjusted until the rule balances horizontally once again. The distances d_1 and d_2 are measured and recorded.

The experiment is repeated several times and the results tabulated including values of w_1d_1 and w_2d_2.

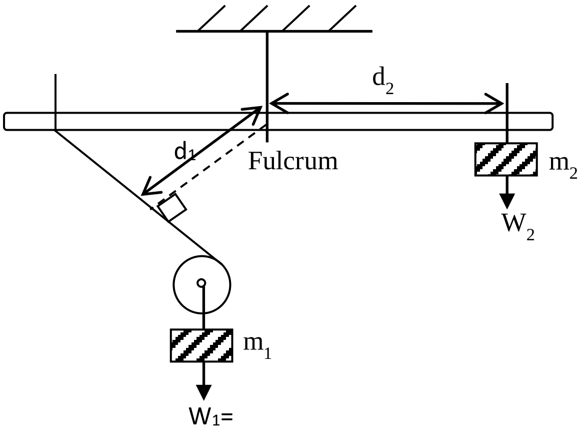
It is found that; $\mathbf{w_2d_2 = w_1d_1}$. Where w_2d_2 is the clockwise moment and w_1d_1 is the anticlockwise moment. This verifies the principle of moments.

The points from which moments are being taken acts as the pivot and the moments of force at that point is zero (0).

$$\begin{pmatrix}\text{Clockwise}\\ \text{moments}\end{pmatrix} = \begin{pmatrix}\text{clockwise}\\ \text{force}\end{pmatrix} \times \begin{pmatrix}\text{Perpendicular}\\ \text{distance from pivot}\end{pmatrix}$$

$$\begin{pmatrix}\text{Anti}-\\ \text{clockwise}\\ \text{moments}\end{pmatrix} = \begin{pmatrix}\text{Anti}-\\ \text{clockwise}\\ \text{force}\end{pmatrix} \times \begin{pmatrix}\text{Perpendicular}\\ \text{distance from pivot}\end{pmatrix}$$

Taking moments about the pivot;



Clockwise moments $=W_1 \times d_1 = W_1 d_1$
Anticlockwise moments $=W_2 \times d_2 = W_2 d_2$
And by the law of moment;
Sum of clockwise moments = sum of anti-clock moment about any point. Thus, $W_1 d_1 = W_2 d_2$

Note: *When calculating moments about a point (pivot) all distances should be measured from that point.*

Finding the mass and weight of uniform body

- ✓ When body is uniform, the mass or weight must act at the centre.
- ✓ A metre rule is marked from 0-100cm mark. If it is uniform, then its mass/weight must act in the middle, which is 50cm mark.
- ✓ The mass or weight is calculated by applying the principle of moment.

Example 2:
A metre-rule suspended from the centre of gravity is in equilibrium, i.e balanced at G, when forces of W_1, W_2 and W_3, act at distances of a, b and c respectively from the pivot.

(i) Draw a labeled diagram to show all the forces acting on the metre-rule.

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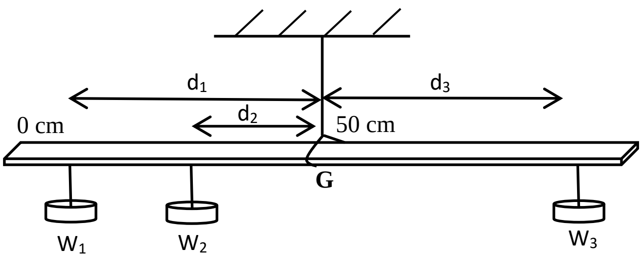
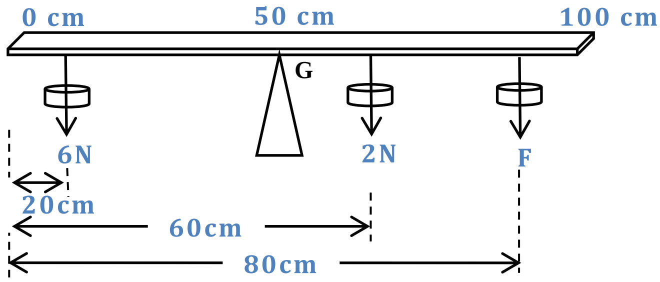


(ii) Write an expression for the sum of the moments.
Taking moments about the pivot;
Sum of Anticlockwise moments $= W_1 \times d_1 + W_2 \times d_2$
Sum of Clockwise moments $= W_3 \times c$

Applying the principle of moments;
Sum of clockwise moments = Sum of anticlockwise moments
$W_3 \times c = W_1 \times a + W_2 \times b$

Example3:
A uniform metre rule is pivoted at its centre and three forces of 6N, 2N and F act at distances of 20cm, 60cm, and 80cm respectively from the zero mark. If the metre rule balances horizontally, find the value of F.

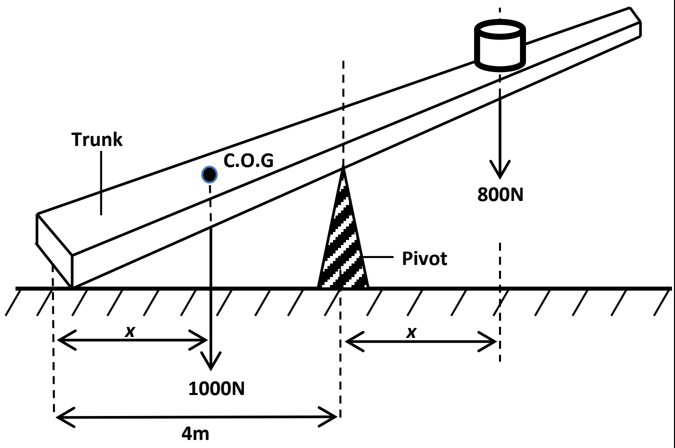
Solution



Taking moments about the pivot;
Sum of Anticlockwise moments $=6\times30 = 180$Ncm
Sum of Clockwise moments $=2\times10+F\times30$
$=(20+30F)$ Ncm
Applying the principle of moments;
Sum of clockwise moments = Sum of anticlockwise moments
$(20+30F)$ Ncm $=180$Ncm
$30F = 160$
$F = 5.3$ N

Example 4:
A non-uniform tree trunk of weight 1000N is placed on a pivot, 4m from the thick end. A weight of 800N is placed on the other side of the pivot, at a distance equal to that from the thick end to the centre of gravity, just tips off the tree trunk. How far is the weight from the thick end?

Solution:



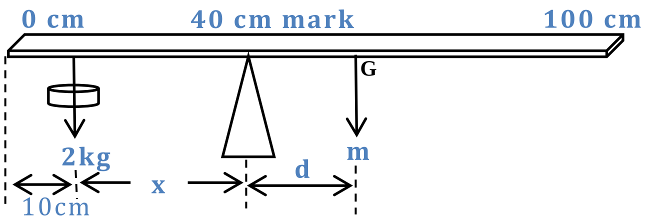
Let the distance from the thick end to the Centre of gravity (C.O.G) be ***x***.

Taking moments about the pivot;

Applying the principle of moments;
Sum of clockwise moments = Sum of anticlockwise moments
$(800 \times x)$ Nm $=1000\times(4 - x)$ Nm
$800x = 4000 - 1000x$
$1800x = 4000$
$$\frac{\cancel{1800}x}{\cancel{1800}} = \frac{4000}{1800}$$
$x = 2.2$m

Thus the heavy weight, is (4+2.2) m = 6.2m from the thick end.

Example: 1
A uniform metre rule is suspended from 40cm marking as shown in the diagram below. Find the mass of the metre rule if it's in equilibrium.



<u>Taking moments about the pivot;</u>
$\boldsymbol{x} = (40 - 10) = 30cm$
$\boldsymbol{d} = (50 - 40) = 10cm$

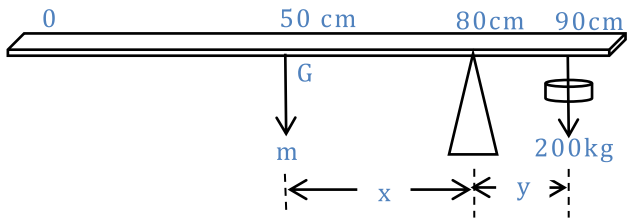
<u>Applying the principle of moments;</u>
Sum of clockwise moments = Sum of anticlockwise moments

$$(2 \times x) = m \times d$$
$$2(30) = 10m$$
$$60 = 10m$$
$$\frac{\cancel{10}m}{\cancel{10}} = \frac{60}{10}$$
$$m = 6kg$$

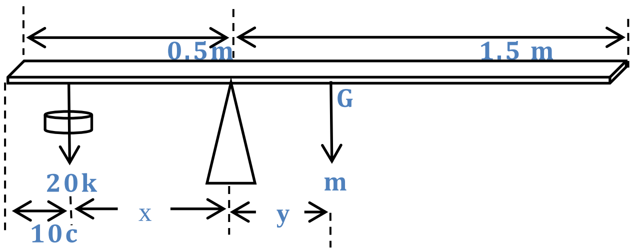
<u>Thus, the mass of the metre rule is 60kg</u>

Example 2: A uniform metre rule pivoted at 10cm mark balance when a mass of 400g is suspended at 0cm mark. Calculate the mass of the metre rule. **(Ans: m=100g)**

Example 3: The diagram below is a metre rule pivoted at 80cm mark. Calculate the mass of the metre. **(Ans: m=67g)**



Example 4: A uniform beam 2m long is suspended as shown below. Calculate the mass of the metre. **(Ans: m=16kg)**



Interpreting the question in diagram form.
- ✓ the diagram for any body should be drawn in the form.
- ✓ if the body is uniform, its mass or weight will act from the centre of gravity which is obtained by,

$$\text{C.o.g} = \frac{L}{2}$$

i.e. For a uniform metre rule, which is marked from 0-100cm, the centre of gravity from which the mass or weight acts is,

$$\text{C.o.g} = \frac{L}{2} = \frac{100\text{cm}}{2} = 50.0\text{cm}$$

- ✓ Then the required value is calculated from the principle of moment.

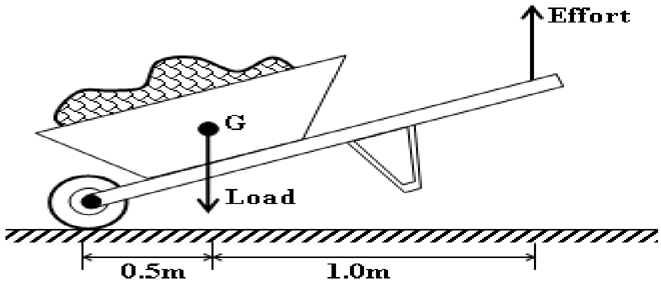
Example:5 A uniform metre rule is pivoted at 30cm mark. It balances horizontally when a body of mass 20g is suspended at 25cm mark.

a) Draw a force diagram for the arrangement.
b) Calculate the mass of the metre rule
(Ans: m=5g)

Example: 6 A uniform half-metre rule is pivoted at 15cm mark and balances horizontally when a body of 40g is hanging from 2cm mark.
i) Draw a diagram of the arrangement.
ii) Calculate the mass of the metre rule.
(Ans: m=52g)

Example: 7 A uniform rod AB of length 5cm is suspended at 2m from end A. if the mass of the rod is 10kg. Calculate the mass of the body, which must be suspended at 1m from end A so as for the rod to balance horizontally.
(Ans: m=5kg)

Example: 8 A hand cart of length 1.5 m, has the centre of gravity at length 0.5 m from the wheel when loaded with 50kg as shown below.



If the mass of the hand cart is 10 kg, find the effort needed to lift the hand cart.

Condition for Body to be in Equilibrium Under action of parallel forces.

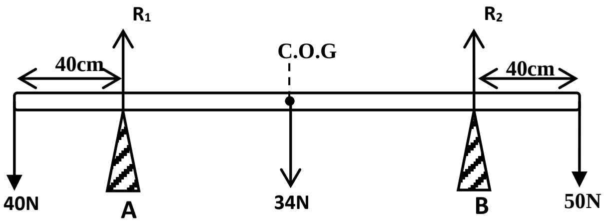
When a number of parallel forces act on a body such that the body attains equilibrium, then the following conditions must be met or fulfilled:
(i) The sum of the forces is one direction is equal to the sum of forces in the opposite direction.
(ii) The sum of the clockwise moment about any point is equal to sum of the anti-clockwise moments about the same point.

The above conditions are useful in calculations involving two unknown forces. The following steps should be taken.
(i) An equation for sum of force in one direction equaling to sum of forces in the opposite direction is written.
(ii) Moments should be taken about one of the unknown force. Where by the sum of anticlockwise moment is equal to sum of the clockwise moments.

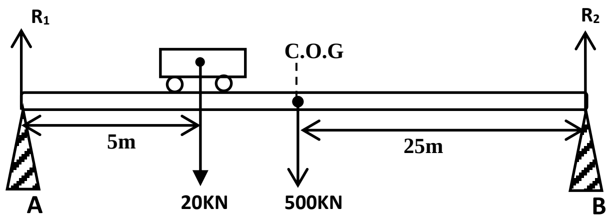
Example:
A uniform wooden beam of length 2m and weight 34N rests on two supports A and B placed at 40cm from either end of the beam. Two weights of 40N and 50N are suspended at the end of the beam.

(i) Draw a diagram to show the forces acting on the beam.
(ii) Calculate the reactions at the supports.

Solution:
(a)



Example 1: A truck of weight 20KN is driving across a uniform 50m long bridge of weight 500KN as shown below.



Calculate the reactions at "A" and "B" if the bridge is in equilibrium sum of forces in one direction = sum of forces in opposite direction.

Solution
Sum of upward forces=sum of downward forces

$$R_1 + R_2 = 20KN + 500KN$$

$R_1 + R_2 = 520KN$……………………….(i)

Since R_1 and R_2 are, unknown forces so moments can be taken about either R_1 or R_2 .

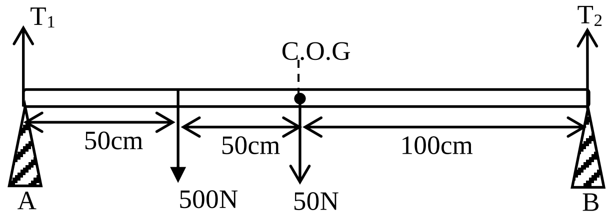
Taking moments about R_1:
Sum of clockwise moments = Sum of anticlockwise moments

$$(20 \times 5)+(500\times25) = R_2\times 50$$
$$100+12500 = 50R_2$$
$$12600 = 50R_2$$
$$\frac{\cancel{50}R_2}{\cancel{50}} = \frac{12600}{50}$$
$$\underline{R_2 = 252KN}$$

Substituting for $R_2 = 252$KN into equation (i), gives;
$R_1 + 252 = 520$
$\underline{R_1 = 268KN}$
<u>Thus, the Reactions R_1 and R_2 respectively are 268KN and 252KN.</u>

Example 2: Two labourers "A" and "B" carry between them a load of 500N on a uniform pole of weight 50N. if the pole is 2m long, and the load is 50cm from A towards B.

(a) Draw a diagram to show the force acting on the poles.



(b) Find the tension on A and B

Solution
Sum of upward forces=sum of downward forces

$$T_1 + T_2 = 500N + 50N$$

$T_1 + R_2 = 550N$……………………….(i)

Since T_1 and T_2 are, unknown forces so moments can be taken about either T_1 or T_2 .

Taking moments about R_1:
Sum of clockwise moments = Sum of anticlockwise moments

$$(500 \times 50)+(50\times100) = T_2\times 200$$
$$25000+5000 = 200T_2$$
$$30000 = 200T_2$$
$$\frac{\cancel{200}T_2}{\cancel{200}} = \frac{30000}{200}$$
$$\underline{T_2 = 150N}$$

Substituting for $T_2 = 150$N into equation (i), gives;
$T_1 + 150 = 550$
$\underline{T_1 = 400N}$
<u>Thus, the Tensions T_1 and T_2 respectively are 400N and 150N.</u>

(c) Find the fraction of the total weight that is supported by B.

$$\text{Fraction } = \frac{\text{Weight supportd by B}}{\text{Total weight}}$$

$$\text{Fraction } = \frac{150}{550}$$

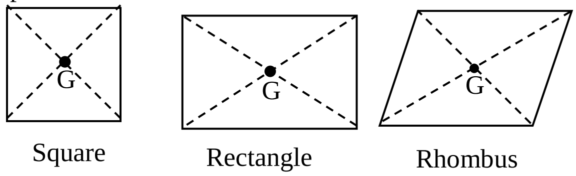
$$\text{Fraction } = \frac{3}{11}$$

Centre of gravity
Centre of gravity is the point of application of the resultant force due to the earth's attraction on it. All bodies are made of a large number of tiny equal particles each of mass "m" and pulled towards the earth with a force "**mg**". If the total mass of the entire particle in a body is "m" then the resultant force of gravity on the body is mg and it acts vertically downwards at the point G.

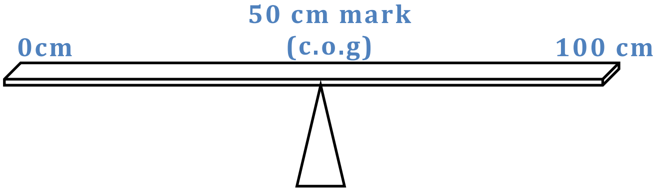
The centre of gravity or centre of the mass is a fixed point in the object where the resultant weight, (force of gravity) seems to act. If the centre of gravity is taken to, any other point of support is not zero.

Centre of gravity or regularly shaped object.

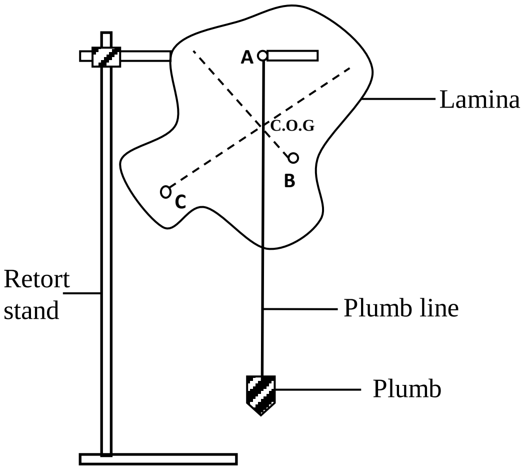
The mass or weight is evenly distributed and its centre or gravity is in the middle, which is at the geometric centre of the shape.



e.g. uniform metre rule.



Finding the centre of gravity of an irregularly shaped object (lamina).



Marking holes: Three holes “A”, “B” and “C” are made in the object at the edges far away from each other.

Marking the cross lines: The object is suspended on a retort stand from each of the holes and plumb (or pendulum bob) is used to trace the centre of gravity by marking a line on the object tracing the plumb line thread when swinging stops.

Repeating: The experiment is repeated with the object hung at B and C and cross lines marked. The point C.O.G at which all the lines cross is the centre of gravity of the body.

1:5:2 STABILITY:

Stability is the difficulty with which a body topples.

When a body is at rest, it is said to be in a state of equilibrium or stability.

Types or states of stability or Equilibrium

Some bodies are in a more stable state than others.

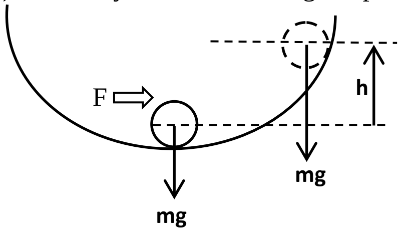
There are three types or states of equilibrium or stability:

a) stable equilibrium
b) unstable equilibrium
c) neutral equilibrium

(a) Stable equilibrium:

Is the type of equilibrium where, if the body is slightly tilted and then released:

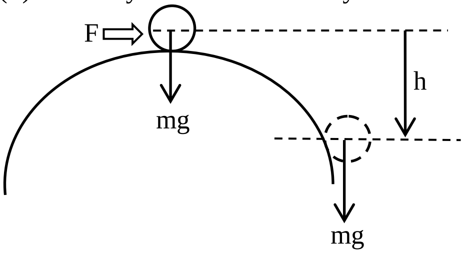
(i) the centre of gravity of the body is raised.
(ii) the body returns to its original position.



(b) Unstable equilibrium:

Is the type of equilibrium where, if the body is slightly tilted and then released:

(i) the centre of gravity of the body is lowered.
(ii) the body moves farther away from its original position.



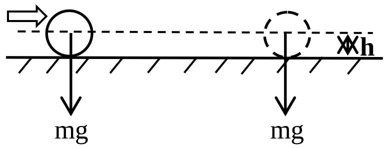
(c) Neutral equilibrium:

Is the type of equilibrium where, if the body is slightly tilted and then released:

(i) the centre of gravity of the body is neither raised nor lowered.
(ii) the body stays in its new position or it just rolls on before stopping.

Example:

A ball on a flat surface.



How to increase the stability of a body.

The stability of a body can be increases by:

(i) Lowering the centre of gravity by putting more weight at the base.
(ii) Increasing the area of the base.
(iii) If the body is slightly displaced and then released.

Exercise: See UNEB

2003 Qn. 5 1987 Qn.10 1988 Qn.2 and Qn.7 1989 Qn.15 and Qn.38 1991 Qn.30	1993 Qn.14 2000 Qn.11 and Qn.2 2002 Qn.11 2003 Qn.5 2007 Qn.17 and Qn.5

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

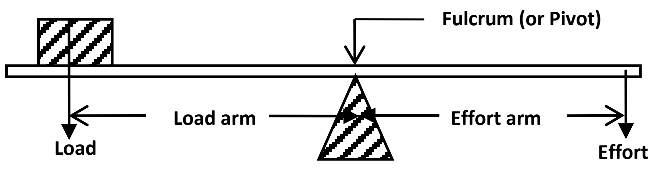
(a) LEVER SYSTEM:
A lever is a rigid bar, which is free to move about a fixed point called fulcrum or pivot.
It works on the principle of moments.

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

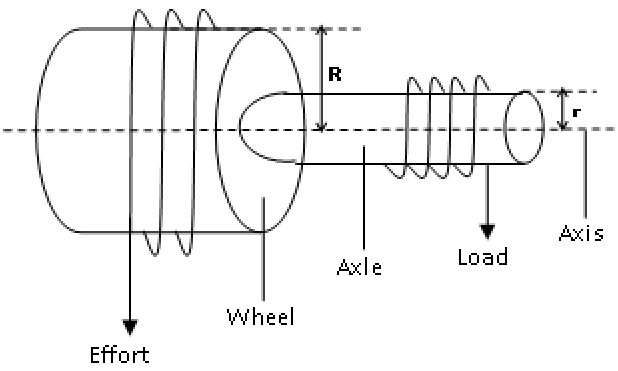
Class of lever	Examples
(i) First class lever: Is a lever system where the fulcrum (or pivot) is between the load and the effort.	• See-saw • Pair of scissors • Pair of pliers • Weighing scale • Claw Hummer
(ii) Second class lever: Is a lever system where the load is between the fulcrum (or pivot) and 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.
$-\mathbf{M.A} \approx \mathbf{V.R} \Longrightarrow \frac{\textbf{Load}}{\textbf{Effort}} \approx \frac{\textbf{Effort arm}}{\textbf{Load arm}}$
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.

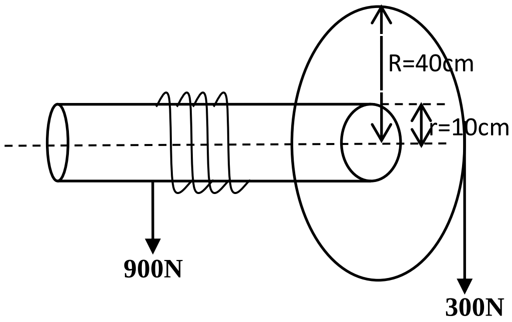
- ❖ Thus, from; V.R = $\frac{\text{Distance moved by effort}}{\text{Distance moved by load}}$

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

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

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:

R= 40cm, r =10cm; L= 900N, E=300N;

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

(i)

$$V.R = \frac{R}{r} = \frac{40}{10} = 4$$

Thus, the velocity ratio is 4.

(ii).

M.A = $\frac{\text{Load}}{\text{Effort}} = \frac{900}{300} = 3$

M.A = 3

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

$$\eta = \frac{3}{4} \times 100\%$$

$$\eta = 75\%$$

Thus, efficiency is 75%

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;

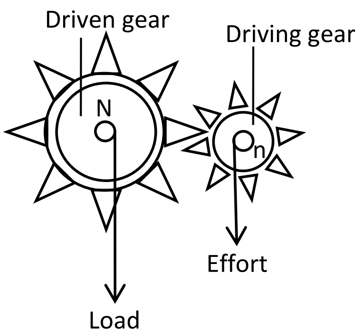
(i) Velocity ratio. (Ans: V.R=3)

(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 $= \frac{N_B}{n_A}$

$= \frac{40}{20}$

<u>V.R = 2.</u>
<u>The velocity ratio is 2.</u>

(ii)
V.R $= \frac{N_A}{n_B}$

$= \frac{20}{40}$

<u>V.R = 0.5.</u>
<u>The velocity ratio is 0.5.</u>

(iii) M.A = $\frac{\text{Load}}{\text{Effort}} = \frac{600}{400} = 1.5$
V.R = 2.

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

$\eta = \frac{1.5}{2} \times 100\%$

<u>η = 75%</u>

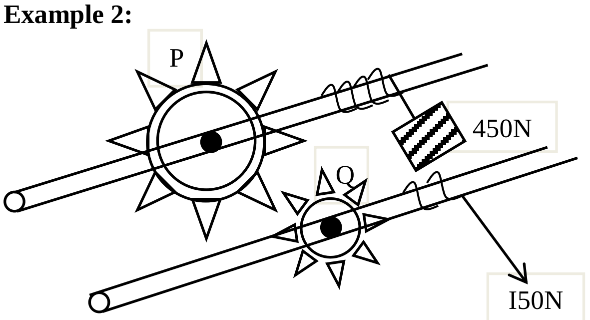
(ii) M.A=1.5
V.R =2

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

$\eta = \frac{1.5}{0.5} \times 100\%$

<u>η = 300%</u>

Example 2:



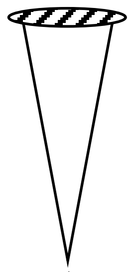
Two gear wheels P and Q with 80 and 20 teeth respectively, lock each other. They are fastened on axles of equal diameters such that a weight of 150 N attached to a string wound around one-axle raises a load of 450N attached to a string wound around the other axle. Calculate the;
(i) Velocity ratio of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

.

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

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

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.

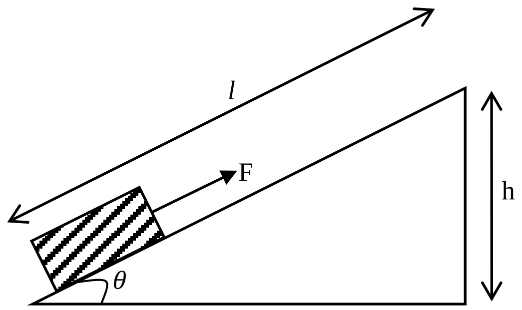
$$\text{V.R of a screw} = \frac{2\pi l}{1\text{Pitch}}$$

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

= 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.



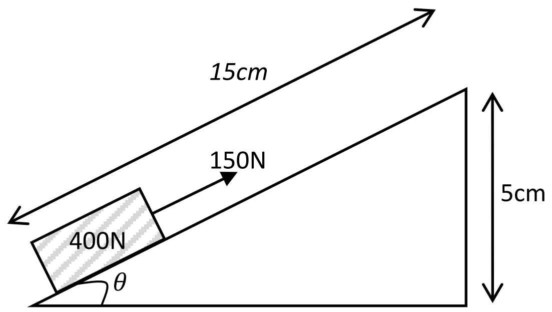
$$\text{V.R} = \frac{\text{Distance moved by effort}}{\text{Distance moved by load}} = \frac{\text{length of the plane}}{\text{height of the plane}}$$

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

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

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 $(\eta) = \frac{\text{M.A}}{\text{V.R}} \times 100\%$ $\eta = \frac{2.67}{3} \times 100\%$ η = 88.9%

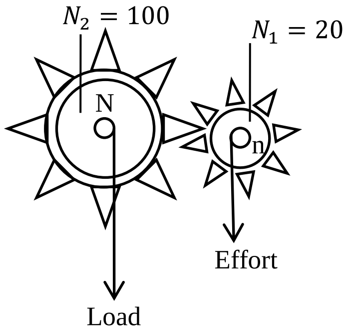
(v) Work input
Work input = Effort × Effort distance
Work input = 150 × 15
= 2250J

(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.

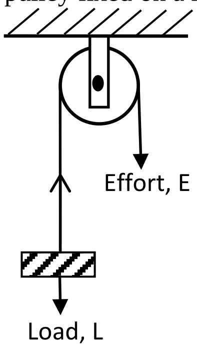
(f) PULLEY SYSTEM:

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.



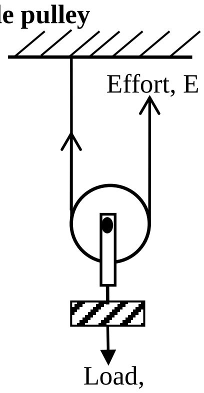
It is applied in:

- ❖ 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 $\text{M.A} = \frac{\text{Load}}{\text{Effort}} = \frac{\text{E}}{\text{E}} = 1.\ (\text{since L} = \text{E})$

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

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

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

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.

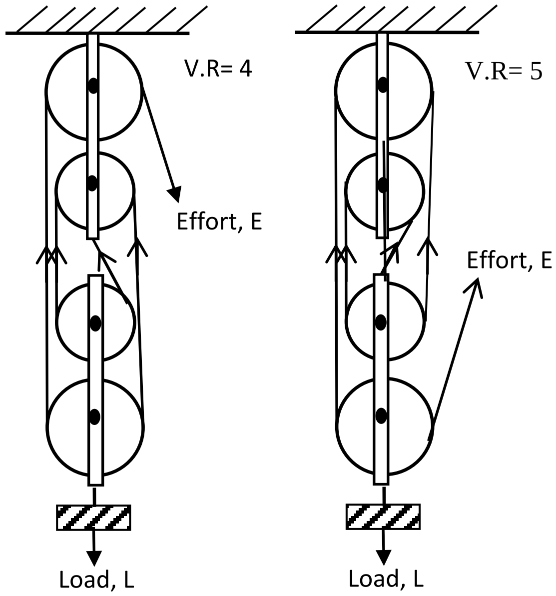
A single movable pulley is more advantageous than a single fixed pulley. In that, for a single movable pulley the effort required to raise a load is less that the load.

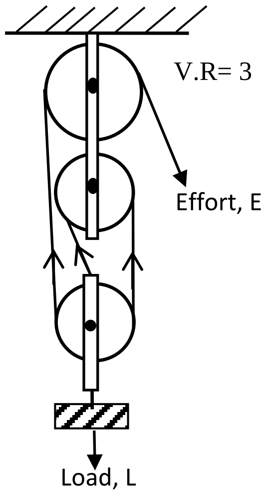
(ii) Block and tackle pulley system
This is consists of two blocks each having one or more pulleys, combined together to form a machine. This is done in order to have high velocity ratio and a higher mechanical advantage.
It is applied in:

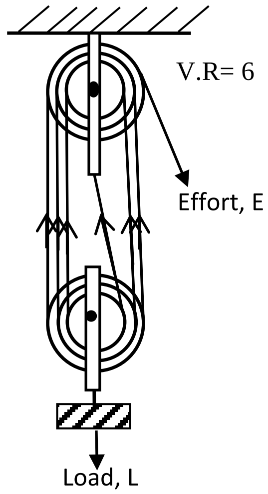
- ❖ Cranes
- ❖ Brake downs
- ❖ lifts

} 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.



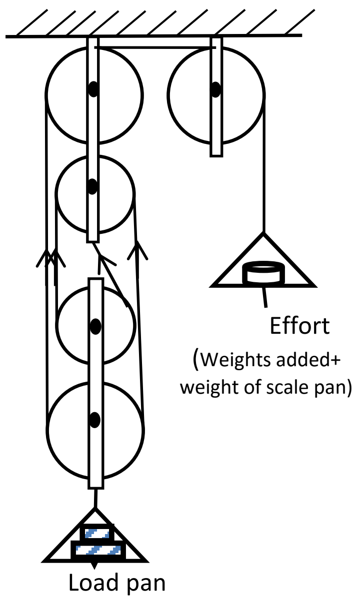




Passing the string

- ❖ 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.

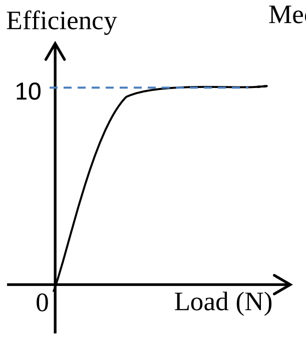
Experiment to measure mechanical advantage and efficiency of pulley system.

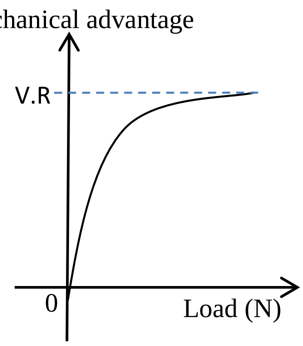


Determining effort: A known load is place on the load pan and knows weights are added to effort pan until the load just rises steadily when given a gentle push.
Repeating: The experiment is repeated with different loads and the results are recorded in table shown bellow:
V.R=……….

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;

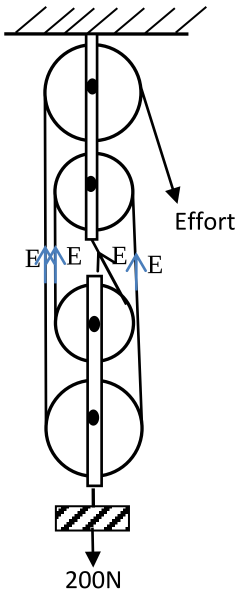
i) some energy is wasted on overcoming friction
ii) Some energy is wasted on lifting useless loads like movable pulley blocks.

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

$V.R = \left(\begin{array}{c}\text{Number of portions of the string} \\ \text{suporting the movable block}\end{array}\right)$

$\underline{V.R = 4}$

(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=?

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

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

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

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

$= 300 \times 5$

$= 1500N$

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.

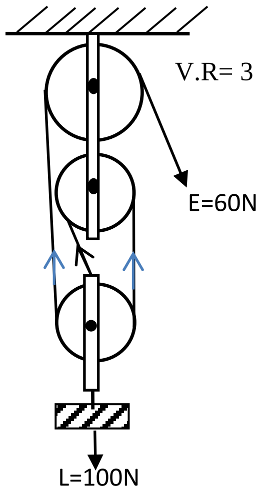
(a) Draw the arrangement of the pulley system.

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

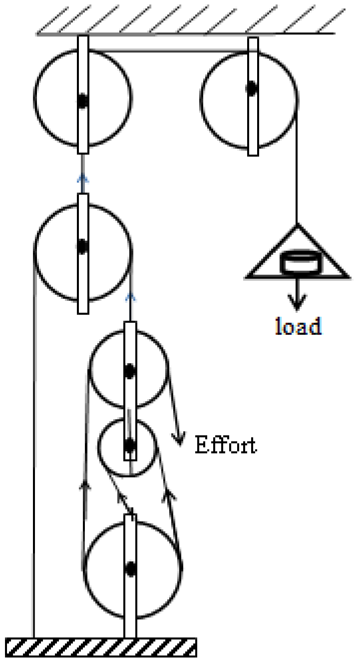
Coupled machines

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

<u>Solution</u>

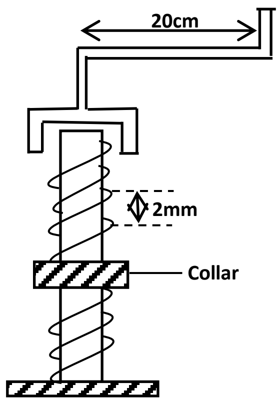
Velocity ratio of lower block = 4
Velocity ratio of middle = 2
Velocity ratio of upper block = 1
<u>Overall V.R = 4 + 2+ 1 = 7</u>

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

<u>Solution</u>

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 $\underline{\text{M.A} = 5.25}$	Then from; M. A= $\frac{\text{Load}}{\text{Effort}}$ 5.25= $\frac{1500}{\text{E}}$ 5.25E= 1500 $\underline{\text{E} = 285.7\text{N}}$

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

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= $\frac{2(3.14)(0.02)}{0.002}$ <u>V.R=62.8</u> Mechanical Advantage Given;Efficiency=15% , V.R= 62.8 Then; Effi = $\frac{\text{M.A}}{\text{V.R}} \times 100\%$ 15%= $\frac{\text{M.A}}{62.8} \times 100\%$ $0.15 = \frac{\text{M.A}}{62.8}$ $\text{M.A} = 0.15(62.8)$ $\underline{\text{M.A} = 9.42}$	(b)The effort required to turn the handle M.A= $\frac{\text{Load}}{\text{Effort}}$ 9.42 = $\frac{5000}{\text{E}}$ 9.42E =5000 $\frac{\cancel{9.42}\text{E}}{\cancel{9.42}} = \frac{5000}{9.42}$ <u>E=530.79N</u> (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.

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

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

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

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

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

In general;
Work wasted = work input - work output
= 8333.33 – 1250
= <u>7083.33J</u>

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.

However the efficiency is very low. Usually lower than 50%. This is because friction is very high so the screw cannot run back if left.

Exercise : See UNEB

1999 Qn.2	**1998 Qn.6**
1994 Qn.8	**2006 Qn.4**
1987 Qn.36	**1992 Qn.6**
1988 Qn.34	**2001 Qn.42**
1991 Qn.26	**2007 Qn.1**

1: 7. WORK, ENERGY AND POWER

1:7:1. WORK

Work is the product of the force applied and the distance moved by the point of application of the force in the direction of the force.

Note that the distance moved has to be in the direction of the applied force. It is common that a force may be applied to move an object to the right, but instead the object moves to the left.

The force in this case has not done any work.

Work done = Force, F × Displacement, S

W = FS

The S.I unit of work done is a **joule** (J)

Definition:

A **joule** is the work done when the point of application of a force of 1N, moves through a distance of 1m in the direction of the force.

Example: 1

1. Calculate the work done when a force of 9000N acts on a body and makes it move through a distance of 6m.

Solution

Force, F= 9000N

Distance, s = 6m

Work done = Force, F × Displacement, S

W= F×S

W= 9000×6

W= 54000J

Note:

If an object is raised vertically or falling freely, then the force causing work to be done is weight.

Force = Weight = mass, m × acceleration due to gravity, g

Force = Weight= mg

Thus, the work done against gravity is given by;

Work done = Weight × height

Work done = mgh

Where m is mass in kg, h is distance in metres and some times, it is height.

Example:2

A block of mass 3kg held at a height of 5m above the ground is allowed to fall freely to the ground. Calculate the workdone.

Solution

Given, mass, m = 3Kg, Distance, s = 5m

Force F= Weight, W =mass × g

F= mg

= 3×10

F = 30N

Work done = Force, F × Displacement, S

W= F×S

W= 30×5

W= 150J

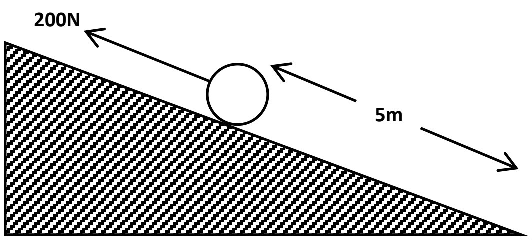
Example: 3
A man of mass 80kg runs up a staircase of 10stairs, each of vertical height 25cm. Find the work done against gravity.
Solution:
Given, mass m = 80Kg,
Distance, $h = 25cm = \frac{25}{100} = 0.25m$
Total Distance, $h_T = 0.25m \times 10stairs$
Total Distance, $h_T = 2.5m$
Then;

Work done = Weight × height
Work done = mgh
= 80×10×2.5
Work done = 2000J

Example: 4
A crane is used to to raise 20 tonnes of concrete to the top floor of a building 30m high. Calculate the total work done by the crane.
Solution:
Given, mass m = 20tonnes=20×1000=20,000Kg,
Distance, $h = 30m$
Then;

Work done = Weight × height
Work done = mgh
= 20,000×10×30
Work done = 6,000,000J

Example: 5
The figure bellow shows a bale of hay being pulled up an inclined plane with a force of 200N. The bale moves down the incline to a distance of 5m.



(i) Calculate the work done by the force.
Solution:
Work done = Force, F × Displacement, S
= 200N×(-5m)
Work done = -1000J

(ii) Explain your answer.
The distance moved by the bale, was in a direction opposite to that of the force applied hence a negative displacement.
The negative in the answer therefore means that the bale did the work instead of the force applied.

1:7:2. ENERGY

Energy is the ability or capacity to do work.
The S.I unit of work done and energy is a joule (J).

Sources of energy:
The raw material for the production of energy is called the energy source.
There are two types of energy sources.

(a) Non-renewable sources of energy
These are energy sources, which cannot be replaced when they get used up.
Examples of non- renewable sources of energy
(i) Fossil fuels; these are formed from plant remains that died million years ago. They include; coal, petroleum oil, natural gas, e.t.c.
(ii) Nuclear fuels; these are fuels found in radioactive elements which may be occurring naturally such as Uranium.
These fuels can be used in nuclear reactions to produce electricity.

Advantages of non-renewable source of energy.
- They have high energy density. I.e a lot of energy can be produced from a small quantity.
- They are readily available as demand increases.

Disadvantages of non-renewable source of energy.
- They are highly polluting.

(b) Renewable sources of energy
These are energy sources which can be replaced when they get used up. They can never get exhausted.
Advantage:
They are non-polluting.

Examples of renewable sources of energy.
(i) Solar energy: This is the form of energy which reaches the earth in form of heat and light.
It can be harvested using solar panels and transformed into electrical energy, which is used for many purposes.
It is also used in direct low temperature heating.
(ii) Wind: Wind can be harvested using giant windmills, which can turn electrical generators to produce electrical energy, which is a more useful form.
(iii) Running water: Running water is used in hydro-electricity plants to turn giant turbines, which produce electrical energy.
The water will always flow hence a renewable source.
Tides can also be used to generate electricity in this way.
(iv) Geothermal energy: Water is pumped to hot under ground rocks where it's heated and then forced out through another shaft where it can turbines.

Forms of energy
Energy can exist in the following forms;
a) Chemical energy:
Chemical energy is the form of energy a body has due to the nature of its atoms and molecules and the way they are arranged.
In the combination of atoms to form compounds, there is gain or loss of energy. This energy is stored in the compound as chemical energy.
If the atoms in such compounds are rearranged to form a new compound, this energy is released. E.g If sugars in the human body are burnt, a lot of chemical energy is released.

b) Nuclear energy:
This is the energy released when atomic nuclei disintegrate during nuclear reactions.
In nuclear reactions, the energy, which holds the nuclear particles together (Binding energy), is released.

There are two types of nuclear reactions i.e. fission (Where large nuclei break to form smaller ones) and fusion (Where smaller nuclei combine to form larger ones). In both cases, large amounts of energy are released.

c) Electrical energy (Electricity):
This is the form of energy which is due to electric charges moving from one point of a conductor to another.
This form of energy is most easily converted to other forms, making it the most useful form.

d) Light energy:
This is the form of energy which enables us to see. Light is part of a wider spectrum of energy called the electromagnetic spectrum. Light consists of seven visible colours, of red, orange, yellow, green, blue, indigo and violet. We are able to see because the eye is sensitive to the colours.

e) Heat energy:
Heat is a form of energy, which results from random movement of the molecules in the body.
It is responsible for changes in temperature.
When a body is heated or when heat energy of the body increases;

(i) The internal kinetic energy of the molecules increases leading to a rise in temperature.
(ii) The internal potential energy of molecules increases leading to expansion and change of state of the body.

f) Sound energy:
This is the energy which enables us to hear.
Like light, sound is also a form of wave motion, which makes particles to vibrate. Our ears are able to detect sound because it produces vibrations in the ear.
g) Mechanical energy:
This is the energy of motion.
Mechanical energy = kinetic energy + Potential energy

There are two forms of mechanical energy.
(i) Kinetic energy:- This is the energy possessed by a body due to its velocity or motion.

$$\text{Kinetic energy} = \frac{1}{2}(\text{mass})\times(\text{velocity})^2$$

$$\mathbf{K.E} = \frac{1}{2}\mathbf{mv^2}$$

(ii) Potential energy:- This is the energy possessed by a body due to its position or condition.
It is equal to the work done in putting the body in that position or condition.
A body above the earth's surface has an amount of gravitational potential energy equal to the work done against gravity.
Weight is the force of gravity acting on a body.
Weight = mg.

$$\begin{pmatrix}\textbf{Gravitational}\\ \textbf{Potential energy}\end{pmatrix} = (\textbf{mass})\times\begin{pmatrix}\textbf{acceleration}\\ \textbf{due to gravity}\end{pmatrix} \times \begin{pmatrix}\textbf{Height above}\\ \textbf{the ground}\end{pmatrix}$$

$$\mathbf{P.E = mgh}$$

Conservation of Energy.
The principle of conservation of energy:
It states that 'energy is neither created nor destroyed' but can be changed from one form to another.

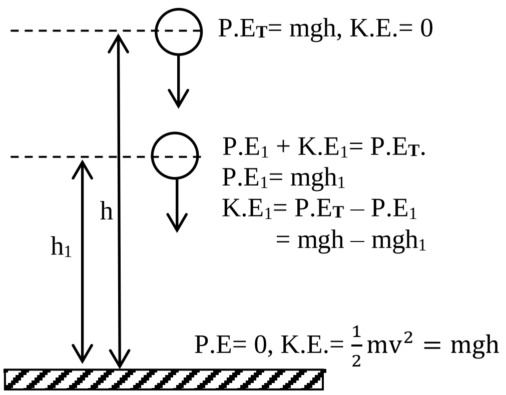
In any system, the total original energy is equal to the total final energy. For example, electrical energy is changed to light energy in the bulb. However, the bulb also feels hot because some of the energy is changed to heat.
Therefore, light energy plus the heat energy is equal to the electrical energy supplied.
Thus from this principle, we conclude that;

- No new energy is created
- Total existing energy is not destroyed
- Energy is only changed from one form to another.

As energy is changed from one form or state to another, an energy converter (Device) is required to ease the conversion. Examples of such devices are shown in the table below.

Energy Change	**Converter**
Chemical to electrical	Cells or Batteries
Light to Electrical	Solar panels
Electrical to light	Electric lamps e.g bulbs
Electrical to heat	Cooker or flat iron, etc.
Heat to Electrical	Thermocouple
Electrical to sound	Loud speakers
Sound to Electrical	Microphones
Electrical to Kinetic	Electric motors
Kinetic to Electrical	Electric generators

Conservation of mechanical energy:



A body of mass m at a height h above the ground, has a potential energy, P.E = mgh. At this point, the velocity of the body is $0ms^{-1}$ hence it has no kinetic energy. (K.E. = 0J).

When the body is released, it begins to fall with an acceleration g. The velocity of the body thus increases as the height, h decreases. The body therefore gains kinetic energy at the expense of potential energy.

When the body is just reaching the ground, the height, h is zero (h = 0m) while its velocity is given by;

$$v^2 = u^2 + 2as; \qquad where\ s = h, a = g\ and\ u = 0$$
$$v^2 = 0^2 + 2gh$$
$$v^2 = 2gh$$
$$\boldsymbol{v = \sqrt{2gh}}$$

Thus, its kinetic energy as it reaches the ground is given by; $\text{K.E} = \frac{1}{2}\text{mv}^2 = \frac{1}{2}\text{m}\left(\sqrt{2\text{gh}}\right)^2 = \text{mgh}$

Hence, $\mathbf{K.E} = \frac{1}{2}\mathbf{mv^2} = \mathbf{mgh}$

Therefore; **Gain in K.E = Loss in P.E.**

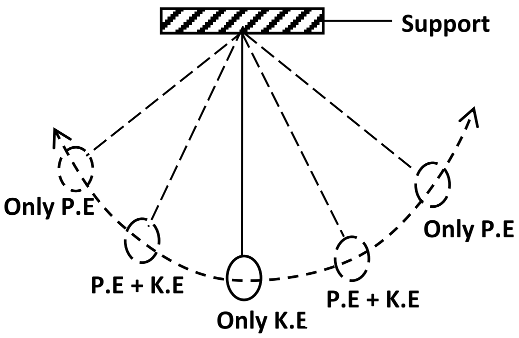
The above illustration shows that energy is conserved. Mechanical energy is continually transformed between kinetic and potential energy.

A swinging pendulum.
The transformation of energy between kinetic and potential energy can also be seen in a swinging pendulum.

At the end (extremes) of the swing, the energy of the pendulum bob is only potential.

As it passes the central position, it has only kinetic energy.

In other positions between the extreme ends and the central position, it has both potential and kinetic energies.



Mechanical energy = P.E + K.E

As the bob falls from the left towards the central position, it gains K.E at the expense of P.E.

As it rises from the central position towards the left end, it gains P.E at the expense of K.E.

Example:
A ball of mass 200g falls freely from a height of 20m above the ground and hits a concrete floor and rebounds to a height of 5m. Given that g = 10ms^{-1}, find the;

i) P.E of the ball before it fell.
ii) Its K.E. as it hits the concrete.
iii) Velocity with which it hits the concrete.
iv) K.E as it rebounds.
v) Velocity with which it rebounds.
vi) Velocity when it has fallen through a height of 15m.

Solution:
(i)
P.E=mgh (h=height from which the ball is dropped)
P.E=0.2×10×20
P.E=40J

(ii)
As it hits the concrete, Total P.E is converted to K.E
K.E=$\frac{1}{2}mv^2$= mgh
(h=height from which the ball is dropped)
K.E=0.2×10×20
K.E=40J

(iii)
As it hits the concrete, Total P.E is converted to K.E
K.E=$\frac{1}{2}mv^2$= mgh
(h=height from which the ball is dropped)
$\frac{1}{2}mv^2$= mgh
v^2= 2gh.
$v = \sqrt{2gh}$
$v = \sqrt{2(10)(20)}$
$v = \sqrt{400}$
$v = 20ms^{-1}$

(iv)
As the bounces from the concrete, the K.E used to move the it from the bottom to the height h_1 is converted to P.E at $h_1$and it is momentarily at rest.
K.E$_1$=$\frac{1}{2}mv_1^2$= mgh$_1$
(h_1=height to which the ball bounces).
K.E$_1$=0.2(10)(5)
K.E$_1$=10J

(v)
As the bounces from the concrete, the K.E used to move it from the bottom to the height h_1 is converted to P.E at $h_1$and it is momentarily at rest.
K.E$_1$=$\frac{1}{2}mv_1^2$= mgh$_1$
(h_1=height to which the ball bounces).
$\frac{1}{2}(0.2)v_1^2$=0.2(10)(5)
$0.1v_1^2$= 10
$v_1^2 = 100$
$v_1 = \sqrt{100}$
$v_1 = 10ms^{-1}$

(vi) As it falls from the top, Total P.E at the top is converted to some K.E and some P.E in
Falling to the height h_1.
K.E$_T$=$\frac{1}{2}mv_1^2$+ mgh$_1$
(h_1=height of the ball from ground).
40=$\frac{1}{2}(0.2)v_1^2$+ 0.2(10)(5)
40= $0.1v_1^2$+ 10
30= $0.1v_1^2$
$v_1^2 = 300$
$v_1 = \sqrt{300}$
$v_1 = 17.32ms^{-1}$

Example 1:
Calculate the kinetic energy of a 2Kg mass trolly traveling at 400m per second.
$Given; m = 2kg, v = 400ms^{-1}$
K.E=$\frac{1}{2}mv^2$
K.E=$\frac{1}{2}(2)(400)^2$
K.E=160,000J

Example 2:
A 5Kg mass falls from a height of 20m. calculate the potential energy lost.
$Given; m = 5kg, h = 20m$
P.E=mgh
P.E=5(10)(20)
P.E=1000J

Example 3:
A 200g ball falls from a height of 0.5m. Calculate its kinetic energy just before hiting the ground.
$Given; m = 200g = \frac{200}{1000} = 0.2kg, h = 0.2m$
K.E gained = P.E lost
K.E=mgh
K.E=0.2(10)(0.5)
K.E=1J

Exercise:

1. A block of mass 2 kg falls freely from rest through a distance of 3m.
i) Find the K.E of the block. (Ans: =60J)
K.E gained = P.E lost
ii) Potential energy (Ans: =60J)
iii) The velocity with which the body hits the ground. (K.E gained = P.E lost).

2. A body falls freely through 3m. Calculate the velocity with which it hits the ground. (Ans: = 7.75ms^{-1})

3. 100g steel ball falls from a height of 1.9m on a plate and rebounds to a height of 1.25m. Find the;

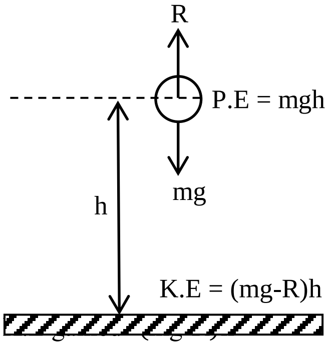
(i) P.E of the ball before the fall. (Ans: =1.8J)
(ii) Its K.E. as it hits the plate. (Ans: =1.8J)
(iii) Its velocity on the plate. (Ans: =6ms^{-1})
(iv) Its K.E as it leaves the plate on rebound. (Ans: =1.25J)
(v) Its velocity of rebound. (Ans: =5ms^{-1})

For a body not falling freely but as it falls it experiences air resistance then the kinetic energy gained by the body just before it hits the ground is calculated from:
$\mathbf{K.E\ gained = (mg - R)h}$

Where mg is the weight of the body, R is the air resistance and h is the height above the ground.

Example 4:
A 20kg body falls from 1.8m above the ground. If the air resistance is 0.9N.
(i) Calculate the kinetic energy just before hitting the ground.

Solution
$Given; m = 20kg, R = 0.9N, h = 1.8m, K.E. =?$



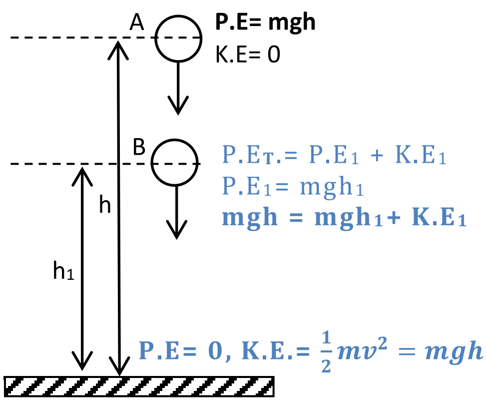
K.E gained=(20×10 - 0.9)×1.8
=(200 - 0.9)×1.8
=(199.1)×1.8
K.E gained =358.38J

(ii) Calculate energy lost due to air resistance
Total energy at h,=mgh
=20×10×1.8
Total energy at h,=360J

Energy lost due to air resistance=360J-358.38J
Energy lost due to air resistance=1.62J

Note:
Energy lost due to air resistance can also be calculated from;
Energy lost due to air resistance=Work done against R
Energy lost due to air resistance=Force × Height
Energy lost due to air R=Air resistance × Height
=0.9×1.8
Energy lost due to air R=1.62J

Calculating the kinetic energy at any point for a body falling freely.

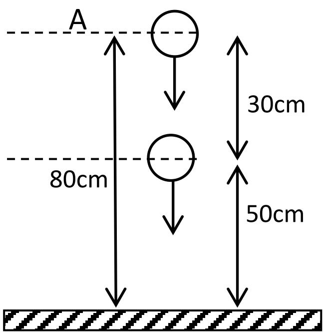


At A the body has all potential energy. So the energy at A is mgh = Total energy.

At B the body has a mixture of kinetic energy and potential energy.
P.E$_T$=K.E$_1$+ P.E$_1$
mgh=K.E$_1$+ mgh$_1$
$\mathbf{mgh=\frac{1}{2}mv_1^2+ mgh_1}$
Where "**h$_1$**" is the height above the ground.

Example 5:
A stone of 150g is dropped from a height of 80m.
Calculate the;
(i) Kinetic energy when it is 50m above the ground.

Solution:
m=150g=$\frac{150}{1000}$=0.15kg, h_1=50m, h=80m.



(i)
$mgh = K.E_1 + mgh_1$
$0.15(10)(80)=K.E_1+ 0.15(10)(50)$
$120=K.E_1+ 75$
$K.E_1=120 - 75$
$K.E_1=45J$

(ii) Its velocity when its 50m above the ground.

Method 1 :
$K.E_1=\frac{1}{2}mv_1^2$
$45=\frac{1}{2}\times0.15\times v_1^2$
$90=0.15v_1^2$
$600 \ =v_1^2$
$\sqrt{600} = v_1$
$v_1 = 24.49ms^{-1}$

Method 2 :
Given; a=10ms^{-2}, u=0ms^{-1}
Where h is the height fallen through.

Then using the third equation of motion, we have;
$\upsilon^2 = u^2 + 2ah$
$v^2 = 0^2 + 2(10)(30)$
$v^2 = 600$
$v = \sqrt{600}\ ms^{-1}$
$v = 24.49\ ms^{-1}$

(iii) Its kinetic energy when it has fallen through 50m.
Given; g=10ms^{-2}, h=80, h_1=(80-50)=30m, K.E=?
Where h is the height above the ground.
Then from;
$mgh = K.E_1 + mgh_1$
$0.15(10)(80)=K.E_1+ 0.15(10)(30)$
$120=K.E_1+ 45$
$K.E_1=120 - 745$
$K.E_1=75J$

1:7:3. POWER
Power is the rate of doing work. Or
Power is the rate of transfer of energy.
Note: Work done is the same as energy transferred.

$$\textbf{Power} = \frac{\textbf{Work done}}{\textbf{Time taken}} = \frac{\text{Energy transfered}}{\text{Time taken}}$$

Where work done=Force × Distance

$$\text{Power} = \frac{F\times d}{t} = F \times \frac{d}{t} = FV$$
$$\textbf{Power} = \textbf{F.V}$$
Where V is the velocity of the body.
$$\textbf{Power} = \frac{\textbf{mgh}}{\textbf{t}}$$

Where mg is the weight of the body and h the height.

The S.I unit of power is **watt** (W).
1watt=1Js^{-1}

Definition:
A watt is the rate of transfer of energy of one joule per second.
Or It is the rate of doing work of 1joule in one second.

Example 1:
An engine raises 20kg of water through a height of 50m in 10 seconds. Calculate the power of the engine.
Solution:

$$\text{Power} = \frac{mgh}{t}$$
$$\text{Power} = \frac{20(10)(50)}{10}$$
$$\text{Power} = 1000W$$

Example 2:
An electric bulb is rated 100W. How much electrical energy does the bulb consume in 2hours.
Solution:

$$\text{Power} = \frac{\text{Energy used}}{\text{time taken}}$$
$$100 = \frac{\text{Energy used}}{2 \times 60 \times 60}$$
$$\text{Enery used} = 100(2 \times 60 \times 60)$$
$$\text{Enery used} = 720{,}000J$$

Example 3:
A man uses an electric motor whose power output is 3000W for 1hour. If the motor consumes 1.44×10^7J of electricity in that time, find the efficiency of the motor.
Solution:
Given;P_{out}=3000W, t=1hr=1×60×60=3600s.
$Energy_{input}=1.44\times10^7J$

$$\text{power input} = \frac{\text{Energy input}}{\text{time taken}}$$

$$P_{in}=\frac{E_{in}}{t}$$

$$P_{in}=\frac{1.44\times10^7}{36000}$$

P_{in}= 4000W

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

$$\text{Efficiency} = \frac{3000}{4000} \times 100\%$$

Efficiency = 75%

For machines

Power input is the power created by effort.

$$\text{Power input}=\frac{\text{Work input}}{\text{Time taken}}=\frac{\text{Effort} \times \text{Effort Distance}}{\text{Time taken}}$$

Power output is the power created by the load.

$$\text{Power output}=\frac{\text{Work output}}{\text{Time taken}}=\frac{\text{Load} \times \text{Load Distance}}{\text{Time taken}}$$

Example 4:
An effort of 250N raises a load of 1000N through 5m in 10 seconds. If the velocity ratio is five, Calculate the:
i) Power input
ii) Efficiency

Solution:

(i) Given; Effort=250N, Load=1000N, V.R=5, L.D=5m, t=10s $V.R=\frac{E.D}{L.D} \Leftrightarrow 5=\frac{E.D}{5}$ E.D=25m $\binom{\text{Power}}{\text{input}}=\frac{\text{Work input}}{\text{Time taken}}$ $=\frac{\text{Effort}\times\text{Effort Distance}}{\text{Time taken}}$ $=\frac{250\times25}{10}$ Power input=625 W	$\binom{\text{Power}}{\text{input}}=\frac{\text{Work output}}{\text{Time taken}}$ $=\frac{\text{Load}\times\text{Load Distance}}{\text{Time taken}}$ $=\frac{1000\times5}{10}$ Power output = 500 W **(ii)** $\text{Eff} = \frac{\binom{\text{Power}}{\text{output}}}{\binom{\text{Power}}{\text{input}}} \times 100\%$ $\text{Efficiency} = \frac{500}{625} \times 100\%$ Efficiency = 80%

INTERNAL COMBUSTION ENGINE

A heat engine is a machine, which changes heat energy obtained by burning fuel to kinetic energy (mechanical energy)

Engines are always less than 100% efficient because:-
i) Some of the energy is lost in over coming friction between walls of the cylinder and pistons.
ii) Some heat energy is lost to surrounding due to conduction.
iii) Some of the energy is also wasted in lifting useless loads like pistons.

Qn1:
A pulley system of V.R six is used to lift a load of 250N through a distance of 3m. If the effort applied is 50N, calculate how much energy is wasted.

Qn2: A girl of mass 40kg runs up a stair case in 16 seconds. If each stair case is 20 cm high and she uses 100 Js^{-1} . Find the number of stairs. [Ans: 20]

See UNEB

1994 Qn. 17	2006 Qn.7
1989 Qn. 29	1997 Qn.5
2007 Qn.33	1995 Qn.9
1987 Qn.3 and Qn.24	1991 Qn.11
1993 Qn.4 and 18	1992 Qn.11
1997 Qn.10	2003 Qn.15
1999 Qn.2 and Qn.8	2007 Qn.6
2000 Qn.23	1993 Qn.4
2001 Qn.26	2005 Qn.45

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, (N/m^2 or $\mathbf{Nm^{-2}}$) or a pascal($\mathbf{Pa}$).

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

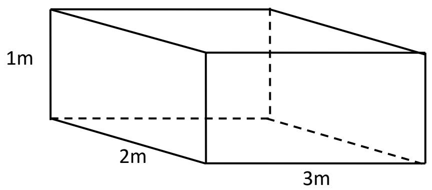
Pressure increases when the area decreases and decreases when the area increases.

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

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

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

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

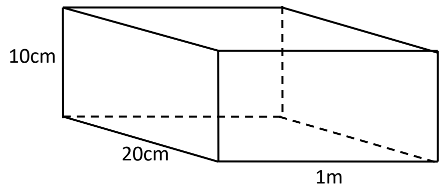
$A_{max} = (3 \times 2) = 6m^2$

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

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

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

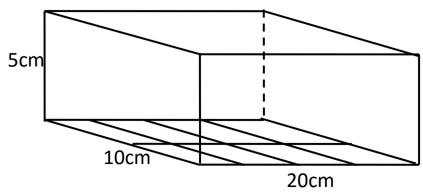
$P_{min} = \dfrac{F}{A_{max}} = \dfrac{300}{0.2} = 1500\ Nm^{-2}$ or 1500 Pa

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

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

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

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

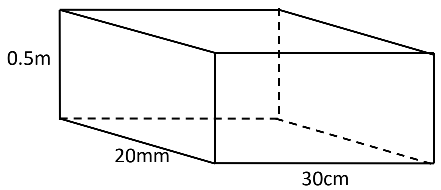
$$P_{max} = \frac{F}{A_{min}} = \frac{60}{0.005} = 12000\ \text{Nm}^{-2} \text{ or } 12000\ \text{Pa}$$

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

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

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

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}

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

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

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

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

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

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

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

(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, $V_w = l \times w \times h$

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

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

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

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

(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, $F = 2.5 \times 10 + (0.0015) \times (1000) \times 10$
$$F = 25 + 15$$
$$F = 40\text{N}$$

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

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

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:

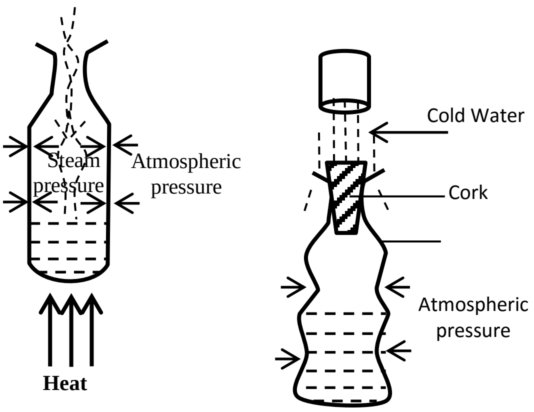
-Blood pressure is slightly greater than atmospheric pressure

-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.

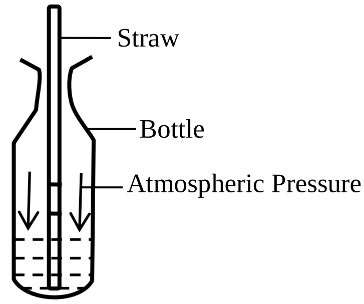
Importance of atmospheric pressure

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.



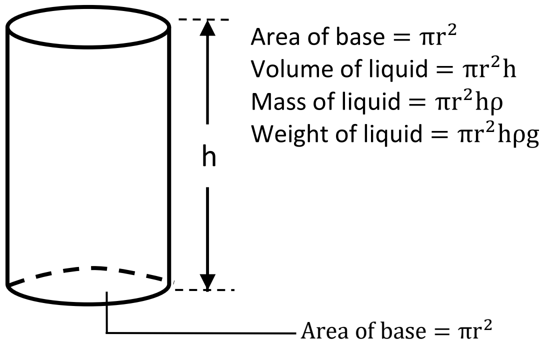
b) Rubber sucker

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:

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

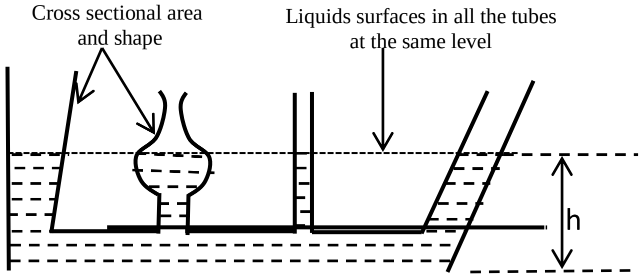
$$\textbf{Pressure} = \mathbf{h\rho g}$$

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.



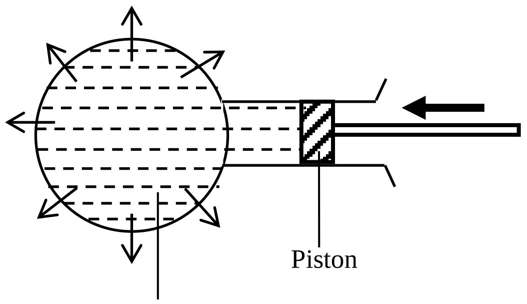
A liquid is poured into the communicating tubes of different cross-sectional areas.

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.

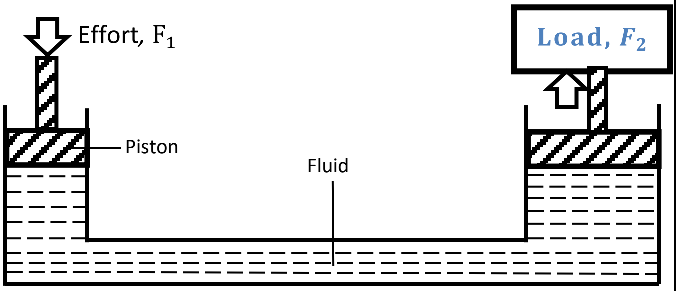


Holes of equal size are drilled in a round bottomed flask and covered with cork.
The flask is then filled with water and the piston pushed inside the flask.
Water shoots out equally in all directions, and travels equal distances. This verifies Pascal`s principle.

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,

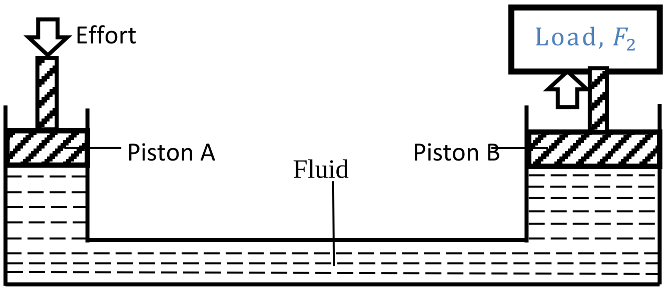
$$\frac{\textbf{Effort}}{\textbf{Load}} = \frac{\textbf{Area of smaller piston}}{\textbf{Area of bigger piston}}$$

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

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

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

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

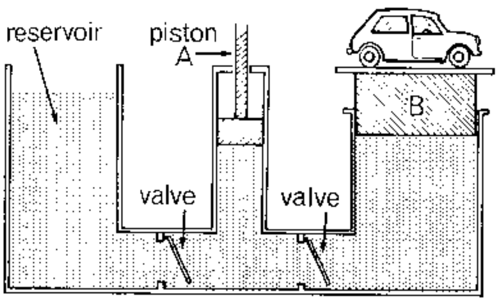
$$\frac{100}{F_2} = \left(\frac{16}{240}\right)$$

$16F_2 = 24000$

$\underline{F_2 = 1500N}$

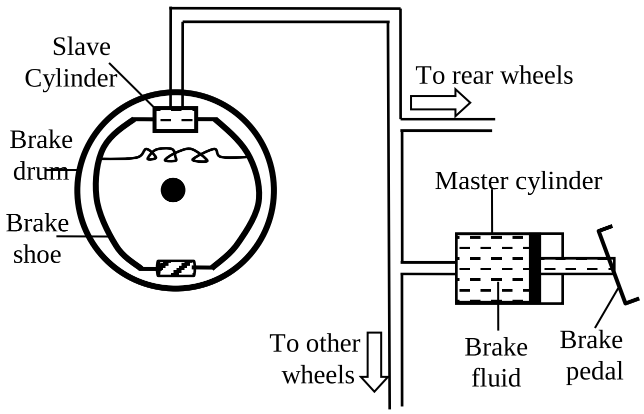
Advantage
A small force applied on small piston can overcome a large place load placed on a large piston.

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:

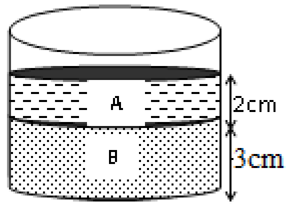
1. A hydraulic press machine is used to raise a load W placed on a piston of cross-sectional area of 100cm^2 by using an effort of 20N at a piston of cross-sectional area of 2cm^2.
Calculate the;
(i) Pressure transmitted through out the liquid [P=100000Pa]
(ii) Load, W. [W=1000N]

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}}

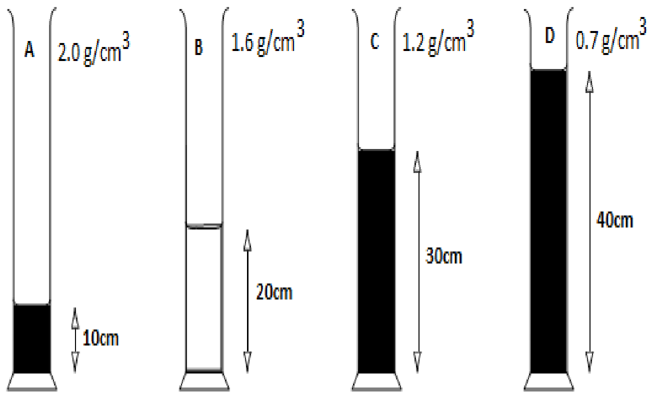
4. A diver dives to a depth of 20m below the surface of sea water of density 1200kgm^{-3}. Calculate the pressure Experienced.

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.

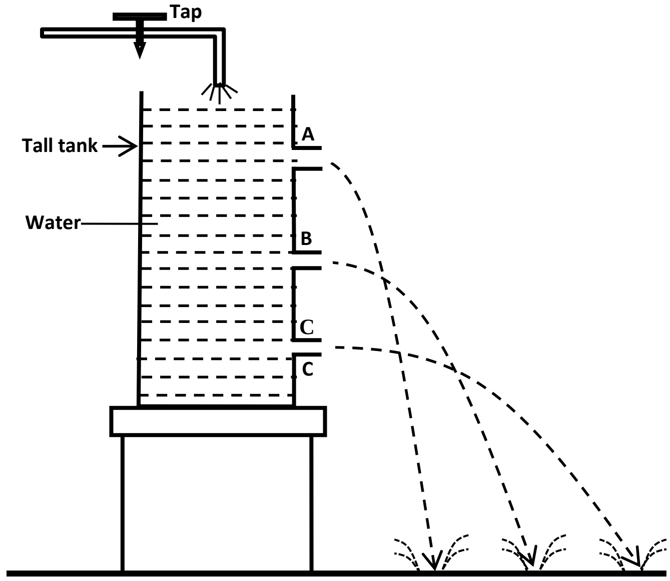
7. Four different liquids are poured into identical measuring cylinders. The diagrams show the depths of the liquids and their densities. Which liquid causes the largest pressure on the base of its measuring cylinder?



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.

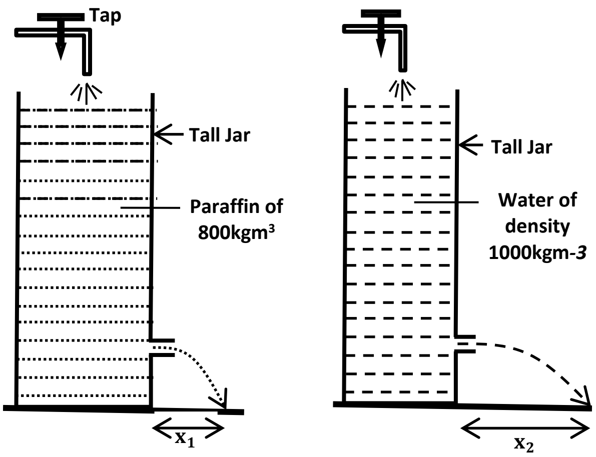


Procedures:
Equally, spaced holes A, B and C of the same size are drilled at different depths along one vertical side of a cylindrical can.
The holes are then closed using corks.
Water is then poured into the can to full capacity.
The corks are then removed at the same time and the distance from the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

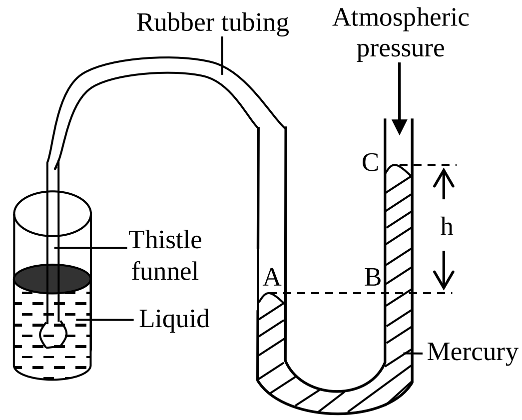
The distance to which the liquids jet out is observed and compared.

It is observed that water jets furthest compared to paraffin i.e; $\mathbf{x_2>x_1}$.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

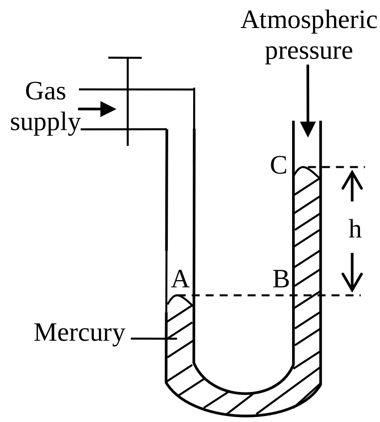


One arm of the manometer is connected to a thistle funnel whose base is covered with a thin membrane and the other end remains open to the atmosphere.

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

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

(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

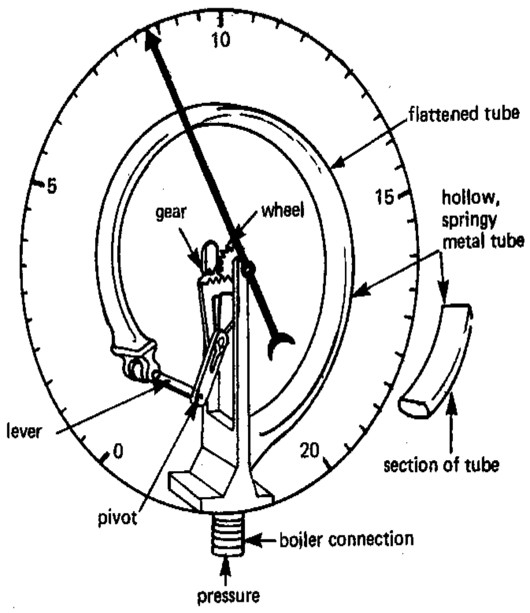
This gauge measures the very high pressures of liquids or gases, e.g. the pressure of steam in boilers.

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.

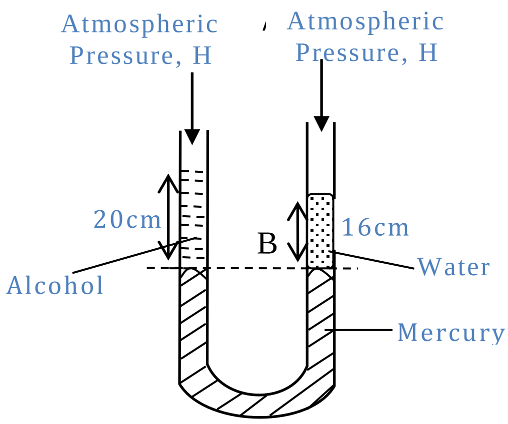


Bourdon gauges are commonly used at filling stations.

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; $\quad P = h\rho g,$

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

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

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

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 ($g = 10ms^{-2}$).

Example 1

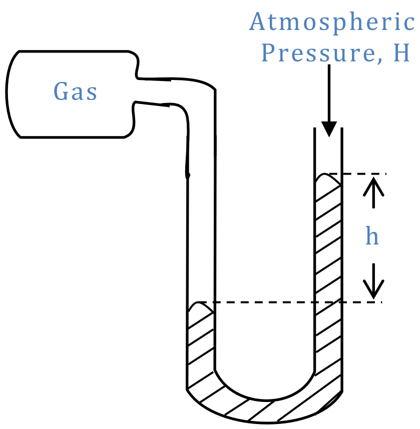
Express a pressure of 75cmHg given that the density of mercury (Hg) is $13600kgm^{-3}$.

Solution

Given: h =75cm, $= \frac{75}{100}$m $= 0.75$m. ρ =13600Kgm^{-3} $g = 10ms^{-2}$	Then from, 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}.



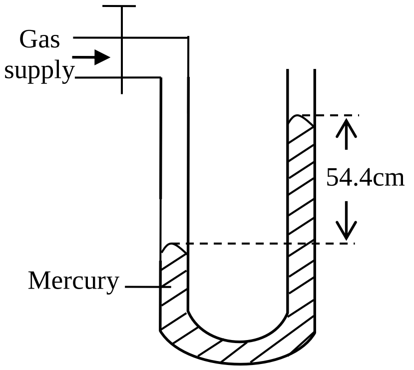
Gas pressure $= H_{atm} + h$ Gas pressure $= 76 + 54.4$ $= 130.4\text{cmHg}$	Expressing in Nm^{-2} Gas pressure $= (H_{atm} + h)\rho g$ $= \left(\frac{130.4}{100}\right) \times 13600 \times 10$ $= 177344\text{Nm}^{-2}$

Exercise:

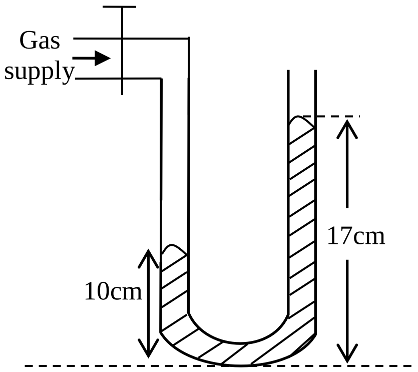
1. In an experiment to compare density of two liquids, water and spirit were used. The height of water was found to be 8cm and that of spirit was 12cm. Given that the density of water is **1000kgm^{-3}**. Find the density of the spirit. [Ans: **666.67kgm^{-3}]**

2. The manometer tubes below contain mercury and connected to a gas supply. Find the gas pressure.
[Atmospheric pressure =103360Pa].

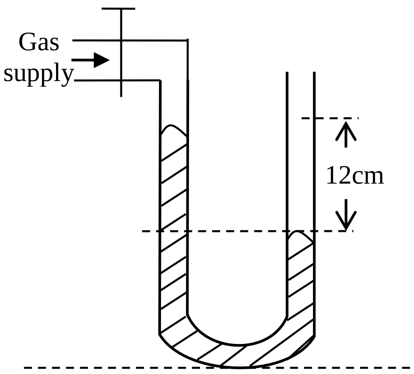
(a) [Ans:177344Pa]



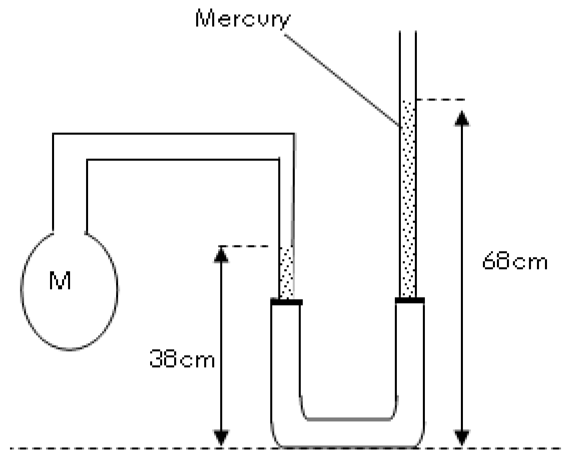
(b) [Ans:109620Pa]



(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.

Describing how a simple mercury barometer is made in the laboratory.

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.

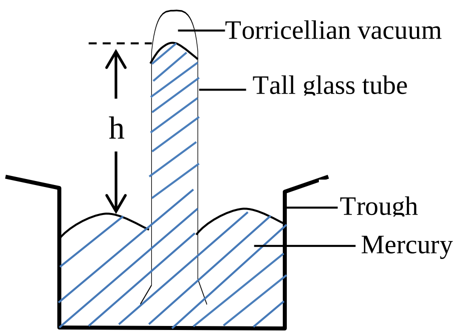
❖ Refilling the tube

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.



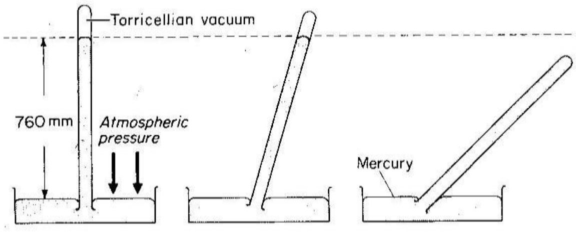
From the above apparatus, when the air above the mercury in the bottle is pumped out, the column falls.

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/m^3 and mercury is 13600Kg/m^3. Calculate the barometer reading.

Solution:

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

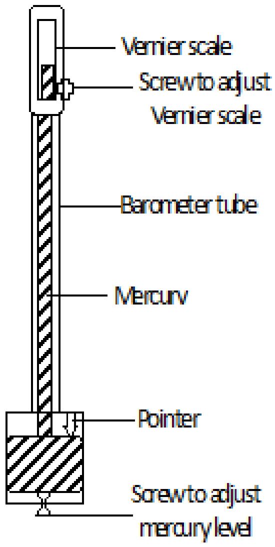
Exercise:

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**

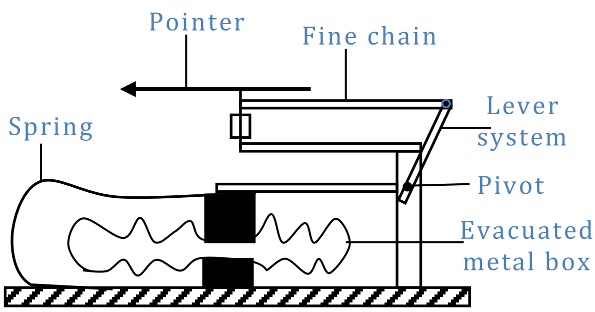


It is constructed like a simple mercury barometer but with a provision for accurate determination of atmospheric pressure.

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.

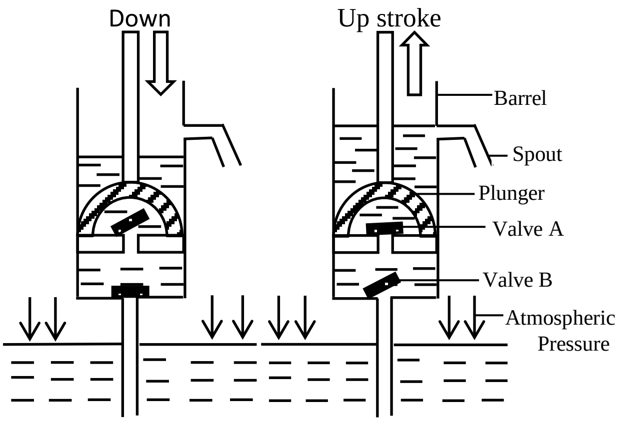
APPLICATIONS OF ATMOSPHERIC PRESSURE:

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.

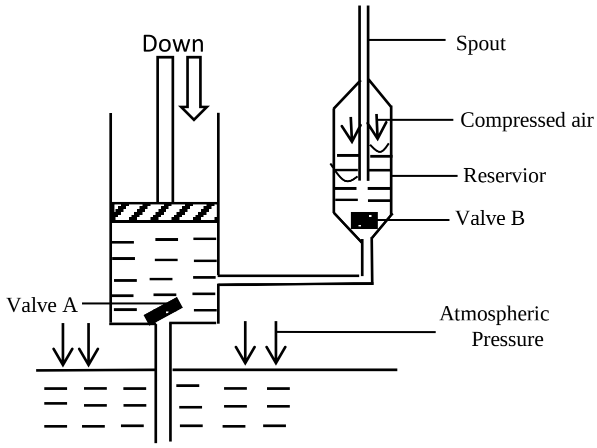
Limitations of the lift pump

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.

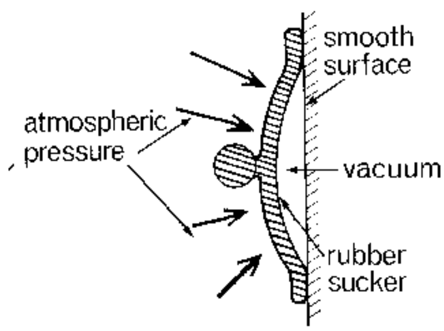
- Valve A closes due to the weight of the water above it.
- The water in the barrel is forced through valve B into the reservoir, C and out of the spout D.
- The air trapped in the reservoir is compressed and as aresult, it keeps on pushing the water out of the reservoir through the spout even when in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

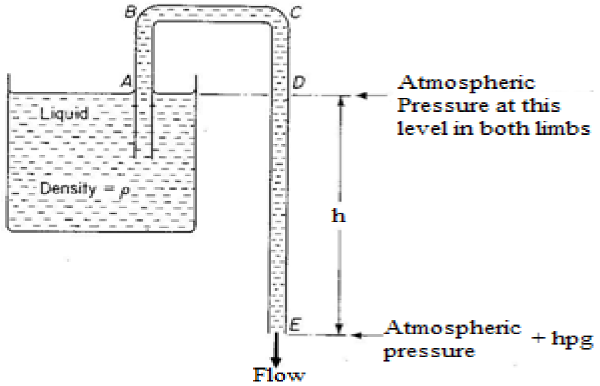


Uses of rubber sucker;

-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..

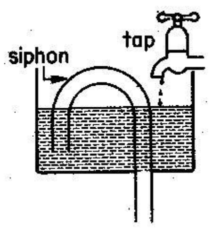
NB: To start the siphon it must be full of liquid and end A must be below the liquid level in the tank.

Applications of siphon principle

1. **Automatic flushing tank**:

This uses siphon principle.

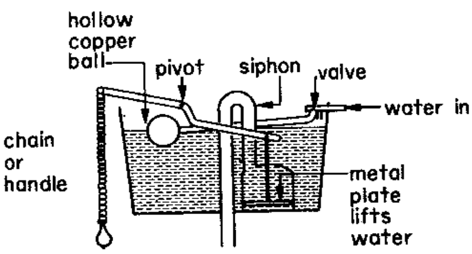
Water drips slowly from a tap into the tank. The water therefore rises up the tube until it reaches and fills the bend In the pipe siphon action starts and the tank empties (the water level falls to the end of the tube).The action Is then repeated again and again.



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:

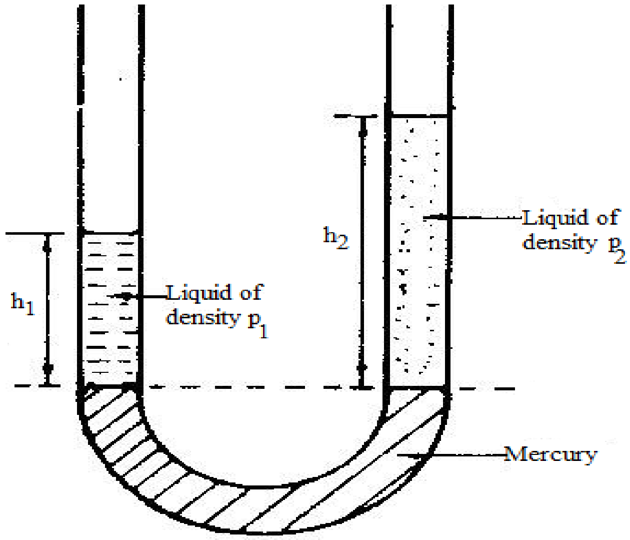


The siphon action at once starts and the tank empties.

Comparison of densities of liquids

(i) Miscible liquids

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

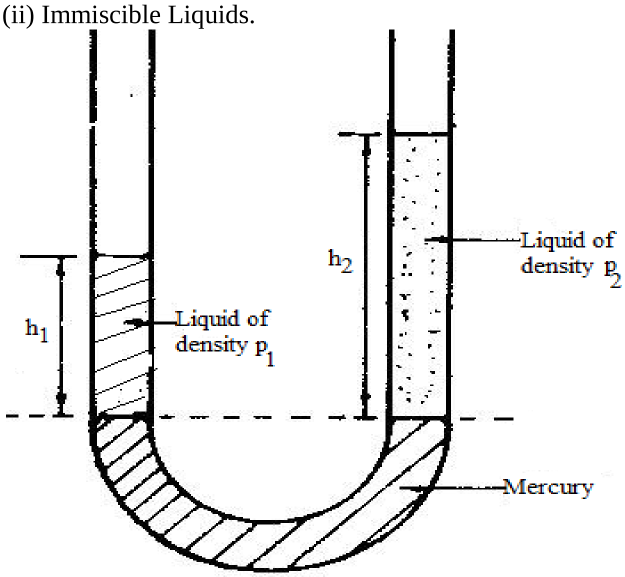


-Pour one liquid in one arm of a manometer and pour the second liquid in the other arm.

-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.

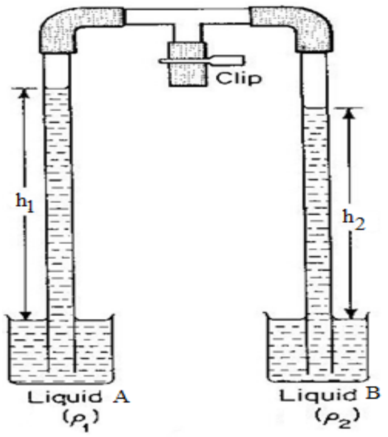


-Pour one liquid in one arm of a manometer and pour the second liquid in the other arm.

-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



Liquids of different densities are placed in glass pots as shown above.

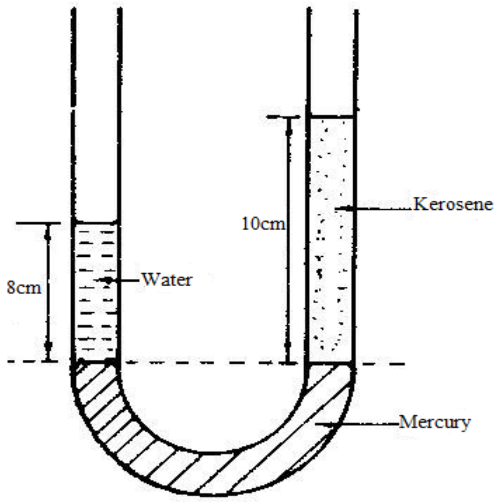
When the gas tap is opened each liquid rises to different height h_1 and h_2. Since they are subjected to the same gas supply,

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

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

Example 1

Water and kerosene are placed in U-tube containing mercury as shown above. Determine the density of kerosene?

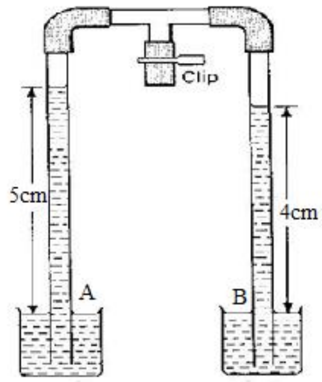


Pressure of kerosene= Pressure of water (since both tube are open to the atmosphere)

$$P_A = P_A$$
$$H + h_1\rho_1 g = H + h_1\rho_1 g$$
$$h_1\rho_1 = h_1\rho_1$$
$$8(1000) = 10\rho_1$$
$$\rho_1 = 800\ \text{kgm}^{-3}$$

Example 2

The diagram below shows heights to which liquids A and B have risen in an inverted U-tube, when some air has been pumped at P. Find the density of liquid B if that of A is $800\ \text{kgm}^{-3}$.[Ans: $\rho = 640\ \text{kgm}^{-3}$]



Example 3

The atmospheric pressure at the bottom of a mountain is 100000Pa. If the mountain is 800m high, and the density of air is$1.25\ \text{kgm}^{-3}$. Find the pressure at the top of the mountain.

Solution:

$$\mathbf{P_{bottom} = P_{top} + h\rho g}$$
$$100000 = P_{top} + 800(1.25)(10)$$
$$P_{top} = 90000\ \text{Pa}$$

Exercise:

1. Using Hare's apparatus, with water another liquid A in a container, water rises to a height of 60cm and liquid A rises to a height of 48cm. If liquid A weighs 5g, determine the volume of liquid A.

2. **See UNEB**

1999 Qn. 17 1989 Qn. 12 1990 Qn.17 1991 Qn. 3 1993 Qn.2 and Qn.20 1994 Qn. 16 1997 Qn.11	1994 Qn. 3 2002 Qn. 9 2007 Qn.17 and Qn.30 2000 Qn.2 2003 Qn.43 1995 Qn.2

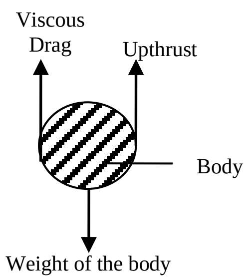
MOTION IN FLUIDS

When a body falls through a fluid it will be acted on by three forces namely:

i) weight of the body
ii) viscous force (Viscous drag)
iii) up thrust

Directions of the above forces.

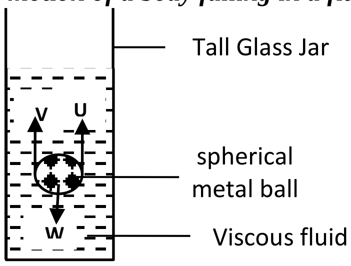
i) Weight of body: down ward direction towards earth.
ii) Up thrust: upward direction
iii) Viscous force; direction opposite to that of motion



Direction of motion

The direction of motion is determined by direction of the viscous force, which is a force that opposes motion like in the above body the direction of motion is down ward because the viscous force is acting in upward direction.

Describing motion of a body falling in a fluid



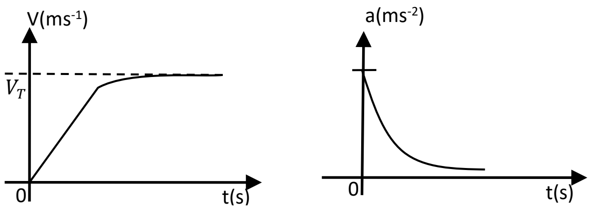
-As the body falls, it accelerates first with a net force (resultant force) given by the equation.

F=W – (v+u) Or F=W – v – u

-As the body continues to fall, it attains a maximum uniform velocity called ***terminal velocity*** when weight of body (W) = Viscous force (v) + up thrust (u)

W = v + u Or W – v= u

Terminal velocity is the uniform velocity attained by a body falling through a fluid when the net force on the body is zero such that: **Weight = Viscous force + up thrust**



Velocity and acceleration graphs for a body falling in a fluid.

BERNOULLI'S PRINCIPLE

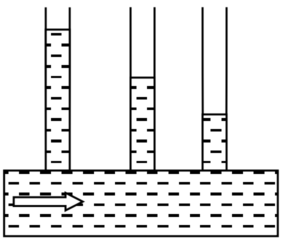
It states that when the speed of the fluid increases, the pressure in the fluid decreases and vice versa.

Liquids flowing in a pipe have three kinds of energies, namely;

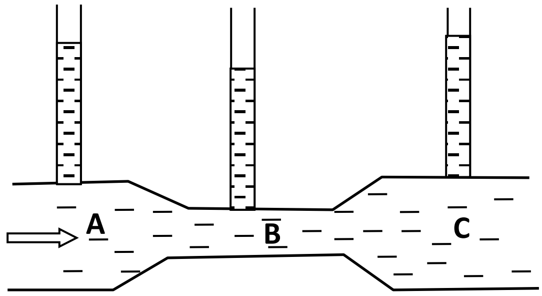
- ✓ kinetic energy
- ✓ potential energy
- ✓ pressure energy

the sum of these three energies is a constant.

a) Liquid



When the liquid flows through the uniform tube, the level goes on decreasing as shown in the diagram, the faster the liquid, the lower the pressure.



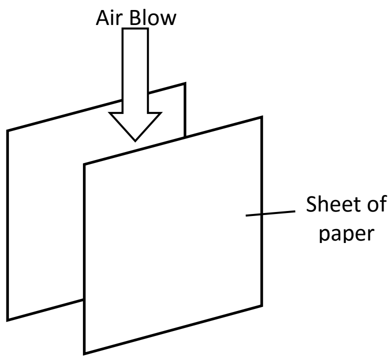
The pressure falls in the in the narrow part B but rises again in the wider part C. This is because, since B is narrow, the speed at which the liquid moves through it is higher, hence the fall in pressure.

Note:

- ✓ Fluid pressure changes with the rate of flow in the pipe
- ✓ Speed of water is greater at the constriction
- ✓ The order of pressure in the tubes decreases in the order A, C and B.

b) Gases

Bernoulli Effect in an air stream can be shown by blowing air between two sheets.



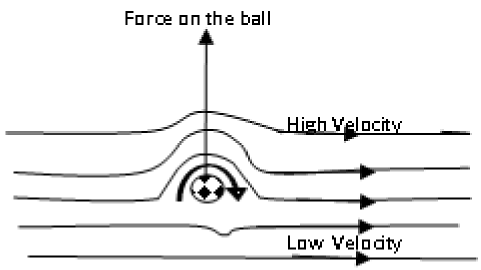
When air is blown the two sheets come together because the air between them moves faster resulting in decrease of pressure between them.

Application of Bernoulli's principle

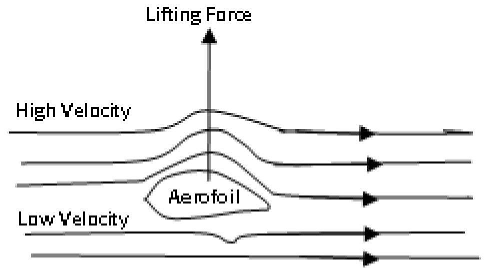
i) When the fluid comes out of a jet, the speed increases as the pressure decreases.

ii) At the jet the gas comes out at high speed so the pressure is low at the jet. This results in air to be drawn in.

iii) A spinning ball takes a curved path because the ball drag air around causing air to pass more rapidly over one side than the other. This results in pressure difference that causes a resultant force on the ball.



iv) An aero plane wing called aero foil is shaped so that air has to travel farther and so faster on the top than underneath. This results in a pressure difference that causes a resultant up ward force on the wing, thus it lifts.



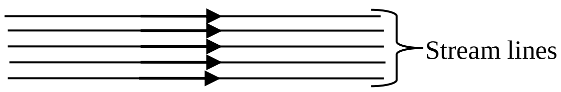
v) When two large vehicles pass each other, a force of attraction is experienced. This is because:
The speeding vehicles drag layers of air along with them. As these layers of air pass each other at high speed, they cause a pressure decrease.
This results in the vehicles being pushed towards each other.

Fluid flow
A fluid is a liquid or gaseous substance.

There are two types of fluid flow namely:
i) Stream line flow
ii) Turbulent flow

Stream line flow or Steady flow or Laminar flow
Is the type of fluid flow where all the fluid particles that pass a given point follow the same path at the same speed.

Stream line flow occurs where the slope falls gently so that the fluid flows slowly and uniformly.
It is obtained by making the;
- ✓ Diameter of the pipe wide
- ✓ Fluid flow slowly and uniformly.



Turbulent flow
Is type of fluid flow in which the speed and direction of the fluid particles passing any given point vary with time.

Turbulent flow occurs where the slope is so steep, such as at a water fall and when there is a constriction.
Due to constriction or steep slope, water tends to flow very fast and so disorderly.
It is obtained by making the;
- ✓ Diameter of the pipe narrow
- ✓ Fluid flow very fast and disorderly, by lying the pipe steeply.

Differences between streamline and turbulent flow.

Turbulent	*Streamline*
Is due to steep slope or constriction so that water flows very fast and disorderly throughout.	Is due to slope falling gently so that the water flows slowly and uniformly throughout.

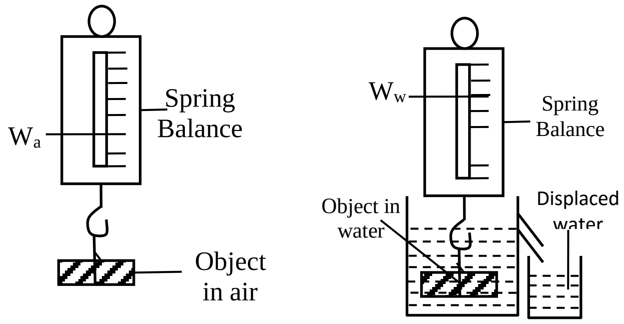
1: 9. ARCHIMEDES' PRINCIPLE

Up thrust is an upward force due to the fluid resisting being compressed. When any object is immersed or submerged into fluid its weight appears to have been reduced because it experiences an up thrust from the fluid.

Archimedes principle states that when a body is either wholly or partly submerged in a fluid the up thrust is equal to the weight of fluid displaced. i.e

$$\boldsymbol{Upthrust} = \begin{pmatrix} \boldsymbol{Weight\ of} \\ \boldsymbol{displaced\ fluid} \end{pmatrix} = (\boldsymbol{V_f \rho_f})\boldsymbol{g}.$$

Experiment: To verify Archimedes principle



❖ Weight W_a of object in air
An object is weighed in air using a spring balance to obtain Wa.
❖ Weight W_w of object in water
The object is weighed when completely immersed in water using a spring balance to obtain W_w and the displacement water collected in beaker as shown below.

❖ Weight of displaced water
By using a spring balance the beaker is weighed with the displaced water when it's empty

❖ Up thrust "U" = W_a - W_w
It is found that weight of displaced water is equal to up thrust. Thus Archimedes' principle.

Calculations involving Archimedes principle
For any calculation involving Archimedes' principle the following should be noted:
i) The body should be completely immersed or submerged.
ii) The weight of the body when completely immersed or submerged is called its apparent weight.
The apparent weight is less than the weight of the body because when the body is immersed it experiences an up thrust.

$$\begin{bmatrix} Apparent\ loss \\ in\ weight \end{bmatrix} = \begin{bmatrix} Weight\ of \\ body\ in\ air \end{bmatrix} - \begin{bmatrix} Weight\ of \\ body\ in\ fluid \\ or\ \begin{pmatrix} Apparent \\ weight \end{pmatrix} \end{bmatrix}$$

$$\boldsymbol{Upthrust, U = W_a - W_f}$$

iii) According to Archimedes Principle;

$$[Upthrust] = \begin{bmatrix} Weight\ of \\ displaced\ fluid \end{bmatrix} = \begin{bmatrix} Apparent\ loss \\ in\ weight \end{bmatrix}$$
$$= \boldsymbol{W_a - W_f}$$
$$= V_f \rho_f g$$

Where V_f *and* ρ_f are the volume and density of the displaced fluid.
For a body completely immersed or submerged fully, according to the displacement method,

$$\left[\begin{matrix}Volume\ of \\ immersed\ boddy\end{matrix}; V_b\right] = \left[\begin{matrix}Volume\ of \\ displaced\ fluid\end{matrix}; V_f\right]$$

Weight = mg and m $=V\rho$ where "m" is mass in kg, V is volume, and ρ is density.
But up thrust = weight of displaced fluid.
= m_f g (where m_f is mass of displaced fluid)
Up thrust = (V_f ρ_f) g

$$\boxed{\textbf{Up thrust} = V_f V_f g}$$

Where "V" is volume of displaced fluid "ρ" is density of fluid.

Example: 1
A glass blocks weight 25N. When wholly immersed in water, the block appears to weigh 15N. Calculate the Up thrust.
Solution
$W_a = 25N$; $W_f = 15N$;
$\text{Upthrust} = W_a - W_f$
$= 25 - 15$
$\text{Upthrust} = 10N$

Example 2:
A metal weighs 20 N in air and 15N when fully immersed in water Calculate the:
i) Up thrust;
ii) Weight of displaced water
iii) Volume of Displaced Water
Solution

$W_a = 20N; W_f = 15N;$	
i) Up thrust; $\text{Upthrust} = W_a - W_f$ $= 20 - 15$ $\text{Upthrust} = 5N$	ii) Weight of displaced water Weight of displaced fluid = up thrust = 5N
iii) Volume of Displaced Water Weight of displaced fluid = up thrust Weight of displaced fluid = up thrust = $\boldsymbol{V\_\rho_f g}$. $Upthrust = V_f \rho_f g$. $5 = V_f \times 1000 \times 10$. $5 = 10000V_f$. $V_f = \frac{5}{10000}$ $V_f = 5 \times 10^{-4}\ m^3$	
iv) Volume of the metal Volume of the metal = Volume of displaced fluid $= 5 \times 10^{-4}\ m^3$	
v) Density of the metal $W_a = 20N$ $W_a = V_b \rho_b g$ $20 = (5 \times 10^{-4}) \times \rho_b \times 10$ $20 = 0.005\rho_b$ $\rho_b = \frac{20}{0.005}$ $\rho_b = 4000\ kgm^{-3}$	

Example 3:
An iron cube of volume 800cm^3 is totally immersed in (a)Water (b) oil of density 0.8gcm^{-3}.Calculate the up thrust in each case. Density of water =1000 kgm^{-3}
$V_b = 800cm^{-3}$ = 800/(100x100x100) kgm^{-3};

Solution
(a) Upthrust in water
ρ_f =1gcm^{-3}=1000 kgm^{-3}
V_f=V_b= $800cm^{-3}$ = 800/(100x100x100) kgm^{-3};
Up thrust = weight of displaced water
$Upthrust\ = V_f \rho_f g$
$\text{Upthrust} = \left(\frac{800}{100 \times 100 \times 100}\right) \times 1000 \times 10$
Upthrust = 8 N

(b) Upthrust in the oil
ρ_f = 0.8 gcm^{-3}=0.8x1000kgm^{-3}=800 kgm^{-3}

Up thrust = weight of displaced water
Upthrust = $V_f \rho_f g$
$\text{Upthrust} = \left(\frac{800}{100 \times 100 \times 100}\right) \times 800 \times 10$
Upthrust = 6.4 N

Note: the greater the density, the greater the up thrust. The apparent weight of a body is less in fluids of greater density.

Example 3:
An iron cube, mass 480g and density 8g/cm^3 is suspended by a string so that it is half immersed in oil of density 0.9g/cm^3. Find the tension in string.

Solution
m = 480g, ρ_b= 8 gcm^{-3}
W_a= mg = $\left(\frac{480}{1000}\right) \times 10 = 4.8N$
ρ_f =0.9gcm^{-3}= 0.9 x 1000 = 900 kgm^{-3}

$V_b = \frac{m_b}{\rho_b} = \frac{480}{8} = 60\ m^3$
Since its half –immersed then: V_f of oil = $\frac{1}{2} \times 60$ = 30cm^3
Up thrust = weight of displaced fluid
Upthrust = $V_f \rho_f g$
$\text{Upthrust} = \left(\frac{30}{100 \times 100 \times 100}\right) \times 900 \times 10$
Upthrust = 0.27 N

Tension in string = Apparent weight (W_f)
$Upupthrust = W_a - W_f$
$0.27 = 4.8 - W_f$
$W_f = 4.8 - 0.27$
$W_f = 4.53\ N$
Thus Tension in string = 4.53 N

Application of Archimedes principle
(a) Relative density of a solid
By Archimedes principle, the apparent weight is equal to the weight of water displaced by the solid. The volume of this water displaced is the same as the volume of the solid.
But *apparent loss in weight of solid in water = Wa – Ww*
RelativeDensity(R.D)

$$\mathbf{R.D} = \frac{\text{Weight of solid in air}}{\text{Apparent loss in weight of solid in water}}$$

$$= \frac{\text{Weight of solid in air}}{\textit{Upthrust in water}} = \frac{\mathbf{W_a}}{\mathbf{W_{a-W_w}}}$$

W_a- W_w = Upthrust: Where; W_a is weight of solid in air. W_w is weight of solid in water

Example
A glass block weighs 25N. When wholly immersed in water the block appears to weigh 15N. Calculate the relative density.

Solution

$W_a = 25N; W_f = 15N;$ $\text{Upthrust} = W_a - W_f$ $= 25 - 15$ $\underline{\text{Upthrust} = 10N}$	$R.D = \frac{W_a}{W_{a-W_w}}$ $R.D = \frac{25}{10}$ $\underline{R.D = 2.5}$

(b) Relative density of liquid
This is determined by using a solid. This solid sinks in water and in the liquid for which the relative density is to be determined.
A solid of weight W_a is weighed when completely immersed in the liquid to obtain W_l. The solid is then weighed when completely immersed in water to obtain Ww.
So $helative\ Density\ of\ the\ liquid\ (R.D)$ is given by;

$$R.D = \frac{\text{Apparent loss in weight of solid in liquid}}{\text{Apparent loss in weight of solid in water}}$$

$$= \frac{\text{Upthrust in liquid}}{\text{Upthrust in water}} = \frac{\mathbf{w_a - w_l}}{\mathbf{w_a} - \boldsymbol{w_w}}$$

Example
A metal weighs 25N in air. When completely immersed in liquid it weighs 15N and it weighs 20N when completely immersed in water. Calculate the relative density of the liquid.

Solution
$W_a = 25N; W_l = 15N; W_w = 20N:$
$\text{Relative density of liquid} = \frac{W_a - W_l}{W_{a-W_w}} = \left(\frac{25-15}{25-20}\right) = \frac{10}{5} = 2.0$

FLOATATION

When a stone is placed on water, it sinks because its weight is greater than the up thrust. When a cork is held below the surface of water, it rises on release. This is because the up thrust on the cork is greater than its weight.

A piece of wood neither rises nor sinks but floats because the up thrust on the piece of wood and its weigh just balance so it experiences no net force.

In general a body floats because up thrust is equal to weight of the body. A body will sink because up thrust on it is less than the weight of the body.

The principle of flotation states *that: A floating body displaces its own weight of fluid i.e. for a floating body; weight of body = weight of displaced fluid*

$$\boldsymbol{W_b = W_f}$$

Where W_a is weight of body floating, W_f is weight of displaced fluid.

$$\boldsymbol{W_f = V_f \rho_f g}$$

Where V_f is volume of displaced fluid

$$\boldsymbol{W_b = V_b \rho_b g}$$

Where V_b is volume of floating body, $\boldsymbol{\rho_b}$ is density of floating body "g" is acceleration due to gravity

In general: $\boldsymbol{V_b \rho_b g = V_f \rho_f g}$

Thus: $\boxed{\boldsymbol{m_b = m_f}}$

Example 1:
A piece of cork of volume 100cm^3 is floating on water.
If the density of the cork is 0.25gcm^{-3}. Calculate the volume of cork immersed in water.

Solution

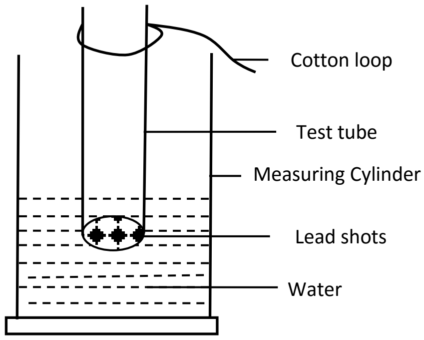
(a) Upthrust in water ρ_f =1gcm^{-3}=1000 kgm^{-3} : ρ_b = 0.25gcm^{-3} = 0.25 x 1000kgm^{-3} V_b= $100cm^{-3}$ = 100/(100x100x100) kgm^{-3};
Up thrust = weight of displaced water $\text{Upthrust} = V_f \rho_f g$ $\text{Upthrust} = \left(\frac{800}{100 \times 100 \times 100}\right) \times 1000 \times 10$ $\underline{\text{Upthrust} = 8\text{ N}}$

$\text{Upthrust} = V_f \rho_f g$ $m_b = V_b \rho_b$ $V_f \times 1000 = \left(\frac{100}{100 \times 100 \times 100}\right) \times (0.25 \times 1000) \times 10$ $1000V_f = 2.5$ $\underline{\underline{V_f = 0.000025\text{ m}^3 \text{ or } 2.5 \times 10^{-5}\text{ m}^3}}$

Exercise:
1. A glass block weighs 25N in air. When wholly immersed in water, the block weighs 15N. Calculate the;
   (i) up thrust on the block [10N]
   (j) density of the glass kgm^{-3} [2500kgm^{-3}]
2. A piece of iron weighs 555N in air. When completely immersed in water, it weighs 530N and weighs 535N when completely immersed in alcohol. Calculate the relative density of alcohol. [R.D=0.8]

3. UNEB 1991. Qn. 7
4. UNEB 1990. P_2 Qn. 5

Experiment: ***To verify the Law of Floatation***



Procedure
- ❖ A test tube is placed in a measuring cylinder containing water and the original reading of the water level (V_1) is noted.
- ❖ Lead shots are added to the test tube until it floats up right and the new water level (V_2) is noted.

$$\text{Volume of displaced water} = (V_2 - V_1)\text{cm}^3$$
$$\text{Weight of displaced water } = \rho_w(V_2 - V_1)g$$

- ❖ The test tube together with the shots is removed from the cylinder and weighed using a spring balance. (The cotton loop helps to attach it to the balance hook). Their weight is recorded, $\mathbf{W}_{-}$.

$(\text{Weight of lead shots} + \text{testtube}) = W_a$

Observation
- ❖ The weight of lead shots and test tube is equal to the weight of displaced water.

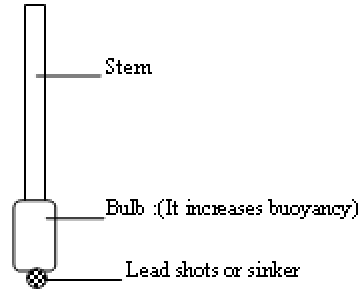
$$\binom{Weight\ of\ lead}{shots + testtube} = \binom{\text{Weight of}}{\text{displaced water}}$$

Conclusion
- ❖ From the above observation, it is noticed that the law of floatation is verified.

Application of the law of floatation

(i) A hydrometer (ii) Submarines	(iii) Ships (iv) Balloons

(i) A hydrometer
The relative density of any liquid may be found using *a **hydrometer.***
-It is used to test the purity of milk.
-It is used to test R.D of a car battery acid.
This consists of a float with along stem. A heavy weight is placed beneath the float to keep the hygrometer up right. The higher the hydrometer float the higher the relative density of the liquid.



(Enable the hydrometer)

(ii) Submarines
The average density of submarines is varied by means of ballast tanks. For the submarines to float, the ballast tanks are filled with air. To sink the submarines, the tanks are filled with water causing average density to rise higher than that of water.

(iii) Ships
Why ships float.
Ships float on water, although they are made from iron and steel which are denser than water. This is because a steel or iron ship is made hollow and contains air. So the average density of the ship is less than that of water.

The loading lines called plimsoul marks on the sides show the level to which it can be safely loaded under different conditions.
Weight of displaced water (W_w) = weight of the ship (W_s) + weight of the cargo (W_c).

$$\mathbf{W_w = W_s + W_c}$$

(iv) Balloons
These are airships used in meteorological measurements.
A balloon filled with hydrogen weighs less than the weight of air it displaces.
The up thrust being greater than its weight, a resultant up ward force on the balloon causes it to rise.
The balloon continues to rise up until the upthrust acting on it is equal to the weight of the balloon plus its content and then it floats.
The lifting power of the balloon is calculated from the formula:

$$U = W_{balloon} + W_{hydrogen} + W_{load}$$
$$U = m_b g + V_h \rho_h g + m_l g$$

$$\text{Upthrust in air} = \text{Weight of displaced air}$$
$$\text{Upthrust in air} = \rho_a V_a g$$

Example: 1
A balloon has a capacity $10\text{m}^3$and is filled with hydrogen. The balloon's fabric and the container have a mass of 1.25kg. Calculate the maximum mass the balloon can lift.
{Density of hydrogen = 0.089kgm^{-3}: density of air=1.29kgm^{-3}}
Solution:

Volume of balloon,$V_b = 10\text{m}^3$
Density of hydrogen, $\rho_h = 0.089\text{kgm}^{-3}$
Density of air, $\rho_a = 1.29\text{kgm}^{-3}$
Volume of air displaced,V_a =Volume of balloon,$V_b = 10\text{m}^3$
Volume of hydrogen, V_h =Volume of balloon,$V_b = 10\text{m}^3$
Mass of balloon and container,$= 1.25\text{kg}$
Let the mass of the load = x

$$\text{Upthrust} = \text{Weight of balloon} + \text{weight of } H_2 + \text{load}$$
$$U = m_b g + V_h \rho_h g + m_l g$$
$$V_a \rho_a g = m_b g + V_h \rho_h g + m_l g$$
$$10 \times 1.29 \times g = 1.25 \times g + 0.089 \times 10 \times g + x \times g$$
$$x = 10.76\text{kg}$$

Relationship between density of a floating body, density of a liquid and fraction submerged

$$\binom{\text{Density of}}{\text{floating object}} = \binom{\text{Fraction}}{\text{submerged}} \times \binom{\text{Density of}}{\text{liquid}}$$

Exercise:

1. A rubber balloon of mass 5g is inflated with hydrogen and held stationary by means of a string. If the volume of the inflated balloon is $0.005m^3$, find the tension in the string.

(Assume hydrogen is a light gas, and density of air = $1.25kg^{-3}$): [Ans: 1.25×10^{-2}N]

2. UNEB: 1995. Qn. 7	5. UNEB: 1989. Qn. 4
3. UNEB: 1988. Qn. 11	6. UNEB: 2001. Qn.2
4. UNEB: 2000. Qn. 40	

1: 10. LINEAR MOTION

Distance: Is the space between two points.

Displacement: Is the distance moved in a specified direction.

The S.I unit of distance and displacement is **metre** or **m**

Distance is a scalar quantity while displacement is a vector quantity.

Speed: Is the rate of change of distance. Or It is distance moved in a unit time.

$$\text{Speed} = \frac{\text{Distance}}{\text{Time taken}}$$

Velocity; is the rate of change of displacement. Or It is speed in a specified direction.

$$\text{Velocity} = \frac{\text{Displacement}}{\text{Time taken}}$$

The S.I unit of speed and velocity is **metre per second.** **(m/s)** or (**ms^{-1}**).

Speed is a scalar quantity while Velocity is a vector quantity.

Differences between velocity and speed

Velocity	speed
- Vector quantity	-scalar quantity
- displacement/time taken	-distance/time taken

Types of velocities

❖ **initial velocity u'**

Is the velocity with which a body starts motion in a given time interval.

Note;

1. For a body starting from rest the initial velocity "u' must be zero ie. u = 0 ms^{-1}

2. For a stationary body starting motion means that the body is starting from rest u = 0 ms^{-1}

3. For a body traveling with a certain velocity, *x*, the initial velocity for such a body will be x so, u = *x* ms^{-1} e.g. a car traveling at 20 ms^{-1}, has u =20 ms^{-1}

❖ **Final velocity v'**

The velocity with which a body ends motion for a given time.

Note: if a body is brought to rest, then the final velocity is zero ie, v = 0m/s.eg; A body traveling at 20m/s is uniformly brought to rest in 2s. Then; v = 0m/s.

The units of velocity must include m/s or km/hr or cm/s.

Average velocity:

$$\text{Average Velocity} = \frac{\text{Final velocity} + \text{Initial velocity}}{2}$$

$$\text{Average Velocity} = \frac{V+u}{2}$$

Uniform velocity

Is the constant rate of change of displacement.

OR

Uniform velocity is when a body makes equal displacements in equal time intervals.

When a body moves with uniform velocity, initial velocity (u) must be equal to final velocity, v. i.e. V = u.

E.g. A car traveling with uniform velocity of 20m/s has u=20m/s. V=20m/s.

When a body moves with uniform velocity, its acceleration is zero. (i.e a = 0).

Acceleration (a)

Is the rate of change in velocity with time.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}}$$

$$\textbf{Acceleration},\ \mathbf{a} = \frac{\mathbf{V - u}}{\mathbf{t}}$$

Change in velocity = final velocity (V) - initial-velocity (U)

The S.I unit for change in velocity is **m/s^2** or **ms^{-2}**.

Uniform acceleration

Uniform acceleration is the constant rate of change in velocity with time.

OR:

Uniform acceleration is when a body moves with equal change in velocity in equal time intervals.

When a body moves with uniform acceleration, the final velocity is not equal to initial velocity.

Example.

A car starts from rest and it accelerates to 10m/s. Calculate the change in velocity.

U=0m/s

V=20m/s

$$\text{Change in velocity} = v - u$$
$$\text{Change in velocity} = 20 - 0$$
$$= 20ms^{-1}$$

Note: the velocity to which a body is accelerating becomes the final velocity for that given time interval.

Differences between velocity and acceleration

Velocity	Acceleration

i) S.I unit is ms^{-1} ii) Is the rate of change of displacement	i) S.I unit is ms^{-2} ii) Is the rate of change of velocity with time?

Equations Of Motion
The units of acceleration must always be m/s^2 and units m/s or km/hr are for velocity.

1st Equation of motion
From the definition of acceleration.

$$\text{Acceleration} = \frac{\text{Change in velocity}}{\text{Time taken}}$$

, $$a = \frac{V - u}{t}$$

$at = v - u$

$\mathbf{v = u + at}$

This is called the first equation of motion.

Example1
A car started from rest it accelerates uniformly for 5s at a rate of $4m/s^2$. Calculate the final velocity.

Solution

Given	From;
u=0 m/s v=0 m/s a=$4ms^{-2}$ t=5s v=?	$v = u + a$ $v = 0 + (4)(5)$ $v = 20$ $\underline{\underline{v = 20ms^{-1}}}$

Example 2.
A body starting from rest is accelerated to 30m/s in two seconds. Calculate the acceleration of the body.
Solution

Given	From;
u=0m/s v=30m/s t=2s	$v = u + at$ $30 = 0 + a(2)$ $30 = 2a$ $15 = a$ $\underline{\underline{a = 15ms^{-2}}}$

Example 3.
A body starts from rest and accelerated uniformly at $2m/s^2$ for 3s. Calculate the final velocity.
Solution

Given	From;
u=0m/s a=$2m/s^2$ t=3s	$v = u + at$ $v = 0 + (2)(3)$ $v = 6$ $\underline{\underline{v = 6ms^{-1}}}$

Example 4.
A body traveling at 10m/s is accelerated uniformly for 3 seconds at $5m/s^2$. Calculate the velocity at the end of the third second.
Solution

Given	From;
u=10m/s a=$5m/s^2$ t=3s	$v = u + at$ $v = 10 + (5)(3)$ $v = 10 + 15$ $\underline{\underline{v = 25ms^{-1}}}$

Example: 5.
A body traveling at 20m/s is accelerated for 4s at $5m/s^2$. Calculate the average velocity.
Solution

Given	From;	Then from ;
u=20m/s a=$5m/s^2$ t=4s	$v = u + at$ $v = 20 + (5)(4)$ $v = 20 + 20$ $\underline{\underline{v = 40ms^{-1}}}$	Average Velocity $= \frac{V+u}{2}$ Average Velocity $= \frac{40+20}{2}$ Average Velocity $= \frac{60}{2}$ $\underline{\underline{\text{Average Velocity} = 30ms^{-1}}}$

Example: 5.
A car travels with a uniform velocity of 20m/s for 6s. Calculate its acceleration.
Solution

Given	From;
u=20 m/s v=20 m/s a=? t=6s	$v = u + at$ $20 = 20 + a(6)$ $20 = 20 + 6a$ $6a = 0$ $\underline{\underline{a = 0ms^{-2}}}$
From the above example, it's noted that for a body moving with uniform velocity, its acceleration is zero because the change in velocity becomes zero as initial velocity is equal to final velocity.	

Example: 6.
A car traveling at 90km/hr is uniformly brought to rest in 40 seconds. Calculate the acceleration.
Solution

Given	From;
u=90km/hr = $\frac{90\times1000}{1\times60\times60} = 25m/s$ a=? t=40s v=0 m/s	$v = u + at$ $0 = 25 + (a)(40)$ $0 = 25 + 40a$ $-40a = 25$ $\underline{\underline{a = -0.625ms^{-2}}}$
***Note**: If the value obtained for acceleration is negative, it implies that the body is decelerating or retarding. This occurs when there's a decrease in velocity.*	

2nd Equation of motion
Displacement: "***S*** or ***x***" is length moved in specified direction
From the definition of Displacement.

$$Displacement = (Average\ velocity) \times (Time)$$

$$s = \left(\frac{v+u}{2}\right) \times t \quad Where: v=u+at$$

$$s = \left(\frac{u + at + u}{2}\right) \times t$$

$$s = \left(\frac{2u + at}{2}\right) \times t$$

$$s = \left(\frac{2ut + at^2}{2}\right)$$

$$\boldsymbol{s = ut + \frac{1}{2}at^2}$$

This is called the second equation of motion. This equation is mainly used when the question involves distance and time.

Example: 1

A body starts from rest and accelerates uniformly at 2ms^{-2} for 3s. Calculate the total distance travelled.

Solution

Given	From;
u=0 m/s a=2ms^{-2} t=3s s=?	$s = ut + \frac{1}{2}at^2$ $s = (0)(3) + \frac{1}{2}(2)(3^2)$ $\underline{\underline{s = 9\ m}}$

Calculations involving deceleration or Retardation

When calculating a problem involving deceleration; it should be remembered that the value of "a" should be negative.

Example 2:

A body moving at 40m/s decelerates uniformly for 20s at 3m/s^2. Calculate distance covered.

Solution

Given	From;
u=40 m/s a=-3ms^{-2} t=20s s=?	$s = ut + \frac{1}{2}at^2$ $s = (40)(20) + \frac{1}{2}(-3)(20^2)$ $s = 800 - 600$ $\underline{\underline{s = 200\ m}}$

Example 3:

A car traveling at 40m/s is uniformly decelerated to 25m/s for 5s. Calculate the total distance covered.

Solution

Given	From;	Then, from:
u=40 m/s v=25 m/s a=? t=5s s=?	$v = u + at$ $25 = 40 + 5a$ $5a = 25 - 40$ $5a = -15$ $\underline{\underline{a = -3ms^{-2}}}$	$s = ut + \frac{1}{2}at^2$ $s = (40)(5) + \frac{1}{2}(-3)(5^2)$ $s = 200 - 37.5$ $\underline{\underline{s = 162.5\ m}}$

Third Equation of motion

From:

$Displacement = (Average\ velocity) \times (Time)$.

Making ***'t'*** the subject of the formula in the first equation of motion and substituting it in here, we get;

$Displacement, s = \left(\frac{v+u}{2}\right) \times \left(\frac{v-u}{a}\right)$

$$s = \frac{(v+u)(v-u)}{2a}$$

$2as = v^2 - u^2$

$\boldsymbol{v^2 = u^2 + 2as}$

This is called the third equation of motion

This equation is applied when time is not given and not required.

Example 1:

Calculate the final (maximum) velocity of a body traveling at 4m/s. When it accelerates at 2m/s^2 and covers a distance of 5m.

Solution

Given	From;
u=4 m/s v=? a=2ms^{-2} s=5m	$v^2 = u^2 + 2as$ $v^2 = 4^2 + 2(2)(5)$ $v^2 = 16 + 20$ $v^2 = 36$ $\boldsymbol{v = 6ms^{-1}}$

Example 2:

A body traveling at 90km/hr is retarded to rest at 20m/s^2. Calculate the distance covered.

Solution

Given	From;
u=90km/hr=$\frac{90\times1000}{1\times60\times60} = 25m/s$ a=-20m/s^2 v=0 m/s s=?	$v^2 = u^2 + 2as$ $0^2 = (25)^2 + 2(-20)s$ $0^2 = 625 - 40s$ $40s = 625$ $\frac{40s}{40} = \frac{625}{40}$ $\underline{\underline{s = 15.625m}}$

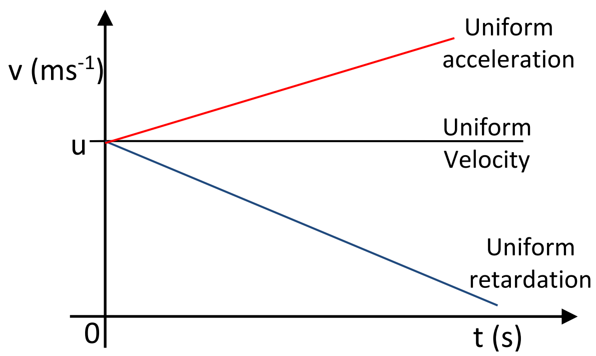
Graphical presentation of uniform velocity and uniform acceleration.

Uniform velocity can be represented on a 2 type of graphs.

i) Velocity against time graph

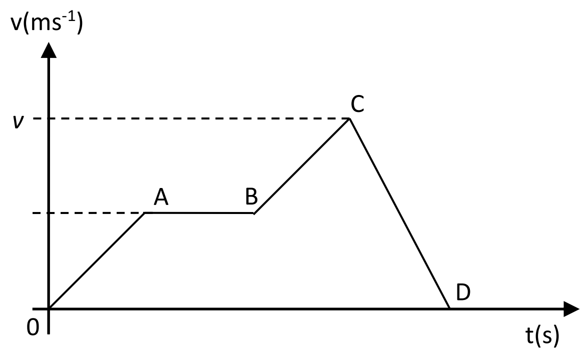
ii) Distance against time.

i) velocity against time graph



Note:

When a body maintains the same speed, it implies that it moves with uniform velocity.



OA- uniform acceleration

AB- uniform velocity

BC- uniform acceleration

CD- uniform deceleration or uniform retardation

- The slope of a velocity time graph gives the acceleration of the body. ie:

$$\textbf{slope}, \boldsymbol{s} = \frac{\textbf{Change in v}}{\textbf{Change in t}} = \textbf{acceleration}$$

- The Area under any stage or section of velocity time graph gives the distance covered during that time.

Drawing a velocity against time graph

This involves the following steps:

- ✓ Divide the motion into stages basing on the timing.
- ✓ Obtain the initial velocity (u) and final velocity (v) for each stage.
- ✓ The final velocity for one stage becomes the initial for the next stage.

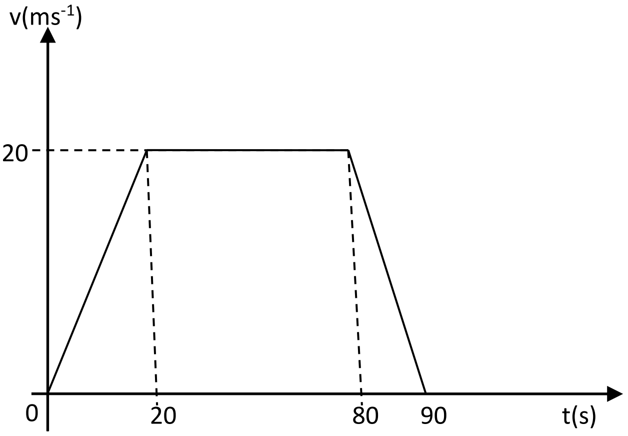
Example 1:
A cyclist starts from rest and accelerate uniformly at $1m/s^2$ for 20s. Then he maintains the maximum speed so reached for 1 minute and finally decelerates to rest uniformly for 10s.

i) Draw a velocity against time graph for the body.
ii) Calculate the total distance travelled.

Solution

Stage1 u=0 ms^{-1} a=$1ms^{-2}$ t=20s v=?	**Stage 2** u = $20ms^{-1}$ a= 0 ms^{-2} t= 1min=60s	**Stage 3** u = $20ms^{-1}$ v= 0 ms^{-1} t = 10s	Then from; $v = u + at$ $v = 0 + (1)(20)$ $v = 20ms^{-1}$

(i) A velocity against time graph for the motion.



ii) Total distance travelled

Stage 1:
Distance $= \frac{1}{2}$bh
Distance $= \frac{1}{2} \times 20 \times 20$
Distance $= 200$m

Stage 2:
Distance = lw
Distance $= 60 \times 20$
Distance $= 1200$m

Stage 3:
Distance $= \frac{1}{2}$bh
Distance $= \frac{1}{2} \times 10 \times 20$
Distance $= 100$m

Then Total Distance is;
=Stage1 + Stage2 + Stage3
=200m + 1200m + 100m
= 1500m

Example 2:
A car traveling at 10m/s is uniformly accelerated for 4s at $2m/s^2$. It then moves with a constant speed for 5s after which it is uniformly brought to rest in another 3s.

i) Draw a velocity against time graph.
ii) Calculate the total distance travelled.

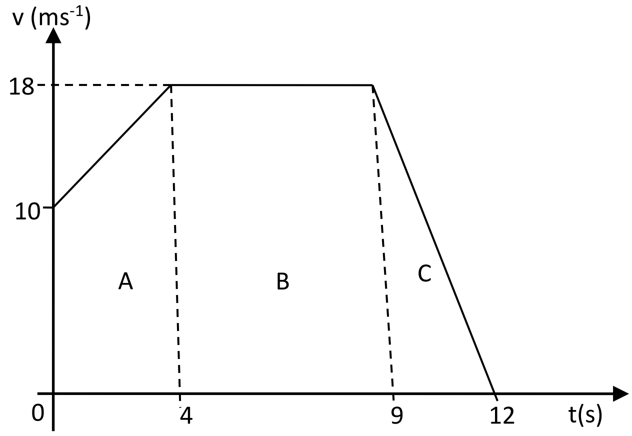
Solution

i) Stage A
u=10 ms^{-1}
a=2 ms^{-2}
t=4s

Stage B
u = $18ms^{-1}$
a = 0 ms^{-2}
t =5s
v=?

Stage C
u = $18ms^{-1}$
v = 0 ms^{-1}
t = 3s

Then from;
$v = u + at$
$v = 10 + (2)(4)$
$v = 18ms^{-1}$



i) Total distance travelled

Stage A: Distance $= \frac{1}{2}h(a + b)$ Distance $= \frac{1}{2} \times 4 \times (10 + 18)$ Distance = 56 m	**Stage B:** Distance = lw Distance $= 5 \times 18$ Distance = 90 m
Stage C: Distance $= \frac{1}{2}$bh Distance $= \frac{1}{2} \times 3 \times 18$ Distance = 27 m	**Then Total Distance is;** =Area (A+B+C) =56 m + 90 m + 27 m **= 173 m**

Note: Distance covered during stage A can also be obtained by dividing the area A into a triangle and a rectangle and then finding the sum of the two areas.
ie;$A_1 = \frac{1}{2}bh = \frac{1}{2} \times 4 \times 8 = 16$m
$A_2 = lw = 4 \times 10 = 40$m
Thus: Area, A = Area A_1 + Area A_2
= 16 m + 40 m
= 56m

Example 3:
A body moving with uniform velocity:
A car travels at a velocity of 20m/s for 6s. It is then uniformly brought to rest in 4s.

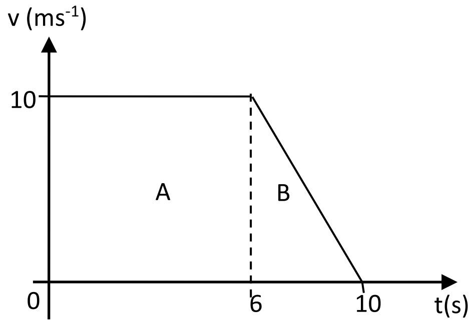
i) Draw a velocity against time graph.
ii) Calculate the retardation
iii) Find the total distance traveled
iv) Calculate the average speed of the body

Solution

i) Stage A
u=20 ms^{-1}
a=0 ms^{-2}
t=6s
v=20 ms^{-1}

Stage B
u = $20ms^{-1}$
a =?
t = 4s

Then from;
v = u + at
v =20+ (a) (4)
-4a=20
a=-5ms^{-2}



ii) The retardation

Retardation or deceleration occurs in region B.

u=20 ms^{-1} v=0 ms^{-1} t = (10 - 6) t=4s	Then from; $v = u + at$ $0 = 20 + (a)(4)$ $-4a = 20$ $a = -5ms^{-2}$ Thus the retardation is $\mathbf{5ms^{-2}}$

iii) Total distance travelled

Stage A: $Distance = l \times w$ $Distance = 6 \times 10$ $Distance = 60\ m$	**Stage B:** $Distance = \frac{1}{2}bh$ $Distance = \frac{1}{2} \times 4 \times 10$ $Distance = 20\ m$
Then Total Distance is; =Area (A+B) =60 m + 20 m **= 80 m**	

iv)

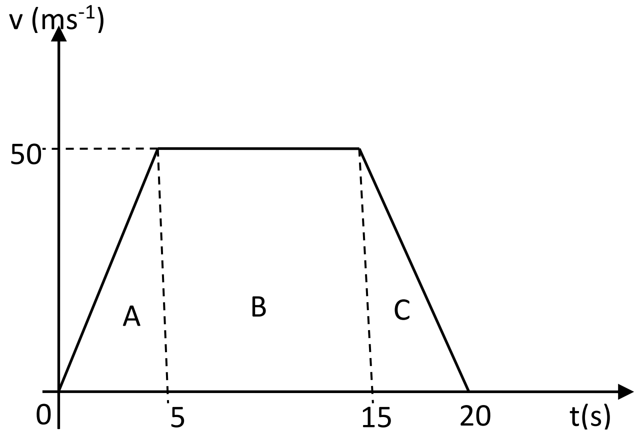
$$\text{Average speed} = \frac{\text{Total Distance travelled}}{\text{Total Time Taken}}$$

$$\text{Average speed} = \frac{80\ \text{m}}{10\ s}$$

Average speed $= \mathbf{8ms^{-1}}$

EXERCISE

Qn1. The graph below shows motion of a body of mass 2kg accelerating from rest.



(a) Describe the motion of the body

(b) Use the graph to calculate the:

(i) total distance covered

(ii) Distance covered when moving with uniform velocity.

(iii) acceleration

(iv) retardation

(v) average retarding force

Solution

For A	For B	For C
u=0ms^{-1};v=50ms^{-1} Then from; $v = u + at$ $50 = 0 + (a)(5)$ $5a = 50$ $a = 10\ ms^{-2}$	u=50ms^{-1}; v=50ms^{-1} Then from; $v = u + at$ $50 = 50 + (a)(5)$ $5a = 50$ $a = 00\ ms^{-2}$	u=50ms^{1};v=0ms^{-1} Then from; $v = u + at$ $0 = 50 + (a)(5)$ $-5a = 50$ $a = -10\ ms^{-2}$

Description of the motion

- The body *accelerates uniformly at* $10\ ms^{-2}$ from *rest* to 50 ms^{-1} for the *first* 5s.
- It then moves with a *uniform velocity* of 50 ms^{-1} for the *next* 10s. (Or it maintains it for next 10s).
- It finally *decelerates or retards uniformly* at $10\ ms^{-2}$ from 50 ms^{-1} to *rest* in the last 5s.

a) i) Total distance= Area A +Area B + Area C

Area A = $\frac{1}{2}bh$

= $\frac{1}{2} \times 5 \times 50$

= 125 m

Area B = *lw*

=10×50

= 500 m

Area A = $\frac{1}{2}bh$

= $\frac{1}{2} \times 5 \times 50$

= 125 m

Total distance= Area A +Area B + Area C

= 125m + 500m +125m

= 750 m

ii) Distance covered when moving with uniform

Area B = *lw*

=10×50

= 500 m

iii) Acceleration

For A

u= 0 ms^{-1}

v=50 ms^{-1}

t = 5s

$v = u + at$

$50 = 0 + (a)(5)$

$5a = 50$

$a = 10\ ms^{-2}$

iv) Retardation or Deceleration

For C

u= 50 ms^{-1}

v=0 ms^{-1}

t = 5s

$v = u + at$

$0 = 50 + (a)(5)$

$-5a = 50$

$a = -10\ ms^{-2}$

Thus the retardation is $\mathbf{10\ ms^{-2}}$

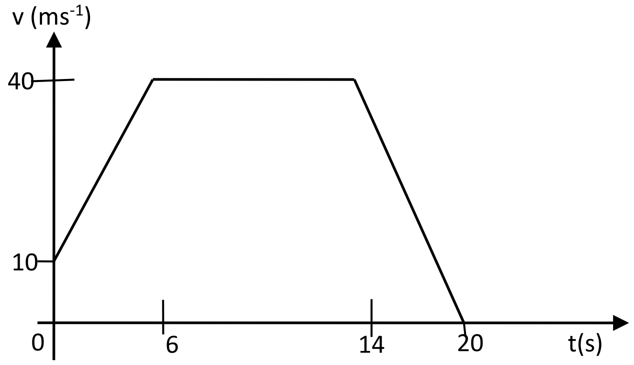
i) Average retarding force

Mass, m = 2kg

Retardation = 10 ms^{-2}

Then from;
Force = mass × acceleration
Average retarding force = mass × retardation
= 2 × 10
= 20 N

Qn2. The graph below shows motion of abody of mass 3kg.Use it to answer the questions that follow.

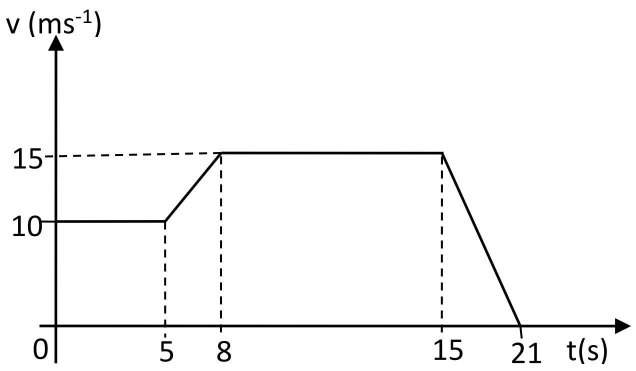


a) Describe the motion of the body
b) Use the graph to calculate the:
   (i) Distance covered during acceleration. (150 m)
   (ii) Distance covered when moving at constant velocity. (320 m)
   (iii) total distance covered.(590 m)
   (iv) acceleration. ($a = 5\ ms^{-2}$)
   (v) retardation. ($a = -6.67\ ms^{-2}$)
   (vi) average accelerating force. ($F = 15\ N$)

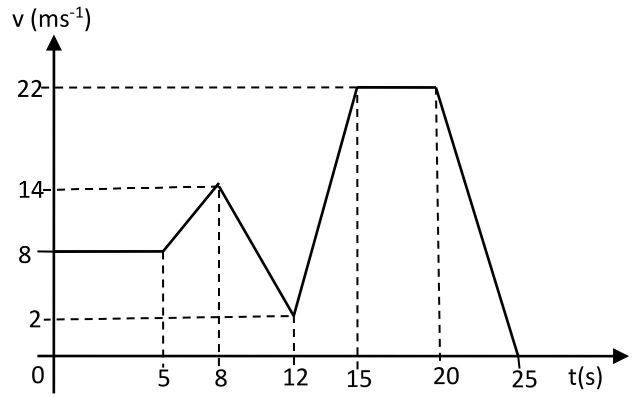
Qn3. The graphs below show motion of bodies. Use them to answer the following questions.

a) Describe the motion of the body
b) Use the graph to calculate the:
   i) Total distance covered.
   ii) Average velocity
   iii) Acceleration.
   iv) Retardation.

(A)



(B)

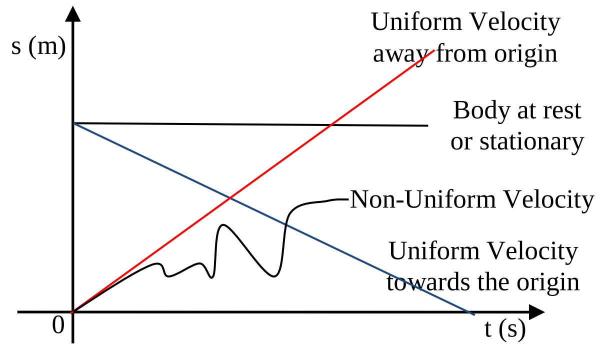


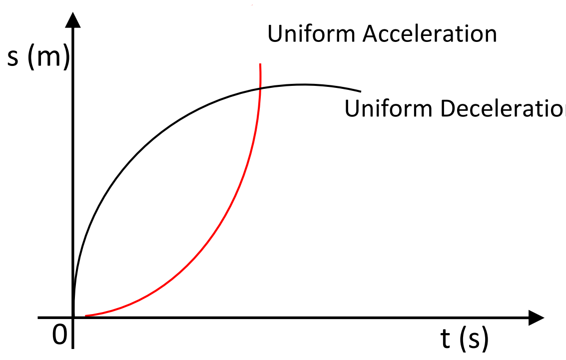
Qn4. A body accelerates uniformly from rest at 3ms^{-2} for 4 seconds. Its velocity then remains constant at the maximum value reached for 7 seconds before retarding uniformly to rest in the last 5 seconds. Calculate the:
   i) uniform velocity ($v = 12\ ms^{-1}$)
   ii) total distance travelled ($= 138\ m$)
   iii) retardation ($a = -2.4\ ms^{-2}$)
   iv) average velocity for the journey.($v = 8.63\ ms^{-1}$)

Qn5. A body moves from rest at a uniform acceleration of 2ms^{-2}.
a) Sketch a velocity time graph for the motion of the body.
b) Find:
   i) its velocity after 5 seconds. ($v = 10ms^{-1}$)
   ii) how far it has gone in this time. ($s = 25\ m$)
   iii) how long it will take the body to be 100 m from the starting point. ($t = 10\ s$)

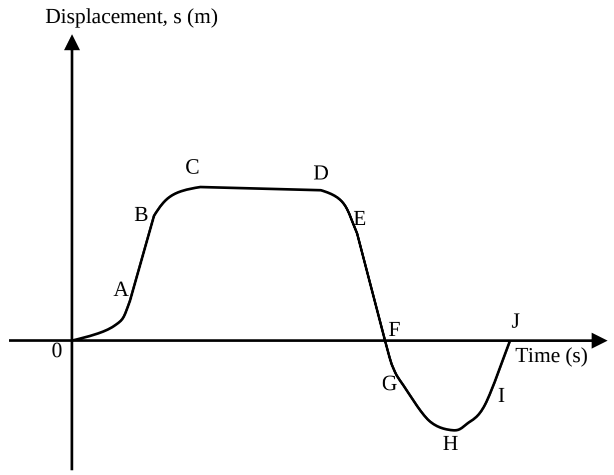
Non-uniform acceleration is when the rate of change of velocity with time is not constant.

ii) Displacement against time graph



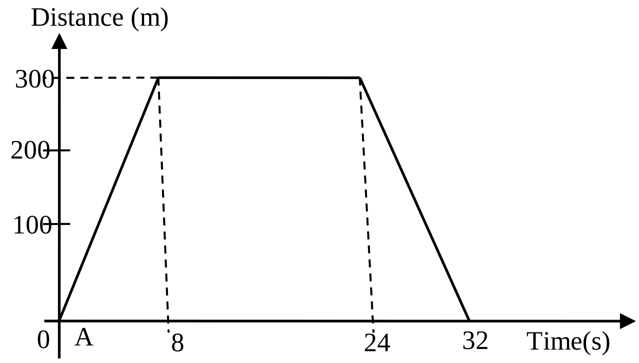


Describing the motion on a displacement time graph



Along:
OA- accelerating
AB- moving with uniform velocity away from the origin
BC- Decelerating
CD- Stationary
DE- Accelerating and moving toward the origin
EF- Moving with uniform velocity
FG- Moving with uniform velocity in opposite direction to the original direction.
GH- Decelerating
At "H"- Momentarily stationary
HI- Accelerating and moving back towards the origin.

Example 1:
The graph below shows the variation of distance with time for a body.



a) Describe the motion of the body
b) Calculate the:
    i) acceleration of the body
    ii) maximum velocity attained by the body

Solution

For A
s = 300 m
t = 8s
Speed, u= $\frac{distance}{time}$
u= $\frac{300}{8}$
u =37.5ms^{-1}

Then from;
$s = ut + \frac{1}{2}at^2$

$300 = 37.5(8) + \frac{1}{2}(a)(8^2)$
$32a = 0$
$a = 0\ ms^{-2}$

Description of the motion
- The body starts from A and moves 300m with a uniform velocity of 37.5 ms^{-1} for the first 8seconds.
- It then a rests for the next 16 seconds.
- It finally returns to A with the uniform velocity of 37.5 in the last 8 seconds.

Exercise:
Qn: 1; [UNEB 1997 Paper II Qn.2]
Two vehicles A and B accelerate uniformly from rest. Vehicle A attains a maximum velocity of $30ms^{-1}$ in 10s while B attains a maximum velocity of $40ms^{-1}$ in the same time. Both vehicles maintain these velocities for 6s before they are decelerated to rest in 6s and 4s respectively.
(i) Sketch on the same axes, velocity time graphs for the motion of the vehicles.
(ii) Calculate the velocity of each vehicle 18s after the start. ($v_A = 20ms^{-1}$ and $v_B = 20ms^{-1}$)
(iii) How far will the two vehicles be from one another during the moment in (ii) above? ($S_A = 380m$ and $S_B = 500m: S_{AB} = 120m$)

Qn. 2 See : UNEB:

1993.Qn.25 and Qn.5 PII 1996.Qn.1 Paper II 2000.Qn.1 Paper I	1994. Qn.10 and Qn.26 1987. Qn.25

MOTION UNDER GRAVITY (FALLING BODIES)
In a vacuum, all bodies fall at the same rate. However, in atmosphere different bodies fall at different rate because the air resistance is greater to light objects.

Acceleration due to gravity, **g**.
Acceleration due to gravity is the change in velocity with time for body falling freely under the force of gravity.
Note: Acceleration due to gravity varies from place to place because:
- ❖ The earth is not a perfect sphere
- ❖ The earth is always rotating

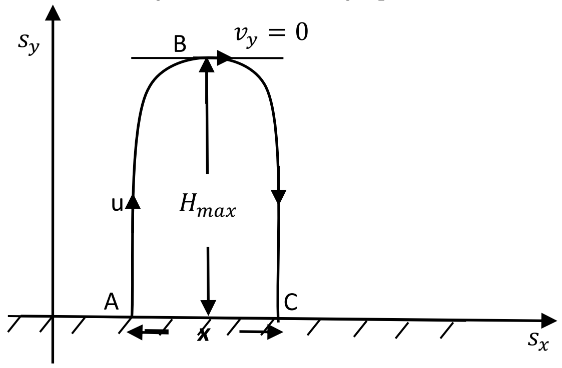
All bodies thrown upwards or falling freely in the earth's surface, have a constant acceleration called Acceleration due to gravity, *i.e*: $\boldsymbol{a = g = 10\ ms^{-2}}$.

Since the gravitational force acts vertically down wards, ie accelerates all objects down wards towards the earth's surface. Thus for downward motion (falling objects), $\boldsymbol{a = +g = +10\ ms^{-2}}$***. And for upward motion (objects thrown upwards),*** $\boldsymbol{a = -g = -10\ ms^{-2}}$.

Projectile motion

A projectile is a particle which has both vertical and horizontal motions when thrown in air.

Consider a body thrown vertically upwards from A.



In projectiles, the horizontal and vertical motions are handled separately but simultaneously. The horizontal velocity of the body in motion remains the same throughout since there is no acceleration due to gravity in the horizontal.

First equation of motion

$$\begin{pmatrix} v_x \\ v_y \end{pmatrix} = \begin{pmatrix} u \\ u \end{pmatrix} + \begin{pmatrix} 0 \\ g \end{pmatrix} t \qquad \Rightarrow \begin{cases} v_x = & u \\ v_y = & u + gt \end{cases}$$

Second equation of motion

$$\begin{pmatrix} s_x \\ s_y \end{pmatrix} = \begin{pmatrix} u \\ u \end{pmatrix} t + \frac{1}{2} \begin{pmatrix} 0 \\ g \end{pmatrix} t^2 \qquad \Rightarrow \begin{cases} s_x = & ut \\ s_y = & ut + \frac{1}{2} gt^2 \end{cases}$$

Third equation of motion

$$\begin{pmatrix} v_x^2 \\ v_y^2 \end{pmatrix} = \begin{pmatrix} u^2 \\ u^2 \end{pmatrix} + 2 \begin{pmatrix} 0 \\ g \end{pmatrix} \begin{pmatrix} s_x \\ s_y \end{pmatrix} \quad \Rightarrow \begin{cases} v_x^2 = & u^2 \\ v_y^2 = & u^2 + 2gs_y \end{cases}$$

Where $\boldsymbol{g = +10\ ms^{-2}}$*.for downward motion (freely falling objects or objects dropped from a height), If a body is dropped from a height, then* $\boldsymbol{u = 0\ ms^{-1}}$ *hence.* $\boldsymbol{S = \frac{1}{2} gt^2}$ ***and*** $\boldsymbol{v = gt}$ ***or*** $\boldsymbol{v = \sqrt{2gs}}$**.**

.

Alternatively the principle of conservation of energy may be used for a freely falling body.

ie: $\frac{1}{2} cv^2 = mgh \Rightarrow \boldsymbol{v = \sqrt{(2gh)}}$**.**

$\boldsymbol{g = -10\ ms^{-2}}$*.for upward motion (objects thrown upwards),*

Maximum Height, $\boldsymbol{s_y = H_{max}}$**:** Is the highest vertical distance attained by a projectile.

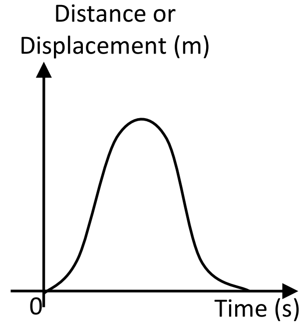
At H_{max}, $v_y = 0$:

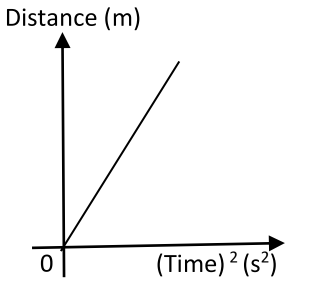
Time of Flight, T: Is the total time taken for a projectile to move from origin until it lands. This time is twice the time taken to reach the maximum height.

If **t** is the time taken to reach the maximum height, then

T=2t

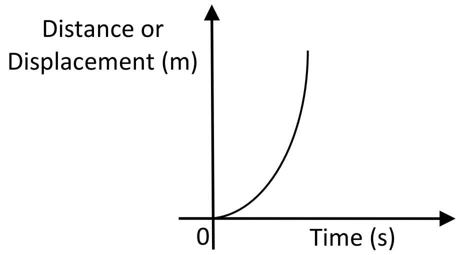
Distance - Time or Displacement –Time Graphs for a body thrown vertically upward.





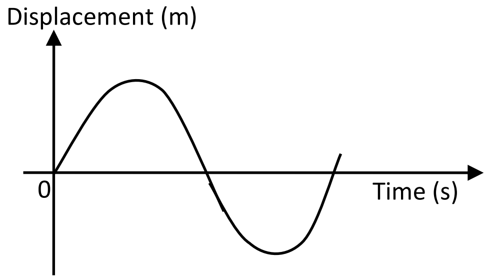
$$\mathbf{S = \quad ut - \frac{1}{2} gt^2}$$

Distance- Time or Displacement –Time Graph for a body falling freely from rest.

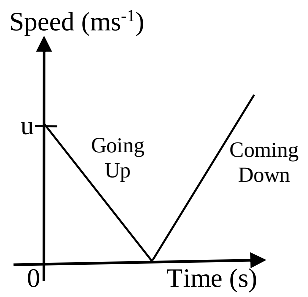


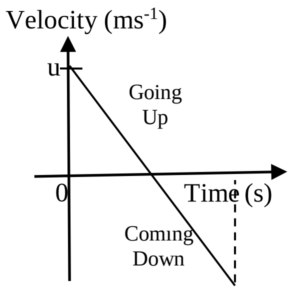
$$\mathbf{S = \quad ut + \frac{1}{2} gt^2}$$

Displacement –Time Graph for a body thrown vertically upwards from appoint above the ground.



Speed- Time and Velocity –Time Graphs For a body thrown vertically upwards.

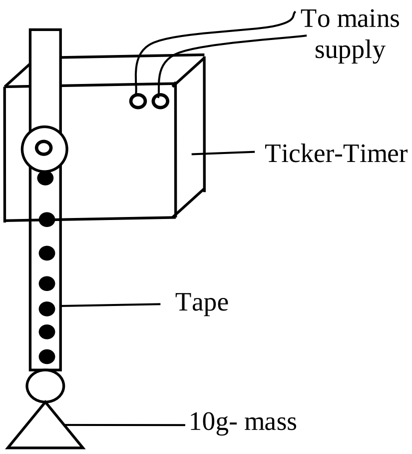




The speed of the object decreases as it goes higher. At maximum height reached the speed is zero because the object is momentarily at rest and when the object starts to fall the speed increases.

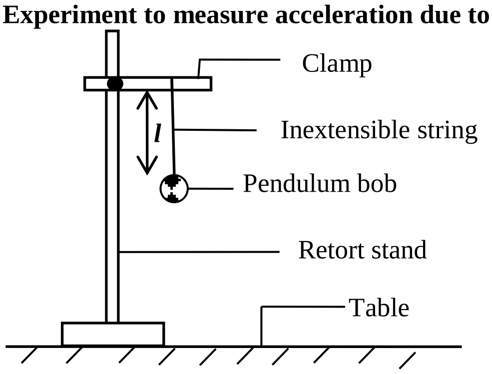
The velocity decreases upwards and it is zero at the maximum height. However the velocity increases downwards and negative because of the change in direction.

Experiment to measure acceleration due to gravity.



- A tape is passed through a ticker-timer and attached to a 10g- mass.
- The ticker-timer makes dots on the tape at an interval determined by the frequency of the mains supply. i.e $T = \frac{1}{f}$. This is the time taken to make **one space** (2 dots).
- The distance **S** between the first dot to the last dot made just before the mass hits the ground is measured using a metre-rule.
- The time,**t** taken to make n- spaces in distance S is calculated from: $t = nT$.
- The acceleration due to gravity, g is then calculated from $\mathbf{S = \frac{1}{2}gt^2}$

Experiment to measure acceleration due to gravity

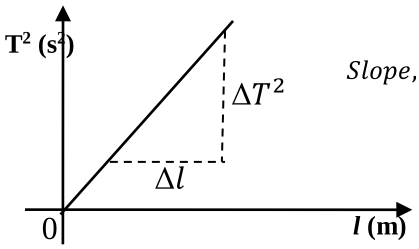


- A pendulum bob is suspended from a clamp using an inextensible string as shown in the diagram above.
- The length of the string of the pendulum bob 'l' is adjusted such that *l=0.3m*.
- The bob is the slightly displaced through a small angle and released.
- The stop clock is started and the time taken to make 20 oscillations (20T) is measured and recorded.
- The period time T for a single oscillation is calculated and recorded.
- The experiment is repeated for other increasing values of *l*, and the corresponding values of 20T, T and T^2 calculated and tabulated.

$l(m)$	20T(s)	T(s)	$T^2(s^2)$

A graph of T^2 against l is plotted. It is a straight line graph through the origin and its slope, S is calculated.

A gragh of T^2 Against ***l***



$$Slope, S = \frac{\Delta T^2}{\Delta l}$$

The acceleration due to gravity,g. is then calculated from;

$$\boldsymbol{g = \frac{4\pi^2}{S}}$$

NOTE: *Experiments have shown that the periodic time T does not depend on the mass of the bob, but it depends on the length of pendulum l bob and acceleration due to gravity g at that point. i.e:*

$$\boldsymbol{T = 2\pi\sqrt{\frac{l}{g}}}$$

Example1:
A stone falls from rest from the top of a high tower. Calculate the velocity after 2s.

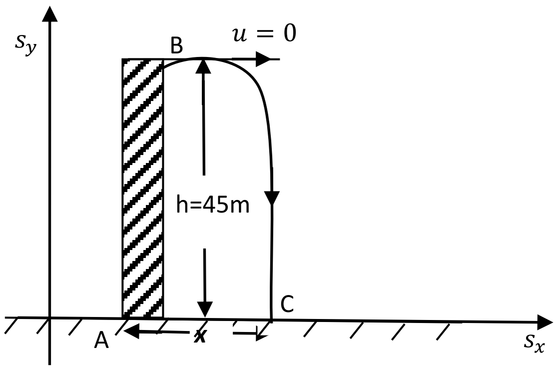
Solution

u= 0 ms^{-1} a = g =10 ms^{-2} t = 2s	Then from: $v = u + gt$ $v = 0 + (10 \times 2)$ $v = 20$ $\underline{\underline{v = 20\ ms^{-1}}}$

Example 2:
An object is dropped from a helicopter. If the object hits the ground after 2s, calculate the height from which the object was dropped.
Solution

u= 0 ms^{-1} a = g =10 ms^{-2} t = 2s Then from: $s = \quad ut + \frac{1}{2}gt^2$ $s = \quad 0(2) + \frac{1}{2}(10)(2^2)$ $s = 20$ $\underline{\underline{s = 20\ m}}$	**Alternatively** From conservation of energy $\mathrm{P.E_{Bottom}} = \mathrm{K.E_{Top}}$ $mgh = \frac{1}{2}mv^2$

Example 3:
An object is dropped from a helicopter at a height of 45m above the ground.
a) If the helicopter is at rest, how long does the object take to reach the ground and what is its velocity on arrival?
Solution
u= 0 ms^{-1}
a = g =10 ms^{-2}
t = ?
s = 45m



$s = \quad ut + \frac{1}{2}gt^2$ $45 = \quad 0(t) + \frac{1}{2}(10)(t^2)$ $45 = 5t^2$ $\underline{\underline{t = 3\ s}}$	Then from: $v = u + gt$ $v = 0 + (10 \times 3)$ $v = 30$ $\underline{\underline{v = 30\ ms^{-1}}}$

b) If the helicopter had a velocity of $1ms^{-1}$ when the object was released, what would be the final velocity of the object?

Solution

u= 1 ms^{-1} a = g =10 ms^{-2} t = ? s = 45m v = ?	$v^2 = u^2 + 2gs$ $v^2 = 1^2 + 2(10)(45)$ $v^2 = 901$ $v = \sqrt{901}$ $\underline{\underline{v = 30.02\ ms^{-1}}}$

Example 4:
An object is released from an aircraft traveling horizontally with a constant velocity of $200ms^{-1}$ at a height of 500m.
a) Ignoring air resistance, how long it takes the object to reach the ground?

Solution

For vertical motion u= 0 ms^{-1} a = g =10 ms^{-2} t = ? s = 500 m v = ?	Then from: $s = \quad ut + \frac{1}{2}gt^2$ $500 = \quad (0)t + \frac{1}{2}(10)(t^2)$ $500 = \quad 5t^2$ $100 = \quad t^2$ $\underline{\underline{t = \quad 10\ s}}$

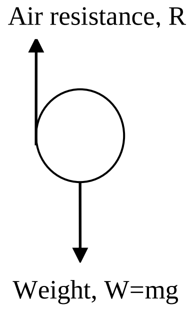
b) Find the horizontal distance covered by the object between leaving the aircraft and reaching the ground.

Solution

For vertical motion u= 200 ms^{-1} a = g = 0 ms^{-2} t = 10s s = 500 m v = ?	Then from: $x = \quad ut + \frac{1}{2}gt^2$ $x = \quad 200(10) + \frac{1}{2}(0)(10^2)$ $x = \quad 2000 + 0$ $\underline{\underline{x \ = \quad 2000\ m}}$

Note: For a body thrown vertically up ward, the time taken to reach the maximum vertical height is equal to the time taken for the body to fall from maximum height.

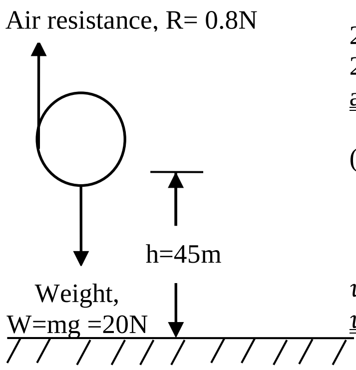
Note; If a body is not falling freely but there is air resistance R then the acceleration of the body can be calculated from:-
ma = mg – R , where m is the mass of the body



Resultant force, F
F= mg – R ……………. (i)
Then from:
F= ma …………………. (ii)
From equations (i) and (ii)
ma = mg – R

Example 4:
An object of 2kg is dropped from a helicopter at a height 45m above the ground. If the air resistance is 0.8N, calculate the:
i) acceleration of the body
ii) velocity with which the body hits the ground

Solution
For vertical motion
m = 2kg
u= 0 ms^{-1}
g =10 ms^{-2}
R = 0.8 N
s = 45m
a = ?
v = ?



(i) Then from**:**
ma = mg – R
2a = 2 (10) -0.8
2a = 19.2
$\underline{\underline{a \quad = 9.6\ ms^{-2}}}$

(ii) Then from**:**
$v^2 = u^2 + 2as$
$v^2 = 0^2 + 2(9.6)(45)$
$v^2 = 864$
$v = \sqrt{864}$
$\underline{\underline{v = 29.39\ ms^{-1}}}$

Exercise

Qn: 1. The table below shows the variation of velocity with time for a body thrown vertically upwards from the surface of a planet.

Velocity(ms^{-1})	8	6	4	2	0	-2
Time(s)	0	1	2	3	4	5

(a) What does the negative velocity mean?
(b) Plot a graph of velocity against time.
(c) Use the graph in (b) above to find the
i) Acceleration due to gravity on the planet.($= 2ms^{-2}$)
ii) Total distance travelled. .($= 17$m)
(d) If the body weighs34n on earth, what is its weight on the planet? ($= 6.8$N)

2. An aeroplane travelling at $200ms^{-1}$ at a height of 180m is about to drop an aid package of medical supplies onto an IDP camp in northern Uganda.
(a) At what horizontal distance before the target should the package be released? [x = 1200m]

(b) Find the time taken by the package to hit the target.[t=6s]

See UNEB

2000 Qn.20 1995 Qn.10 1987 Qn.12 1989 Qn.1	1992 Qn.23 1996 Qn.24 1991 Qn.2

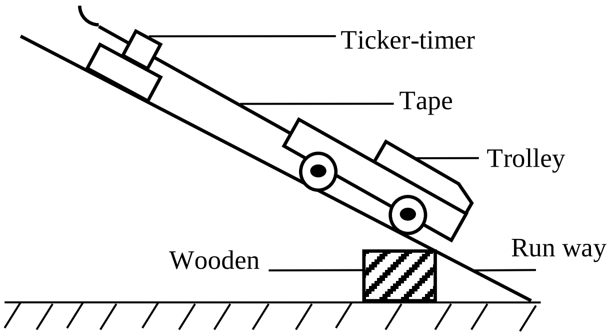
THE TICKER- TAPE TIMER

DETERMINING THE VELOCITY AND ACCELERATION OF A BODY USING A TICKER TAPE TIMER:

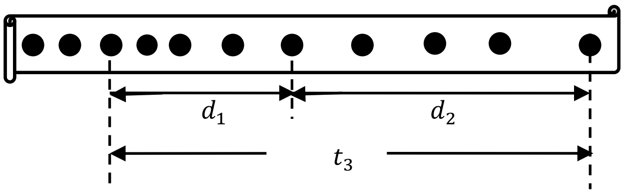
COMPENSATION FOR FRICTION

Before each experiment with a trolley, it is necessary to compensate for friction.

This can be done by tilting the runway with suitable packing pieces until it moves with uniform velocity after having been given a slight push.



- A paper tape is driven through a ticker timer connected to a mains supply of known frequency e.g 50Hz by a trolley running freely on an inclined plane.
- After the trolley has reached the end of the run way, the tape is removed and marked every after 5dots.The first mark made is the zero tme.



- The time 't' between n- spaces, is calculated from: $t = number\ of\ spaces \times Periodic\ time$
  $t = nT,$ where. $T = \frac{1}{f}$
- The speed or velocity at different times is the calculated by measuring the distances d_1 *and* d_2 covered in those times. Thus: $v_1 = \frac{d_1}{t_1}$ and $v_2 = \frac{d_2}{t_2}$
- The acceleration of the trolley is then calculated from: $acceleration, \boldsymbol{a} = \frac{v_2 - v_1}{t_3 - t_1}$: Whre $\boldsymbol{t_3} = n_3T$ is the total time taken to cover distances d_1 *and* d_2.

OR

❖ The procedures are repeated, various velocities determined and a graph of velocity against time plotted. The slope of the graph gives the acceleration of the body.

<u>Using the ticker tape timer to determine Acceleration After it has printed dots on A tape.</u>

Frequency: These are vibrations per second or number of dots per second. The S I unit is Hertz. (Hz).

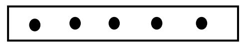
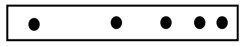
Example: A frequency of 60Hz mean 60 dots per second.

NB: Frequency is also number of dots printed per second.

Period: This is the time taken for a dot to be printed on a tape. The SI unit of period is seconds.

Period, T= $\frac{1}{\text{frequency,f}}$ $\Leftrightarrow \mathbf{T} = \frac{\mathbf{1}}{\mathbf{f}}$

Ticker tapes showing dots for bodies in motion

State of motion	Sample tape	Direction of motion
Uniform velocity		⇨ ⇦
Uniform acceleration		⇨
Uniform deceleration		⇨

Example:

Calculate the period for a frequency of 60 Hz

Frequency, f = 60Hz

Period time, T=$\frac{1}{f}$

T=$\frac{1}{60}$

T= 0.0167

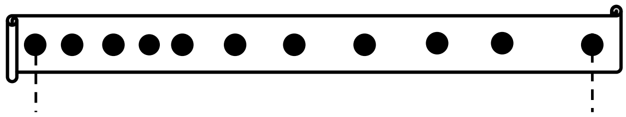
<u>**Calculating time taken from a tape**</u>

Time taken, t = number of spaces(n)×Periodic time(T)

Time taken, t = nT

Example: 1

Below is a tape printed by ticker- tape timer vibrating at 100Hz. Find the time taken to print these dots.



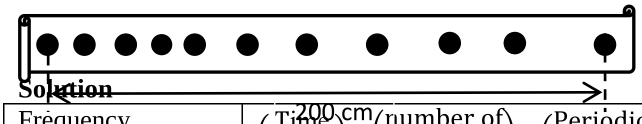
Frequency, f = 100Hz Period time,T=$\frac{1}{f}$ T=$\frac{1}{100}$ T= 0.01	$\binom{\text{Time}}{\text{taken}} = \binom{\text{number of}}{\text{spaces}} \times \binom{\text{Periodic}}{\text{time}}$ Time taken,t=nT Time taken,t=10(0.01) <u>Time taken,t=0.1s</u>

<u>**Calculating the average speed**</u>

$$\text{Average speed} = \frac{\textbf{Distance, (d)}}{\textbf{Time taken, (t)}} = \frac{d}{t}$$

Example: 2

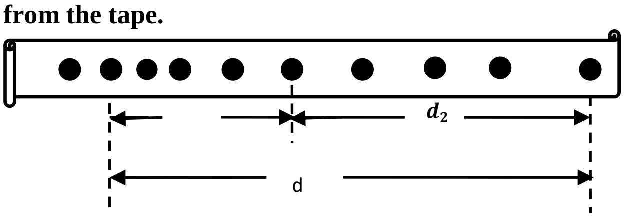
Below is a tape printed by a ticker –tape timer vibrating at 50Hz. Calculate the average speed.



Solution

Frequency, f = 50Hz Period time, $T = \frac{1}{f}$ $T = \frac{1}{50}$ $T = 0.02$	$\begin{pmatrix}\text{Time}\\ \text{taken}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{spaces}\end{pmatrix} \times \begin{pmatrix}\text{Periodic}\\ \text{time}\end{pmatrix}$ Time taken, t=nT Time taken, t=10(0.02) Time taken, t=0.2s Distance=200cm=$\frac{200}{100} = 2\text{m}$ Average speed=$\frac{\text{Distance, (d)}}{\text{Time taken, (t)}}$ Average speed=$\frac{d}{t}$ Average speed=$\frac{2}{0.2}$ Average speed=$10ms^{-1}$

Calculating the initial velocity "u" and final velocity "v" from the tape.



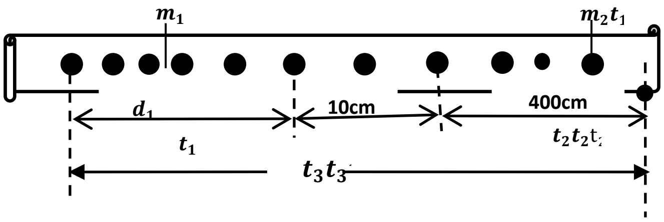
Initial velocity,u = Average speed for initial distance =initial distance "d_1" divided by time taken "t_1"

Initial speed, $u = \frac{d_1}{t_1}$; where, Time taken, $t_1 = n_1T$

Final velocity (v) = Average speed for final distance = final distance "d_1" divided by time taken "t_2"
i.e.

Final speed, $v = \frac{d_2}{t_2}$; where, Time taken, $t_2 = n_2T$

Example:3
Below is a tape printed by a timer vibrating at 50Hz



Calculate the;
i) Initial velocity
ii) Final velocity
iii) Acceleration

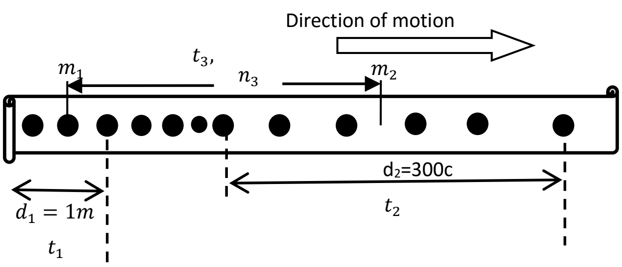
For the above, the following steps should be involved.

- ✓ identifying the frequency
- ✓ finding the periodic time from T= 1/f
- ✓ finding the time taken to cover given distances
- ✓ calculating the required velocities
- ✓ finding the time taken to cover distance between mid points of the distances
- ✓ calculating the required acceleration

Solution

Frequency, f = 50Hz Period time, $T = \frac{1}{f}$ $T = \frac{1}{50}$ $T = 0.02s$ When, d_1=200cm, $= \frac{200}{100}$ $= 2m$	(i) $\begin{pmatrix}\text{Time}\\ \text{taken}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{spaces}\end{pmatrix} \times \begin{pmatrix}\text{Periodic}\\ \text{time}\end{pmatrix}$ Time taken, $t_1 = n_1T$ Time taken, $t_1 = 5(0.02)$ Time taken, $t_1 = 0.1s$ Initial speed, $u = \frac{d_1}{t_1} = \frac{200}{0.1} = 2000cms^{-1}$ Or Initial speed, $u = \frac{d_1}{t_1} = \frac{\left(\frac{200}{100}\right)}{0.1} = 20ms^{-1}$
(ii) When, d_2=400cm, $= \frac{400}{100} = 4m$ Time taken, $t_2 = n_2T$ Time taken, $t_2 = 3(0.02)$ Time taken, $t_2 = 0.06s$ Final speed, $v = \frac{d_2}{t_2} = \frac{400}{0.06} = 6666.67cms^{-1}$ Or Final speed, $v = \frac{d_2}{t_2} = \frac{\left(\frac{400}{100}\right)}{0.06} = 66.67ms^{-1}$	
(iii) $\begin{pmatrix}\text{Time taken}\\ \text{for change}\end{pmatrix} = \begin{pmatrix}\text{number of}\\ \text{spaces}\\ \text{between mid}\\ \text{points of}\\ d_1 \text{ and } d_2\end{pmatrix} \times \begin{pmatrix}\text{Periodic}\\ \text{time}\end{pmatrix}$ Time taken, $t_3 = n_3T$ Time taken, $t_3 = 6.5(0.02)$ Time taken, $t_3 = 0.13s$	
Acceleration; Acceleration calculated applying v = u + at **Acceleration, a =** $\frac{\textbf{change in velocity}}{\textbf{Time for the change}}$ Acceleration, a = $\frac{v-u}{t_3}$ Acceleration, a = $\frac{66.67-20}{0.13}$ Acceleration, a = $359ms^{-2}$	

Example II:
Below is a tape printed by a ticker timer vibrating at 20Hz. Calculate the acceleration.

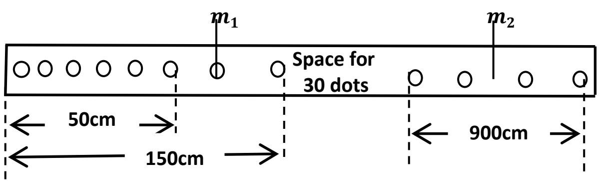


Solution

Frequency, f = 20Hz Period time, $T=\frac{1}{f}$ $T=\frac{1}{20}$ $T= 0.05\ s$ When, $d_1= 1m$ Time taken, $t_1=n_1T$ Time taken, $t_1=2(0.05)$ Time taken, $t_1=0.1s$ Initial speed, $u=\frac{d_1}{t_1}=\frac{1}{0.05}$ $=10ms^{-1}$ When, $d_2=300cm$, $=\frac{300}{100} = 3m$ Time taken, $t_2=n_2T$ Time taken, $t_2=4(0.05)$ Time taken, $t_2=0.2s$	Final speed, $v=\frac{d_2}{t_2}=\frac{3}{0.2}$ $=15ms^{-1}$ Time taken, $t_3= n_3T$ Time taken, $t_3= 7.5(0.05)$ Time taken, $t_3= 0.375s$ **Acceleration;** Acceleration calculated Applying: v = u + at $a = \frac{\textbf{change in velocity}}{\textbf{Time for the change}}$ Acceleration, $a = \frac{v-u}{t_3}$ Acceleration, $a = \frac{15-10}{0.375}$ Acceleration, $a = 13.33ms^{-2}$

Example III

The timer is vibrating at 20Hz. Calculate the acceleration



Solution

Frequency, f = 20Hz Period time, $T=\frac{1}{f}$ $T=\frac{1}{20}$ $T= 0.05s$ $d_1 = 150cm - 50cm$ $d_1 = 100cm$ $d_1 = \frac{100}{100} = 1m$ $t_1 = n_1T$ $t_1 = 2(0.05)$ $t_1 = 0.1s$ $u = \frac{d_1}{t_1}$ $u = \frac{1}{0.1}$ $u = 10ms^{-1}$ $d_2 = 900cm$ $d_2 = \frac{900}{100}$ $d_2 = 9m$	$t_2 = n_2T$ $t_2 = 3(0.05)$ $t_2 = 0.15s$ $v = \frac{d_2}{t_2}$ $v = \frac{9}{0.15}$ $v = 60ms^{-1}$ Time taken, $t_3=n_3T$ Time taken, $t_3=31.5(0.05)$ Time taken, $t_3=1.575s$ **Acceleration;** Acceleration calculated applying v = u + at **Acceleration, a** = $\frac{\textbf{change in velocity}}{\textbf{Time for the change}}$ Acceleration, $a = \frac{v-u}{t_3}$ Acceleration, $a = \frac{60-10}{1.575}$ Acceleration, $a =31.75\ ms^{-2}$

NOTE:

If there are n-dots, then there are (n-1) spaces.

i.e: $\boldsymbol{n_s = (n_d - 1)}$.

Where $\mathbf{n_s}$ is the number of spaces and $\mathbf{n_d}$ is the number of dots.

Example:

A ticker timer is vibrating at 10Hz. Calculate the time taken if the timer prints 21 dots.

Solution

Number of dots, $n_d=21$ dots Number of spaces, $\boldsymbol{n_s = (n_d - 1)}$. Number of spaces, $\boldsymbol{n_s = (21 - 1)}$. Number of spaces, $\boldsymbol{n_s = 20}$ spaces Frequency, f = 10Hz Period time, $T=\frac{1}{f}=\frac{1}{10}=0.1s$ $\begin{pmatrix}\text{Time}\\ \text{taken}\end{pmatrix}=\begin{pmatrix}\text{Number of}\\ \text{spaces}\end{pmatrix}\times\begin{pmatrix}\text{Period}\\ \text{time}\end{pmatrix}$	$t = nT$ $t = 20(0.1)$ $t = 2s$

Example:

A ticker timer prints 11 dots at 20Hz in a space of 2m. Calculate the average speed.

Solution

Number of dots, $n_d=11$ dots Number of spaces, $\boldsymbol{n_s = (n_d - 1)}$. Number of spaces, $\boldsymbol{n_s = (11 - 1)}$. Number of spaces, $\boldsymbol{n_s = 10}$ spaces Frequency, f = 20Hz Period time, $T=\frac{1}{f}=\frac{1}{20}=0.05s$ $\begin{pmatrix}\text{Time}\\ \text{taken}\end{pmatrix}=\begin{pmatrix}\text{Number of}\\ \text{spaces}\end{pmatrix}\times\begin{pmatrix}\text{Period}\\ \text{time}\end{pmatrix}$	$t = n_sT$ $t = 10(0.05)$ $t = 0.5s$ Average speed, $v = \frac{\text{Distance}}{\text{Time taken}}$ $v = \frac{2}{0.5}$ $v = 4ms^{-1}$

Note:

In experiments with ticker timer being pushed by a trolley, the first dots are ignored because they are overcrowded for accurate measurements.

Calculating Acceleration from given number of dots.

If the distance is measured from $\mathbf{m^{th}}$ dot to $\mathbf{n^{th}}$ dot then the number of spaces can be calculated directly by subtracting m from n.

Number of spaces, $\boldsymbol{n_s = (n^{th} dot - m^{th} dot)}$.

Time taken, **t** = Number of spaces, $\boldsymbol{n_s}$×Period time, **T**

Period time, $\mathbf{T}=\frac{1}{\text{frequency, } \mathbf{f}}$

Example:

The distance between 15th dot and 18th dot is 10cm. if the ticker timer is vibrating at 20Hz. Calculate the;

i) time taken

Number of spaces, $n_s = (n^{th} dot - m^{th} dot)$

Number of spaces, $n_s = (18 - 15)$

Number of spaces, n_s = 3 spaces

Frequency, f = 20Hz

Period time, $T = \frac{1}{f}$

$T = \frac{1}{20}$

T= 0.05s

Time taken, **t**=Number of spaces, $\boldsymbol{n_s}$×Period time, **T**
Time taken, **t**=3(0.05)
t=0.15s

ii) average speed

Distance covered = 10cm = 0.1m

$$\text{Average speed, v} = \frac{\text{Distance}}{\text{Time taken}}$$

$$v = \frac{0.1}{0.15}$$

$$v = 0.67ms^{-1}$$

Example:
A trolley is pulled from rest with a constant force down an inclined plane. The trolley pulls a tape through a ticker timer vibrating at 50Hz. The following measurements were made from the tap.
Distance between 16th dot and 20th dot= $\mathbf{d_1}$=20cm
Distance between 20th dot and 30th dot = 34cm
Distance Q between 30th dots and 40th dot = 48cm
Distance between 40th dot and 50th dot = $\mathbf{d_2}$=62cm

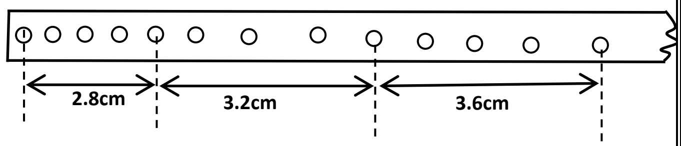
Calculate the acceleration of the trolley.

Solution

$\begin{pmatrix}\text{Number of}\\ \text{spaces}, n_s\end{pmatrix}$ $= (n^{th}\text{dot} - m^{th}\text{dot})$ $= (20 - 16)$ $= 4$ spaces Number of spaces, n_s = 4 spaces Frequency, f = 50Hz Period time, $T = \frac{1}{f}$ $T = \frac{1}{50}$ T=0.02s $d_1 = 20cm$ $d_1 = \frac{20}{100}$ $d_1 = 0.2m$ $t_1 = n_1T$ $t_1 = 4(0.02)$ $t_1 = 0.08s$	$t_2 = n_2T$ $t_2 = 10(0.02)$ $t_2 = 0.2s$ $v = \frac{d_2}{t_2}$ $v = \frac{0.62}{0.2}$ $v = 3.1ms^{-1}$ For $\mathbf{d_1}$ last dot is 20th For $\mathbf{d_2}$ last dot is 50th $\begin{pmatrix}\text{Time taken}\\ \text{for change}; t_3\end{pmatrix} = (50^{th} - 20^{th}) \times 0.02$ $\begin{pmatrix}\text{Time taken}\\ \text{for change}; t_3\end{pmatrix} = 30 \times 0.02$ $t_3 = 0.6s$ **Acceleration;** Acceleration calculated applying v = u + at **Acceleration, a =** $\frac{\textbf{change in velocity}}{\textbf{Time for the change}}$
$u = \frac{d_1}{t_1}$ $u = \frac{0.2}{0.08}$ $u = 2.5ms^{-1}$ $d_2 = 62cm$ $d_2 = \frac{62}{100}$ $d_2 = 0.62m$	Acceleration, a = $\frac{\boldsymbol{v-u}}{\boldsymbol{t_3}}$ Acceleration, a = $\frac{\mathbf{3.1-2.5}}{\mathbf{0.6}}$ Acceleration, a =$1.0\ ms^{-2}$

Exercise
1. A paper tape dragged through a ticker timer by a trolley has the first ten dots covering a distance of 4cm and the next ten dots covering a distance of 7cm. If the frequency of the ticker timer is 50Hz, calculate the acceleration of the trolley.(Ans:**=75cms^{-2}** or **0.75ms^{-2}**)

2. The ticker timer below was pulled by a decelerating trolley. The tape consists of 3 five dot spaces and the frequency of the timer is 50Hz.



Exercise: See UNEB

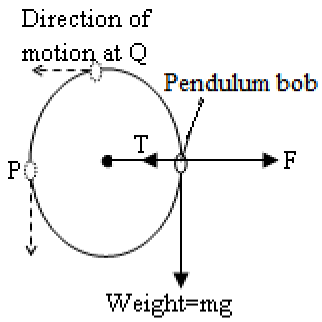
2003.Qn.26 1998.Qn.1(b)	2001.Qn.25 2006.Qn.9

1: 11. CIRCULAR MOTION

Circular motion is motion in which a body moves in a circle about a fixed point.

For a body moving in a circle;
- ✓ Its direction and velocity are constantly changing.
- ✓ It has an acceleration called centripetal acceleration.

- ✓ It has a force called Centripetal force acting towards the centre of the circular path.



T=Tension in the string which produces the centripetal force

Note: When the object is released, it moves such that the direction of motion at any point is along a tangent to the circular path.

Forces acting on the body describing circular motion.

(i) **Tension:** Force acting towards the centre of the circular path. It provides the centripetal force.

(ii) **Centripetal force**: Force acting towards the centre of the circular path.

(iii) **Centrifugal force**: Force acting away from the centre of the circular path.

(iv) **Weight:** Force acting vertically down wards towards the centre of the earth.

Examples of circular motion

-Pendulum bob tied to a string whirled in a vertical or horizontal plane

-Planetary motion etc

Exercise: See UNEB

1999 Paper II Qn.1	

1: 12. NEWTON'S LAWS OF MOTION

These are three laws that summarize the behavior of particles in motion.

1:12:1. Newton's First Law of motion

Newton's first law of motion states that a body continues in its state of rest or uniform motion in a straight line unless acted upon by an external force.

Inertia

Inertia is the reluctance of a body to move, when at rest or to stop when moving.

Thus, when a force acts on a body, the body;

- ✓ Starts or stops moving.
- ✓ Increases or reduces speed depending on the direction of the force.
- ✓ Changes direction of motion.

1:12:2. Newton's second law of motion

Newton's second law states that the rate of change in momentum is directly proportional to the force acting on the body and takes place in the direction of the force.

$$F \,\alpha\, \frac{mv - mu}{t} \Leftrightarrow F \,\alpha\, m\left(\frac{v-u}{t}\right) \Leftrightarrow F \,\alpha\, ma \Leftrightarrow F = k\,ma$$

When we consider a force of 1N, mass of 1kg and acceleration of $1ms^{-2}$, then, **k=1**.Therefore;

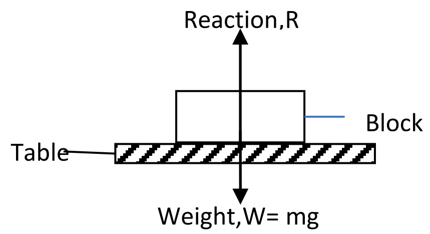
$$\mathbf{F = ma}$$

A newton; Is the force which acts on a mass of 1kg to produce an acceleration of $1ms^{-2}$.

1:12:3. Newton's third law of motion

It states that action and reaction are equal but opposite.

When a body, A exerts a force on body B, body B also exerts an equal force in the opposite direction.



The block exerts a weight, W= mg on the table and the table also exerts an equal reaction R on the block. R= mg, so that the net force on the block is zero and therefore there is no vertical motion.

Applications of Newton's third law of motion

(a) Rockets and jets

Rockets and jet engines are designed to burn fuel in oxygen to produce large amounts of exhaust gases.

These gases are passed backwards through the exhaust pipes at high velocity (large momentum).

This in turn gives the Rocket or jet a high forward momentum which is equal but opposite to that of the exhaust gases.

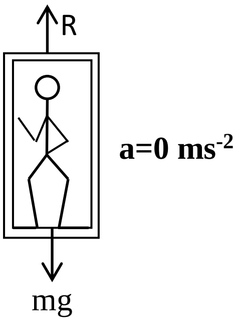
$$\boldsymbol{m_g v_g = -m_R v_R}$$

Where $m_g v_g$ is the momentum of the exhaust gases, and $m_R v_R$ is momentum of the Rocket.

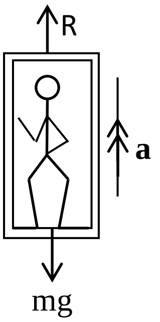
(b) Motion in the lift

Consider a person of mass m standing in a lift, when the;

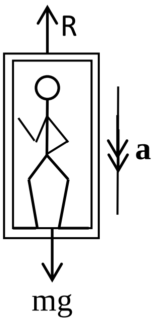
i) Lift is stationary or moving with uniform velocity

	The person exerts a weight, mg on the lift and at the same time, the lift exerts a reaction, R, on the person. **R= mg**.

ii) Lift is moving upwards with acceleration, a.

	In this case, three forces act on the lift. i.e, the resultant accelerating force (**ma**), the weight, **(mg)** and the normal reaction or Apparent weight (**R**). **Accelerating force = Net force** ma = R – mg R = mg + ma **R = m (g+a)**
Thus, the reaction on the person (apparent weight, R) is greater than the actual weight of the person, mg. This is why one feels **heavier** when the lift is just beginning its upward journey.	

iii) Lift is moving down wards with acceleration, a.

	In this case, the resultant accelerating force (**ma**), and the weight, **(mg)** act down wards. The normal reaction or Apparent weight (**R**) act upwards. **Accelerating force = Net force** ma = mg - R R = mg - ma **R = m (g - a)**
Thus, the reaction on the person (apparent weight, R) is less than the actual weight of the person, mg. This is why one feels **lighter** when the lift is just beginning its downward journey.	

Example:1

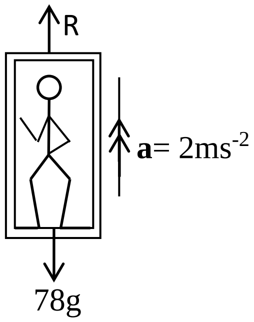
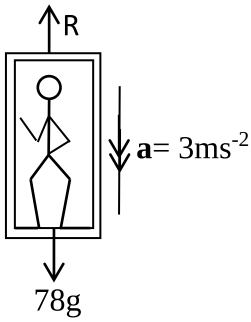
A person of mass 78kg is standing inside an electric lift. What is the apparent weight of the person if the;

d) Lift is moving upwards with an acceleration of $2ms^{-2}$?

e) Lift is descending with an acceleration of $2ms^{-2}$?

Solution

(a)

	m = 78kg $a = 2ms^{-2}$ R=? R = mg + ma **R = m (g+a)** R = 78 (10+2) R = 936N
(b) 	m = 78kg $a = 3ms^{-2}$ R=? R = mg - ma R = 78(10 - 3) R = 546N

1: 12: 4. COLLISIONS AND MOMENTUM

Linear Momentum:

Momentum is the product of mass and its velocity.

$$\left(\begin{array}{c}\textbf{Linear Momentum}\\ \textbf{of a body}\end{array}\right) = \left(\begin{array}{c}\textbf{Mass of}\\ \textbf{the body}\end{array}\right) \times \textbf{Velocity}$$

Impulse:

Impulse is the change in the momentum of a body.

$$\mathbf{Impulse = mv - mu}$$

Impulse can also be defined as the product of force and time of impact.

From Newton's second law of motion,

$$F = \frac{mv - mu}{t} \Leftrightarrow Ft = mv - mu$$

$$\mathbf{Impulse = Ft = mv - mu}$$

The S.I unit of momentum and impulse is $\mathbf{Kgms^{-1}}$

Note: Momentum and impulse are vector quantities.

Principle of conservation of momentum

It states that when two or more bodies collide, the total momentum remains constant provided no external force is acting.

It states that when two or more bodies collide, the total momentum before collision is equal to the total momentum after collision.

Suppose a body of mass m_1 moving with velocity u_1 collides with another body of mass m_2 moving with velocity u_2. After collision, the bodies move with velocities v_1 and v_2 respectively, then;

$$\boldsymbol{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

Types of collisions

✓ Elastic collision

Elastic collision is the type of collision whereby the colliding bodies separate immediately after the impact with each other and move with different velocities.

In short, for elastic collision,

$$\begin{pmatrix}\textbf{Total momentum}\\ \textbf{before collision}\end{pmatrix} = \begin{pmatrix}\textbf{Total momentum}\\ \textbf{after collision}\end{pmatrix}$$

$$\mathbf{m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2}$$

✓ Inelastic collision

Inelastic collision is when the colliding bodies stay together and move with the same velocity after collision.

In short, for inelastic collision,

$$\begin{pmatrix}\textbf{Total momentum}\\ \textbf{before collision}\end{pmatrix} = \begin{pmatrix}\textbf{Total momentum}\\ \textbf{after collision}\end{pmatrix}$$

$$\mathbf{m_1\,u_1 + m_2u_2 = (m_1 + m_2)V}$$

Comparisons between Elastic collision and Inelastic collision

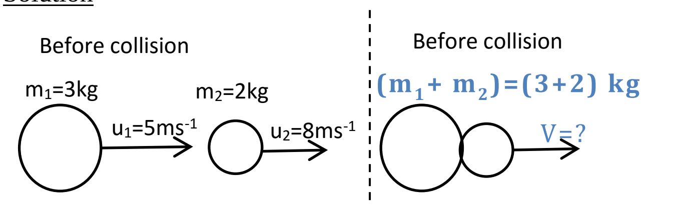
Elastic collision	**Inelastic collision**
(i) Bodies separate after collision	Bodies stick together after collision.
(ii) Bodies move with different velocities after collision	Bodies move with same velocity after collision
(iii) Kinetic energy of the bodies is conserved	Kinetic energy of the bodies is not conserved
Momentum is conserved **Total momentum before collision= Total momentum after collision** $\mathbf{m_1u_1+m_2u_2=m_1v_1+m_2v_2}$	Momentum is conserved **Total momentum before collision= Total momentum after collision** $\mathbf{m_1u_1+m_2u_2=(m_1+m_2)}\boldsymbol{V}$

NOTE; For any stationary body or body at rest, the initial velocity is zero so the initial momentum of such a body before collision is zero.

Example:1

A body of mass 3kg traveling at $5ms^{-1}$ collides with a 2kg body moving at $8ms^{-1}$ in the same direction. If after collision the two bodies moved together, Calculate the velocity with which the two bodies move after collision.

Solution

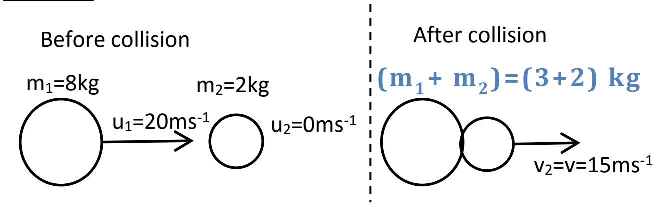


m_1= 3kg, m_2= 2kg $u_1=5ms^{-1}$, $u_2=8ms^{-1}$ v_1=V=?, v_2=V=?	$m_1u_1+m_2u_2=(m_1+m_2)V$ $3(5)+2(8)=(3+2)V$ $15+16=5V$ $31=5V$ $\frac{31}{5}=\frac{5V}{5}$
$\begin{pmatrix}\text{Total momentum}\\ \text{before collision}\end{pmatrix} = \begin{pmatrix}\text{Total momentum}\\ \text{before collision}\end{pmatrix}$	$6.2 = V$ $\underline{\underline{V= 6.2\ ms^{-1}}}$

Example: 2

A body of mass 8kg traveling at 20 ms^{-1} collides with a stationary body and they both move with velocity of $15ms^{-1}$. Calculate the mass of the stationary body.

Solution

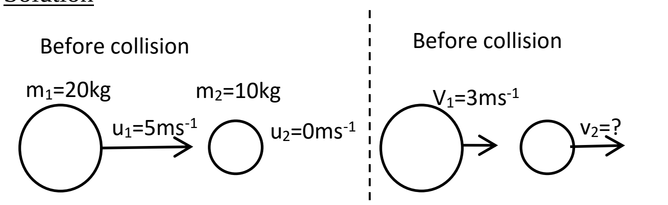


m_1= 8kg, m_2= 2kg $u_1=20ms^{-1}$, $u_2=8ms^{-1}$ $v_1=V=1\ ms^{-1}$, $v_2=V=15\ ms^{-1}$ $\begin{pmatrix}\text{Total momentum}\\ \text{before collision}\end{pmatrix} = \begin{pmatrix}\text{Total momentum}\\ \text{before collision}\end{pmatrix}$	$m_1u_1+m_2u_2=(m_1+m_2)V$ $8(20)+m_2(0)=(8+m_2)(15)$ $160+0=8(15)+15m_2$ $40=15m_2$ $2.67=m_2$ $\underline{\underline{m_2 = 2.67kg}}$

Example: 3

A body of mass 20kg traveling at $5ms^{-1}$ collides with another stationary body of mass 10kg and they move separately in the same direction. If the velocity of the 20kg mass after collision was $3ms^{-1}$. Calculate the velocity with which the 10kg mass moves.

Solution



m_1= 20kg, m_2= 10kg $u_1=5ms^{-1}$, $u_2=0ms^{-1}$ $v_1=3ms^{-1}$ v_2=? $\begin{pmatrix}\text{Total momentum}\\ \text{before collision}\end{pmatrix} = \begin{pmatrix}\text{Total momentum}\\ \text{before collision}\end{pmatrix}$	$m_1u_1+m_2u_2=m_1v_1+m_2v_2$ $20(5)+10(0)=20(3)+10(v_2)$ $100+0=60+10v_2$ $100-60=10v_2$ $\frac{40}{10}=\frac{10v_2}{10}$ $4=v_2$ $\mathbf{v_2= 4ms^{-1}}$

Exercise:

1. A particle of mass 200g moving at $30ms^{-1}$ hits a stationary particle of mass100g so that they stick and move together after impact. Calculate the velocity with which they move after collision.**(Ans:V= 20ms⁻¹)**

2. A military tanker of mass 4tonnes moving at $12ms^{-1}$ collides head on with another of mass 3tonnes moving at $2oms^{-1}$. After collision, they stick together and move as one body. Ignoring the effect of friction, find their common velocity.

(Ans: V=1.7ms^{-1}in the direction of the 2nd tank)

3. A body of mass 10kg moving at 20ms^{-1} hits another body of mass 5kg moving in the same direction at 10ms^{-1}. After collision, the second body moves separately forward with a velocity of 30ms^{-1}. Calculate the velocity of the first body after collision. **.(Ans:v$_1$=10ms^{-1})**

4. A car X of mass 1000kg travelling at a speed of 20 ms-I in the direction due east collides head-on with another car Y of mass1500kg, travelling at 15ms-1 in the direction due west. If the two cars stick together, find their common velocity after collision.

EXPLOSIONS

Momentum is conserved in explosions such as when a riffle is fired. During the firing, the bullet receives an equal but opposite amount of momentum to that of the rifle.

Total momentum before collision = Total momentum after collision

$$m_g u_g + m_b u_b = m_g v_g + m_b v_b$$
$$m_g(0) + m_b(0) = m_g v_g + m_b v_b$$
$$0 = m_g v_g + m_b v_b$$
$$\mathbf{m_g v_g = -m_b v_b}$$

Where; m_g is mass of the rifle (or gun), V_g is velocity of the rifle which is also called recoil velocity. m_b is mass of the bullet, V_b is velocity of the bullet.

For any explosion of bodies, the amount of momentum for one body is equal but opposite to that of another body.

The negative sign indicates that the momenta are in opposite directions.

Example:1

A bullet of mass 8g is fired from a gun of mass 500g. If the missile velocity of the bullet is 500ms^{-1}. Calculate the recoil velocity of the gun.

Solution

m_b= 8g = $\frac{8}{1000} = 0.008kg$, m_g = 500g = $\frac{500}{1000} = 0.5$kg

v_b= 500ms^{-1}, v_g = ?

From, $m_g v_g = -m_b v_b$

$0.5V_g = -0.008(500)$

$0.5V_g = -4$

$$\frac{0.5V_g}{0.5} = \frac{-4}{0.5}$$

$$\mathbf{V_g = -8ms^{-1}}$$

The negative sign indicates that the recoil velocity, V_g is in opposite direction to that of the bullet.

Example:2

A bullet of mass 200g is fired from a gun of mass 4kg. If the muzzle velocity of the bullet is 400ms^{-1}, calculate the recoil velocity.

Solution

m_b= 200g = $\frac{200}{1000} = 0.2$kg, $m_g = 4$kg

v_b= 400ms^{-1}, v_g = ?

From, $m_g v_g = -m_b v_b$

$4V_g = -0.2(400)$

$4V_g = -80$

$$\frac{4V_g}{4} = \frac{-80}{4}$$

$$\mathbf{V_g = -20ms^{-1}}$$

Example: 3

A bullet of mass 12.0g travelling at 150ms^{-1}penetrates deeply into a fixed soft wood and is brought to rest in 0.015s. Calculate

(i) How deep the bullet penetrates the wood [**1.125m]**

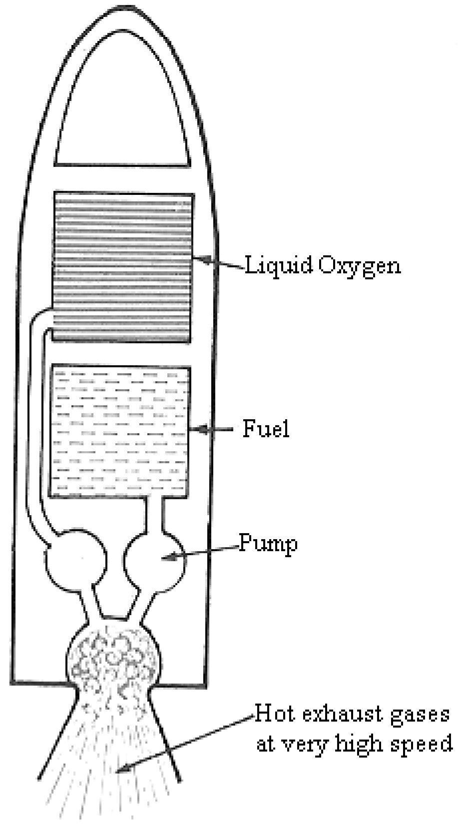
(ii) the average retarding force exerted by the wood on the bullet. [**120N**]

ROCKET AND JET ENGINES

These work on the principle that in any explosion one body moves with a momentum which is equal and opposite to that of another body in the explosion. For the rocket and the jet engine, the high velocity hot gas is produced by the burning of fuel in the engine.

Note: Rockets use liquid oxygen while jets use oxygen from air.

How a rocket engine work:



Principle: the jet and rocket engines work on the principle that momentum is conserved in explosion.

High velocity: the high velocity of the hot gas results in the burning of the fuel in the engine.

Large momentum: the large velocity of the hot gas results in the gas to leave the exhaust pipe with a large momentum.

Engine: the engine itself acquires an equal but opposite momentum to that of the hot gas.

Note: when the two bodies collide and they move separately after collision but in opposite directions then.

$m_1u_1+m_2u_2 = m_1v_1+m_2(-v_2)$

$m_1u_1+m_2u_2 = m_1v_1 - m_2v_2$

Example:

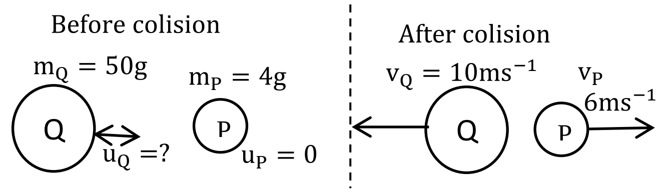
A body Q of mass 50g collides with a stationary body "P" of mass 4g. If a body "Q" moves backward with a velocity of $10ms^{-1}$ and a body "P", moves forward with a velocity of $6ms^{-1}$. Calculate the initial velocity of a body Q.

Solution

$m_Q = 50g, = \frac{50}{1000} = 0.05kg$ $\quad m_P = 4g = \frac{4}{1000} = 0.004kg$

$u_Q = ?$, $\quad u_P = 0ms^{-1}$

$v_Q = 10\ ms^{-1}, \leftarrow$ $\quad v_P = 6ms^{-1} \rightarrow$



Total momentum before collision = Total momentum after collision

$$m_Qu_Q + m_Pu_P = m_Qv_Q + m_pv_P$$

$$0.05u_Q + 0.004(0) = 0.05(-10)+0.004(6)$$

$$0.05u_Q = -0.5+0.024$$

$$0.05u_Q = -0.476$$

$$\frac{0.05u_Q}{0.05} = \frac{-0.476}{0.05}$$

$$\mathbf{u_Q = -9.52ms^{-1}}$$

Thus, the initial velocity of Q is $9.52ms^{-1}$ to the left

Example: 2

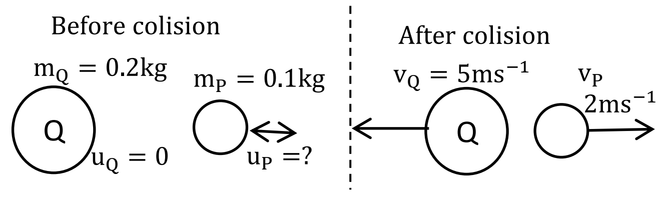
A moving ball "P" of mass 100g collides with a stationary ball Q of mass 200g. After collision, P moves backward with a velocity of $2ms^{-1}$ while Q moves forward with a velocity of $5ms^{-1}$. Calculate the initial velocity of P.

Solution

$m_Q = 200g, = \frac{200}{1000} = 0.2kg$ $\quad m_P = 100g = \frac{100}{1000} = 0.1kg$

$u_Q = 0$, $\quad u_P = ?$

$v_Q = 5\ ms^{-1}, \leftarrow$ $\quad v_P = 2ms^{-1} \rightarrow$



Total momentum before collision = Total momentum after collision

$$m_Qu_Q+m_Pu_P = m_Qv_Q+m_pv_P$$

$$0.2(0) + 0.1u_P = 0.2(5)+0.1(-2)$$

$$0.1u_P = 1 + -0.2$$

$$0.1u_Q = -0.8$$

$$\frac{0.1u_Q}{0.1} = \frac{-0.8}{0.1}$$

$$\boldsymbol{u_P = -8ms^{-1}}$$

Thus, the initial velocity of Q is $8ms^{-1}$ towards Q.

Example: 3.

A body of mass 10kg moves with a velocity of $20ms^{-1}$.Calculate its momentum.

Solution

m=10kg; $v=20ms^{-1}$

Linear Momentum = Mass × Velocity

= 10 × 20

= $200kgm^{-1}$

Initial Momentum = Mass × Initial Velocity

= mu

Final Momentum = Mass × Final Velocity

= mv

Example:2

A 20kg mass traveling at 5mls is accelerated to 8mls. Calculate the change in momentum of the body.

Solution

m=10kg $u=5ms^{-1}$ $v=8ms^{-1}$	
Initial Momentum = mu = 20×5 = $100kgms^{-1}$	Final Momentum = mv = 20×8 = $160kgms^{-1}$
Change in Momentum = mv - mu = 160 - 100 = $60kgms^{-1}$	

Note: The change in momentum is called Impulse.

Example:3

A one tonne car traveling at $20ms^{-1}$ is accelerated at $2ms^{-2}$ for five second. Calculate the;

(i) change in momentum

(ii) rate of change in momentum

(iii) Accelerating force acting on the body.

Solution

m=1tonne =1000kg $u=20ms^{-1}$ v= ? $a=2ms^{-2}$ t= 5s (i) change in momentum Change in Momentum = mv - mu $= m(v-u)$ But ; $v = u + at$ $v = 20 + 2(5)$ $v = 30ms^{-1}$ Change in Momentum	(ii) Rate of change in momentum Rate of change in momentum $= \frac{\text{Change in mometum}}{\text{Time taken}}$ $= \frac{m(v-u)}{t}$ $= \frac{1000(30-20)}{5}$ $= \frac{10000}{5}$

= mv - mu $= m(v-u)$ $= 1000(30-20)$ $= 1000(10)$ $= 10{,}000\text{kgms}^{-1}$	=2000 N

NOTE: The S.I unit for the rate of change in momentum is a newton.

(iv) Accelerating force acting on the body.

Accelerating force, F = Rate of change in momentum

$$= \frac{m(v-u)}{t}$$

$$= \frac{1000(30-20)}{5}$$

$$F = 2000\text{N}$$

From above, the force applied is equal to the rate of change in momentum. This leads to Newton's second law of motion.

Exercise

1. A body of mass 600g traveling at 10mls is accelerated uniformly at 2 ms^{-2} for four seconds. Calculate the;
   (i) change in momentum
   (ii) force acing on a body

Solution

(i) mass, $m = 600\text{g}$ $= \frac{600}{1000}$ $= 0.6\text{kg}$ $u=10\text{ms}^{-1}$ v=? $a=2\ \text{ms}^{-2}$ t = 4s From; $v = u + at$ $v = 10 + 2(4)$ $v = 18ms^{-1}$ Change in Momentum = mv - mu $= m(v-u)$ $= 0.6(18-10)$ $= 0.6(8)$ $= 4.8kgms^{-1}$	(ii) Rate of change in momentum $= \frac{m(v-u)}{t}$ $= \frac{0.6(18-10)}{4}$ $= \frac{4.8}{4}$ =1.2 N (iii) Force acting on the body But ; $v = u + at$ But ; $18 = 10 + 4t$ But ; $a = 2\text{ms}^{-1}$ **F = ma** = 0.6(2) F =1.2 N Thus, Force acting on the body is equal to the rate of change in momentum.

Example:4

A van of mass 1.5 tonnes travelling at 20ms^{-1}, hits a wall and is brought to rest as a result in 0.5seconds. Calculate the;

(i) Impulse

(ii) Average force exerted on the wall.

Solution

m=1.5tonnes =1.5x1000 = 1500 $u=20\text{ms}^{-1}$ $v=0\text{ms}^{-1}$ t=0.5s	(i)Impulse: Impulse = Change in Momentum = mv - mu $= m(v-u)$ $= 1500(0-20)$ $= 1500(-20)$ $= -30{,}000kgms^{-1}$
The Negative sign means that the direction of the impulse is opposite to that in which the van was moving.	
. (ii)Average force exerted on the wall: From;Impuse = Force × Time = Ft $-30000 = F \times 0.5$ $F = -60{,}000\text{N}$	

Example:5

A man of mass 60kg jumps from a high wall and lands on a hard floor at a velocity of 6ms.Calculate the force exerted on the man's legs if;

(i) He bends his knees on landing so that it takes 1.2s for his motion to be stopped.

(ii) He does not bend his knees and it takes 0.06s to stop his motion.

Solution

(i) m=60kg $u=6\text{ms}^{-1}$ $v=0\text{ms}^{-1}$ t=1.2s Force acting on the body But ; $v = u + at$ But ; $0 = 6 + 1.2a$ But ; $a = -5\text{ms}^{-1}$ **F = ma** = 60(-5) F =-300 N	(ii) m= 60kg $u=6\text{ms}^{-1}$ $v=0\text{ms}^{-1}$ t=0.06s Force acting on the body But ; $v = u + at$ But ; $0 = 6 + 0.06a$ But ; $a = -100\text{ms}^{-1}$ **F = ma** = 60(-100) F =-6000 N
Note: ❖ The negative signs means the force acts to oppose that exerted by the man. ❖ Landing in (ii) exerts a larger force on the knees, which can cause injury compared to that in (ii).	

Exercise :

1. An athlete of 80 kg moving at 5ms^{-1}, slides trough a distance of 10m before stopping in 4 seconds. Find the work done by friction on the athlete.

2. A car of mass 1500kg starts from rest and attains a velocity of 100ms^{-1}in 20 seconds. Find the power developed by the engine.
   A. 750kW B. 3,000kW
   C. 30, 000kW D. 750, 000kW

3. A ball of 3kg moves at 10ms^{-1} towards a volley ball player. If the player hits the ball and the ball moves

back with a velocity of 5ms^{-1}. Find the change in momentum.

A. $\frac{5\times3}{10}$ B. $\frac{10\times3}{5}$
C. $3(10-5)$ D. $3(10+5)$

6. A rubber bullet of mass 100g is fired from a gun of mass 5 kg at a speed of 200 ms^{-1}. Find the recoil velocity of the rifle.

A. $\frac{5\times200}{100\times1000}$ B. $\frac{5\times1000}{100\times200}$
C. $\frac{100\times200}{5\times1000}$ D. $\frac{200\times1000}{5\times100}$

4. See UNEB

2001. Qn.1 1988. Qn.9 and Qn.20 1994. Qn.5 and Qn. 3 1995. Qn.8	2006. Qn.32 2007. Qn.24 1992. Qn.2 2003. Qn.2

much kinetic and potential energy the molecules of a body have.
Once heat has been transferred to a body, it becomes internal molecular energy.

Temperature is the degree of hotness or coldness of a body. The S.I unit of temperature is a kelvin (K).

(a) THERMOMETERY

A thermometer is an instrument which is used for measuring temperature on the basis of certain physical properties which change with changes in temperature.
These properties are called thermometric properties

Thermometric properties

A thermometric property is a property of a substance which continuously change with temperature and may be used for temperature measurements, these include:
-Increase in length.
-Change in potential difference
-Change in volume
-Change in pressure.

Thermometer scales.

There are 3 thermometer scales commonly used
(i) Celsius / centigrade scale (^{0}C)
(ii) Fahrenheit scale (^{0}F)
(iii) Kelvin scale/ absolute (k)

Relation between Celsius and Fahrenheit

$$\mathrm{F} = \frac{9}{5}(\mathrm{C}+32)$$

And if Celsius scale reads 1000c then

$$\mathrm{F} = \frac{9}{5}(100+32) = 212^0\mathrm{F}$$

Converting from Fahrenheit to Celsius.

$$\mathrm{C} = \frac{5}{9}(\mathrm{F}-32)$$

Relationship between Celsius scale and Kelvin scale.
$\mathbf{K} = 273 + {}^0\mathbf{C}$
Where C is temperature in Celsius scale and K is temperature in Kelvin scale.

Example:

Convert 0^{0}C to Kelvin scale $\mathrm{K} = 273+{}^0\mathrm{C}$ $\mathrm{K} = 273+0$ $\mathrm{K} = 273\mathrm{K}$	Convert 100^{0}C to Kelvin scale (Absolute scale) $\mathrm{K} = 273+{}^0\mathrm{C}$ $\mathrm{K} = 273+100$ $\mathrm{K} = 373\mathrm{K}$

To obtain a standard scale on a thermometer. Two fixed points must be marked out on it. The upper and lower fixed points.

2. HEAT AND THERMAL PROPERTIES OF MATTER

2. HEAT

Heat is a form of energy, which results from the random movement of molecules of a body. It is a measure of how

a) Lower fixed point:

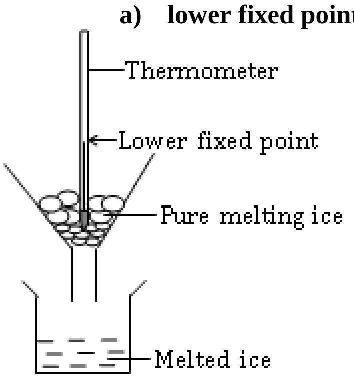
This is the temperature of pure melting ice at standard atmospheric pressure; 76cmHg or 760mm Hg
-On Fahrenheit scale = 32^{0}F

-On Celsius scale = 0^0C
-On Kelvin scale = 237K

The expansion of liquids when the temperature rises is applied in thermometers.
A thermometer has two reference temperatures called fixed point. These are lower fixed point and upper fixed point.
The upper fixed point is the temperature at which pure water boils under normal atmospheric pressure.
The lower fixed point is the temperature at which pure water freezes under normal atmospheric pressure.

Marking upper and lower fixed points

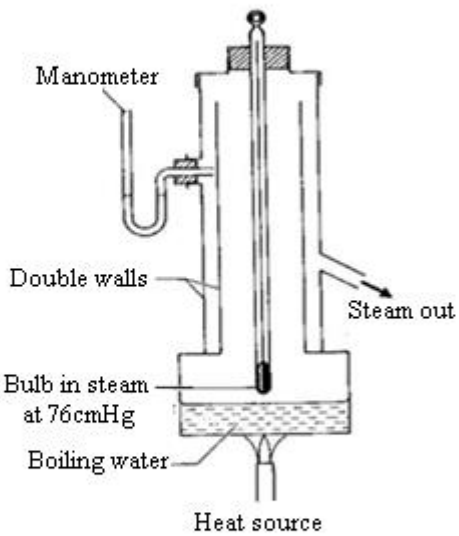
a) lower fixed point



i) Placing thermometer in ice
-A thermometer to be marked is placed in pure ice melting such that the bulb is packed round with ice.
-Adjust the thermometer so that the mercury thread is clearly seen.
ii) Marking lower fixed point
-The thermometer is left in ice until level of mercury remains stationery. This level is marked and it's the lower fixed point.

b) Upper fixed point

A hypsometer is a two walled vessel made out of a round bottom flask.



(i). Placing thermometer in steam
A thermometer to be marked is placed in steam in a hypsometer.
The thermometer should be in steam not boiling water because boiling water temperature is affected by dissolved impurities.
(ii). Double walls
The double walls help to keep the steam at exactly 100ºc so that steam does cool and condense.
(iii). A manometer
The manometer is attached to the hypsometer to ensure that the pressure with in it is 76cm Hg.
(iv). Marking upper fixed point
The thermometer is left in steam until the level of mercury remains stationery. This marked and it's the upper fixed point.

Properties of a liquid that make it suitable for thermometer
(Qualities of a good thermometric liquid).
- It should be opaque so as to be readily seen.
- It's expansion should be regular, i.e. expansion per degree should be the same at different point on the temperature scale.
- It should have high boiling point and low melting point so that both high and low temperature can be measured.
- It should be able to expand so much for a small temperature change.
- It should be a good conductor so that it responds rapidly to the temperature change.
- It must not stick to the inside of the tube.
- Must not be very expensive.
- Must not be poisonous.
- It should be available.

Reasons why water is never used in thermometer
- It has a small range of expansion because its freezing point is 0oc and boiling point is 100ºc.
- The meniscus in the glass is different to read since water is colourless and wets the glass.
- It does not expand uniformly.
- It is not opaque.

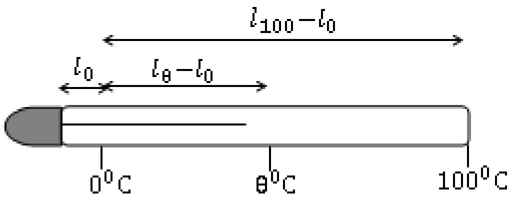
Advantages of mercury over alcohol when used as thermometric liquid.

Mercury	**Alcohol**
-It is opaque	-It is transparent
-Good conduct of heat	-Poor conduct of heat as compared to mercury
-Expand regularly	-Does not expand regularly as mercury
-Has a high boiling point (357^0C)	-Has low boiling point 78^0C
-Mercury does not stick on glass.	-Sticks on glass
-It is opaque so it can be easily seen.	-It is colourless

Advantages of Alcohol over mercury when used as thermometric liquid.

Alcohol	**Mercury**
-Has a low freezing point (It can measure very low temperatures)	Has a high freezing point of -39^0c hence unsuitable to measure very low temperatures.
-Has a high linear expansivity (expands so much for small temperature change)	Has a low linear expansivity (expands little for the same temperature range)

Reading temperature on an un calibrated thermometer



If $\boldsymbol{l_{ice}}$ is the length of the mercury thread above the bulb at melting ice, $\boldsymbol{l_{steam}}$ is the length of the mercury thread of steam at 760 mmHg and $\boldsymbol{l_{object}}$ is the length of mercury thread for the object being measured.
Then the required temperature θ°c is given by

$$\theta = \left(\frac{\boldsymbol{l_{object}} - \boldsymbol{l_{ice}}}{\boldsymbol{l_{steam}} - \boldsymbol{l_{ice}}}\right) \times 100^0\text{C}$$

In other words $\boldsymbol{l_{steam}}$ is also the length of mercury thread at 100°c, $\boldsymbol{l_{ice}}$ is the length of mercury thread at 0°c and $\boldsymbol{l_{object}}$is the length of mercury thread at the un known temperature, θ.

$$\theta = \left(\frac{\boldsymbol{l_\theta} - \boldsymbol{l_0}}{\boldsymbol{l_{100}} - \boldsymbol{l_0}}\right) \times 100^0\text{C}$$

Note: $(l_{100} - l_0)$ is the temperature range of the thermometer. In short the difference between the upper fixed point and the lower fixed point gives the temperature range of the mercury thread.
The interval between the upper fixed point and the lower fixed point is called the fundamental interval. This is divided into a hundred equal parts and each is called a degree.

Example 1:
In an un calibrated mercury thermometer, the length of the mercury thread above the bulb is 18mm at a temperature of melting ice and 138mm at a temperature of steam at 760mm Hg. When placed in a hot liquid the length of the mercury thread is 118mm. calculate the temperature of the liquid.
Solution
$l_0 = 18\text{mm}\,;\ l_\theta = 118\text{mm}\,; l_{100} = 138\text{mm}; \theta = ?$

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{118 - 18}{138 - 18}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{100}{120}\right) \times 100^0\text{C}$$

$$\theta = 83^0\text{C}$$

Example: 2
The top of a mercury thread of a given thermometer is 3cm from the ice point, if the fundamental interval is 5cm, determine the unknown temperature θ.
Solution
$l_\theta - l_0 = 3\text{cm}\,; l_{100} - l_0 = 5\text{cm}; \theta = ?$

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{3}{5}\right) \times 100^0\text{C}$$

$$\theta = 60^0\text{C}$$

Example: 3
The length of a mercury thread at a low fixed point and upper fixed point are 2cm and 8cm respectively for a certain liquid X. Given that the length of mercury thread at un known temperature θ is 6cm determine the value of θ.
$l_0 = 2\text{cm}\,;\ l_\theta = 6\text{cm}\,; l_{100} = 8\text{cm}; \theta = ?$

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{6 - 2}{8 - 2}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{4}{6}\right) \times 100^0\text{C}$$

$$\theta = 66.7^0\text{C}$$

Example: 4
Find the temperature in °C if the length of mercury thread is 7cm from the point and fundamental interval is 20cm.

Solution
$l_\theta - l_0 = 7\text{cm}\,; l_{100} - l_0 = 20\text{cm}; \theta = ?$

$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{7}{20}\right) \times 100^0\text{C}$$

$$\theta = 35^0\text{C}$$

Example: 4
Find the unknown temperature θ given the following lengths of mercury.
-Length of steam = 25cm
-Length of ice point = 1cm
-Length of known temperature θ= 19cm
Solution
$l_0 = 1\text{cm}\,;\ l_\theta = 19\text{cm}\,; l_{100} = 25\text{cm};\ \theta = ?$

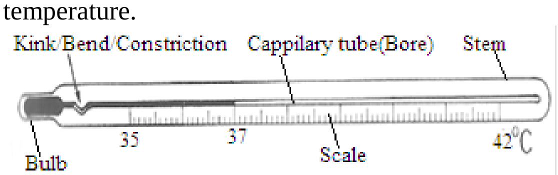
$$\theta = \left(\frac{l_\theta - l_0}{l_{100} - l_0}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{19 - 1}{25 - 1}\right) \times 100^0\text{C}$$

$$\theta = \left(\frac{18}{24}\right) \times 100^0\text{C}$$

$$\theta = 75^0\text{C}$$

THE CLINICAL THERMOMETER:
This thermometer is used to measure the human body temperature.

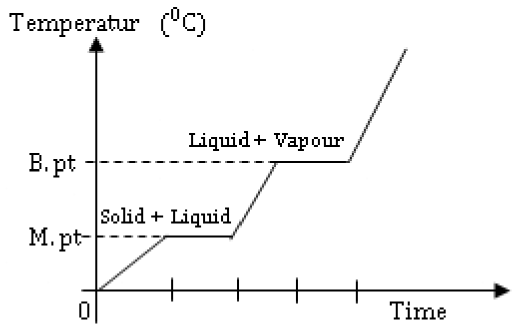


-The thermometer has a very fine bore (narrow capillary tube) which makes it sensitive.
-Expansion of mercury makes it shoot along the tube.
-The glass from which the tube is made is very thin which enables heat to reach the mercury quickly to read body's temperature.
-The bulb is the fluid reservoir. Thus it should be large enough to hold all the fluid. It is thin walled for quick response to heat.
-The glass stem is thick to act as a magnifying glass for the temperature readings.
-When thermometer bulb is placed into the mouth or armpit, the mercury expands and it is forced past the constriction along the tube.
-When removed, the bulb cools and the mercury in it contracts quickly.
-The mercury column breaks at the constriction leaving mercury in the tube. The constriction prevents flow back of mercury to the bulb when the thermometer is temporary removed from the patients mouth or armpits.
The thermometer is reset by shaking the mercury back in the bulb.

Properties/qualities of a thermometer.
Quick action
This refers to the ability of a thermometer to measure temperature in the shortest time possible. This is attained by using;
-A thin walled bulb and using a liquid which is a good conductor of heat e.g. mercury.

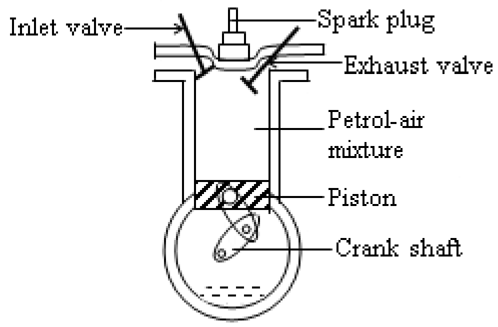
Sensitivity
This is the ability of a thermometer to detect very small changes in temperature. It is attained by:
-Using a thermometer with a big bulb
-Using a liquid which has a high linear expansivity.
-Using a narrow bore or reducing the diameter of the bore hole.

Effect of heat on matter:
-When a solid is heated, the cohesive forces between its molecules are weakened and the molecules begin to vibrate vigorously causing the solid to (expand or) change into a liquid state.
-The temperature at which a solid changes into liquid is called the melting point. At melting point the temperature remains constant until the solid has melted.
-When the entire solid has melted and more heat is applied, the temperature rises. The heat gained weakens the cohesive forces between the liquid molecules considerably causing the molecules to move faster until the liquid changes into gaseous state.
-The temperature at which a liquid changes into gaseous state is called the boiling point. At boiling point temperature of the liquid remains constant since heat supplied weakens the cohesive forces of attraction in liquid molecules.
-If the heated substance is water its temperature rises with time as shown below.



INTERNAL COMBUSTION ENGINE
A Heat engine is a machine which changes heat energy obtained by burning fuel to kinetic energy (Mechanical energy).
Engines are always less than 100% efficient because.
(i) Some of the energy is lost in overcoming friction between walls of the cylinder and pistons.
(ii) Some heat energy is lost to the surrounding due to conduction.
(iii) Some of the energy is also wasted in lifting useless loads like pistons.

Petrol engine
A Petrol engine gets its energy from an exploded mixture of air and petrol vapour.
Petrol engine are also called four stroke cycle engines because four piston stroke or monuments inside the cylinder repeat themselves continuously. The piston strike is in the order intake, compression, power and exhaust.



a) Intake.
-As the piston moves down the cylinder due to the starter motor in a car (or kick start in a motor cycle) it reduces the pressure inside the cylinder.
-The inlet value opens and the petrol air mixture from the carburettor is forced into the cylinder by atmospheric pressure.
-In short intake involves the piston moving down the cylinder, inlet valve opening and allowing petrol – air mixture into the cylinder.

b) Compression
-Both valves close and the piston moves up compressing the mixture to about a sixth of its original volume.
-Near the end of the stroke, the fuel is ignited by a spark from the spark plug.

c) Power stroke
A spark jumps across the points of the sparking plug and explodes the mixture, forcing the piston to move down.

d) Exhaust stroke

The outlet value opens and the piston rises, pushing the exhaust gasses out of the cylinder.

DIESEL ENGINE

The operation of a diesel engine is similar to that of a petrol engine.

However, there are some **differences.**

Diesel engine	Petrol engine
-Diesel is used as fuel	-Petrol is used as fuel
-No spark plug	-Has a spark plug
-Has a fuel injector	-Has a carburettor
-Reliable and economical because its 40% higher	-Not reliable and economical
-Heavier	-Lighter

In a diesel engine air is drawn into the cylinder on down stroke of the piston. On upstroke of the piston, it compresses reducing the volume of the cylinder. The very high compression increase the stroke, oil is pumped into the cylinder by a fuel injector, it ignites automatically. The resulting explosion drives the piston down on its power stroke.

Note: Diesel engine is also called compression ignition (CI). It is heavier than a petrol engine. Diesel engine is reliable and economical. The efficiency is about 40% higher than any other heat engine.

(b) HEAT TRANSFER

Heat flows from a region of high temperature to a region of low temperature. There are three ways by which heat can be transferred, namely;

(i) Conduction
(ii) Radiation
(iii) Convection

(i) CONDUCTION

Conduction is the flow of heat through matter from a region of higher temperature to one of lower temperature without movement of matter as a whole.

Conduction in solids

Heat transfer in solids can occur as a result of;;

(i) Excess energy of vibrations being passed from one atom to another.

(ii) There excess Kinetic energy given to the free electrons near the source of heat being carried by these electrons as they move to colder region.

Note:

For heat to be transferred by conduction there should be a material medium. Metal are good conductors of heat because metals are made up of atom having free electrons that are loosely held.

Examples of metals which are good conductors are;

1. Aluminium
2. iron
3. Copper

New utensils or kettles, saucepans boilers, radiators are made of metals because metals are good conductors of heat as their atoms have free electrons that are loosely held. Non-metals, according to Kinetic theory do not have free electrons that are loosely held so that heat does not pass through them easily. This is why non-metals are called bad conductors or insulators e.g plastics, cork, wood.

Rate of heat transfer

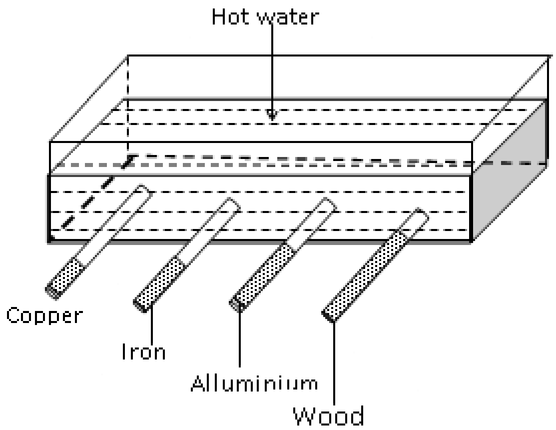
The rate of heat transfer along a metal bar depends on the following factors;

(i) The temperature difference between the ends.

(i) The length and area of cross in short time when the cross section of the metal bar. Much heat is passed across in a short time when the cross sectional area of the bar is large and when the bar is short.

(ii) Material from which the solid is made of.

Comparing the conductivities of different metals.



-The rate of conduction is compared by dipping the ends of four rods coated with wax in hot water.

-The rods are identical but made of different materials.

-After a short while, the wax begins to melt along the rods. It melts fastest along the copper rod and slowest along wood.

-This shows that copper is the best conductor and wood is the poorest of them.

Bad and good conductors and their applications.

(i) Good conductors like aluminium are used in cooking utensils because they allow heat to pass through them easily. Copper is one of the best conductor but aluminium is usually used in making cooking utensils because it is much cheaper.

(ii) Bad conductor also called insulators are used in making of handles of cooking utensils because they do not allow heat to pass through easily.

A metal always feels cold when touched on a cold day because it loses heat from the body and transfer it to the surrounding very fast.

Explain why metals feel colder when touched than bad conductors

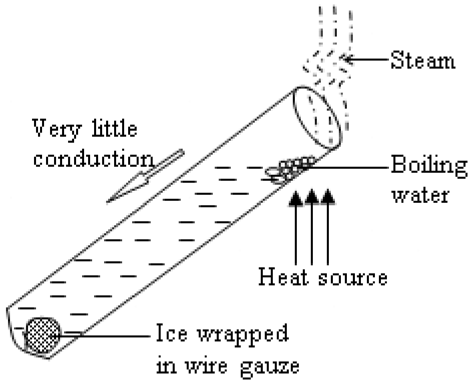
This is because metals carry heat away from the hands due to high degree of conduction while bad conductors do not conduct heat.

This also explains why a cemented floor feels colder than a carpeted floor.

N.B

Liquids conduct heat very slowly. This is because their molecules are apart.

Experiment to show that water is a poor conductor of heat



Procedure
-Water is put in a test tube slanted as shown in the diagram above.
-The upper part of the tube is heated and convection currents are seen at the top of the tube, water begins to boil.
-Ice at the bottom does not melt. This shows that water is poor conductor of heat.

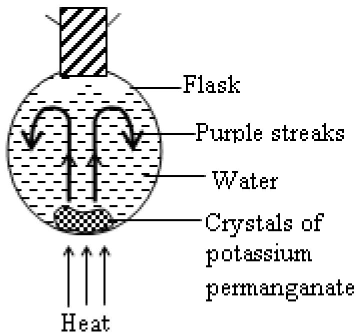
(ii) CONVECTION
Convection is the flow of heat through fluid from a region of higher temperature to one of lower temperature by the movement of the fluid itself.
It is the heat transfer which involves bulk movement of molecules of the medium.
Convection cannot occur in vacuum because it requires a material medium. It occurs in fluids (liquid and gases) because they flow easily.

When a liquid is heated it expands and becomes less dense than the surrounding cold liquid.

Convection current.
Convection current is the cyclic motion of rising hot fluid and falling itself. The hot fluid rises because when heated it becomes less dense.

Explanation of convection current
-When the fluid is heated it expands and becomes less dense.
-The heated fluid is forced upward by the surrounding cooler fluid which moves under it.
-As the warm fluid rises, it gives heat to the surrounding cooler fluid.

Experiment to demonstrate convection current.



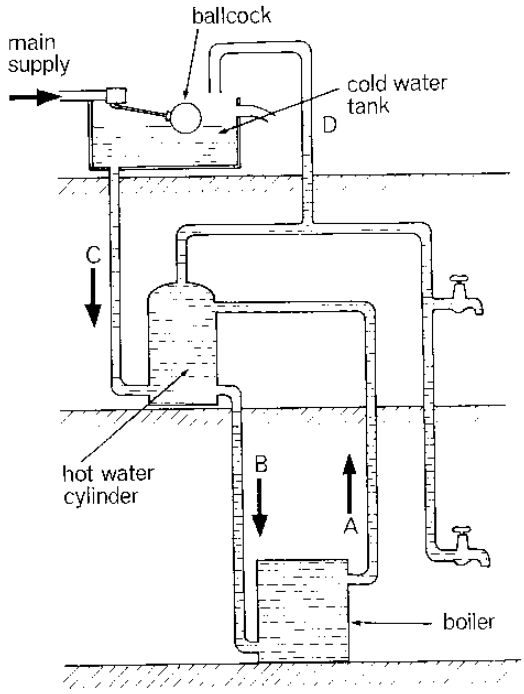
-When the flask is heated from the bottom as shown, the coloured solution of water rises upwards from the crystals and on reaching the top; it spreads as shown in the diagram.

-The solution rises because on heating, it expands and becomes less dense, so it is forced upwards by nearby cooler (denser) water.

Difference between convection and conduction

Conduction	Convection
-Involves no movement of matter itself.	-Involves movement of matter as a whole.

Application of convection current to hot water domestic supply system.



How it works
-Cold water is supplied to the boiler along the cold water supply pipe.
-In the boiler the cold water warms up, expands and becomes less dense, so it rises up.
-As more cold water is applied to the boiler, hot water is displaced upwards and supplied to the hot water taps along hot water pipes A and D.
-The ventilation pipe, D is used to release steam.

The expansion pipe A allows pipe D allows escape of:
(i) Dissolved air which comes out of the water when it is heated.
(ii) Steam, if the water is boiled.

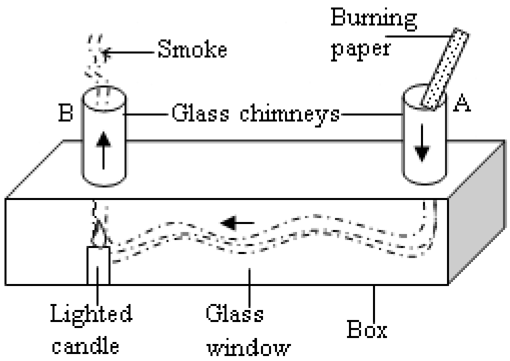
If the expansion pipe is not there;
(i) The dissolved air which comes out when water is heated causes air lock in the pipe.
(ii) The steam if the water is boiled causes explosion.

a) Boiler
When working convection current of less dense hot water from boiler raises up through pipe A to the hot water tank. At the same time the more

b) Circulation
A circulation is set up in the hot water involving filling hot water from top down wards.

-When a volume of hot water flows to the hot water tank through pipe A, an equal volume of cold water flows to the boiler through pipe B.
-At the same time an equal volume flows through pipe C to the hot water tank.
-Pipe A leaves the boiler at the top and enters the hot water tank at the top because it carries more dense hot water.
-Pipe B is connected to the bottom of the hot water tank and to the bottom of the because it carries more dense cold water.

<u>Convection in gases</u>
Experiment to demonstrate convection in gases

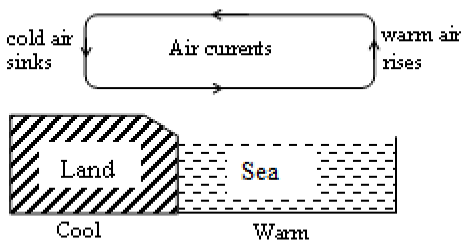


-The hot air above the candle rises up and gets out through B.
-A lighted piece of paper will produce smoke at point A.
-Cold air enters at point A and sweeps all the smoke to go and replace the hot air.
-The movements of smoke from A across the box and out through B shows convection of gases.

<u>Explanation of how smoke moves:</u>
Smoke moves by convection because;
-The air above the candle warms up, becoming less dense and then rises up through C.
-The dense cold air from the paper (smoke) enters X through chimney A to replace the risen air (smoke) causing convection currents.

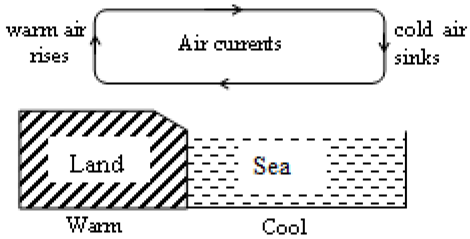
<u>Application of convection in gases:</u>
-Chimneys in kitchens and factories
-Ventilation pipes in VIP latrines
-Ventilators in houses
-Land and sea breezes

Land and sea breezes
<u>Land breeze;</u>



a) Cooling of land
At night land cools faster than sea because land is a better emitter of heat and has lower specific heat capacity than sea water.

b) Movement of air
The air above the sea is heated more than air above land, so the warmer air above sea rises and the cooler air from land occupy the space left. This results in a land breeze blowing towards the sea.
<u>Sea breeze:</u>



a) Heating land.
During day land is heated by the sun more than the sea because land is a better absorber of heat and has lower specific heat capacity than the sea.

b) Movement air
The much more heating of land causes the air above it to expand and rise as it becomes less dense. The space left is occupied by more dense air from the relatively cooler sea. So a cool sea breeze blows from the sea towards the land.

Ventilation:
-Air inside a room, air gets heated up on hot days.
-Roofs are usually provided with small openings called ventilators above the building so that the warm air which is less dense rises up and flow out through them.
-At the same time cool fresh air enters the building through the doors and windows. In this way circulation of air convection is set up

(iii) RADIATION
<u>Radiation is the flow of heat from one place to another by means of electromagnetic waves.</u>

Heat energy is transfer from the sun to the earth by means of radiation. Radiation is the means by which heat can travel through the vacuum.
The energy from the hot body is called <u>radiant energy.</u>
Radiation is emitted by the bodies above absolute zero.
Radiant heat is mainly comprised of infrared which makes the skin feel warm. It travels as fast as light and it is the fastest means of heat transfer. It can travel through a vacuum.

Factors affecting the rate of radiation of heat energy

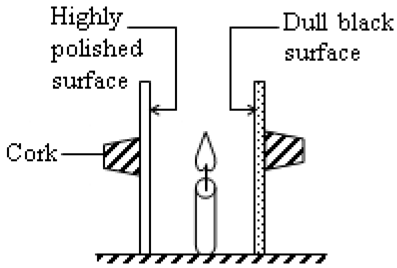
Factor	Explanation
✓ Temperature of the body	A hotter body radiates heat faster.
✓ Surface area of the body	Large surface area allows much heat energy to be radiated per second.
✓ Nature of the body	Dull surfaces radiate heat energy faster than highly polished surface.

Good and bad absorbers
Shiny surface are bad absorbers of radiation while dull black surface are good absorbers. This implies that shiny surface

reflects most of the heat radiations instead of absorbing. The dull black surface absorb most of the heat radiations and reflect very few.

Experiment to show absorbing of radiation in surface
Some surfaces absorb heat radiation better than others as illustrated below;

Method I

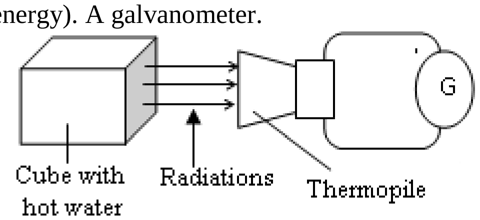


-Stick two pieces of cork using molten wax onto two vertical metal plates.
- The heat source is placed midway between the vertical plates so that the same amount of radiations are received by the two surfaces.

Observation:
-It will be observed that after a few minutes the wax on the dull black plate melts and the cork falls off before that on the shiny polished plate.

Conclusion:
-This indicates that dull black surfaces are better absorbers.

Method II:
Requirements: - A Leslie cube
-Thermopile (instrument that converts heat to electrical energy). A galvanometer.



-One side of the cube is dull black, the other is dull white and the last one is made shiny polished.
-The cube is filled with hot water and radiation from each surface is detected by a thermopile.
-When the radiant heat falling on the thermopile is much, it registers a large deflection of the point.
With different surfaces of the tube made to face the thermopile one at a time.

Observation:
-The greatest deflection of the pointer is obtained when dull dark surface faces the thermopile.
-The least deflection is obtained when a highly polished shiny surface faces the thermopile.

Conclusion:
-The dull and black surface is a good radiator or emitter of heat radiation while a polished shiny surface is a poor emitter of heat radiation.

Application of absorbers.
(i) Building in hot countries are painted white and roof surfaces are shinny because white and shinny surface are bad absorbers of heat radiation.
(ii) Reflection on electric devices are made up of polished metals because they have good reflecting properties.

Good and Bad emitter.
If the backs of the hands are held on either sides of the sheet, one first feels much heat from the black surface.
This shows that a black surface is a better emitter of heat than a shiny one.

-In short, black surface are good absorbers as well as good emitters of heat radiations.
-Shinny surfaces or polished surfaces are bad absorbers as well as bad emitters of radiations.

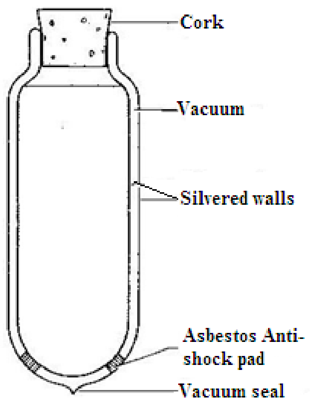
Applications
(i) Cooling fins on the heat exchanger of refrigerator are painted black so that they emit heat more quickly.
(ii) Tea pots and kettles are polished so that they keep heat longer as polished surface are poor emitters of heat radiation.

Laws of radiation:
- Heat radiation travels in a straight line.
- Good absorbers of heat radiation are also good emitters.
- Temperature of the body remains constant when the rate at which it absorbs heat radiation is equal to the rate at which it radiates heat energy.
- Bodies only radiate heat when their temperatures are higher than those of the surroundings and absorb heat from the surroundings if their temperatures are low.

Application of radiation:
Black and dull surfaces
(i) Car radiators are painted black to easily emit heat
(ii) Cooling fins of a refrigerator are black to easily emit heat.
(iii) Solar plates or panels are black to easily emit heat.

Polished and white surfaces
(i) White washed buildings keep cool in summer.
(ii) Roots and petro tanks are aluminium painted to reflect radiant heat.
(iii) White coloured clothes are won in summer to keep us cool.
(iv) Silver tea pots, kettles and saucepan retain heat for a long time.
Thermos/vacuum flasks

THE VACUUM FLASK
It is a flask with two silvered walls enclosing a vacuum. It is used for keeping contents at a fairly constant temperature.



-A thermos flask also called vacuum flask keeps hot liquids hot and cold liquids cold.
-This is because heat losses are minimized. There are three ways by which heat can be lost namely: Conduction, convection and radiation.

Heat losses by the above ways are minimized by the vacuum flask as follows:

-Conduction and convection are minimized by the vacuum since for heat to be transferred by these ways, a material medium is required.
-Convection from the hot liquid upward to the outside is reduced by the cork which also reduces heat loses by conduction because it is a poor conductor of heat.

-Radiation is also minimized by the two silvered surfaces since they are bad emitters.

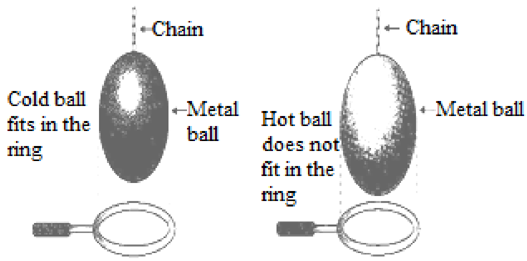
However when a hot liquid is kept in the vacuum flask for a long time, it cools because at a small rate, heat is lost by conduction, convection and radiation.

Choice of dress
The choice of dress one puts on depends on conditions of the environment. On hot days, a white dress is preferable because it reflects most of the heat radiations falling on it.

On cold days a dull black woolen dress is preferred because it absorbs most of the heat incident on it and can retain for a longer time.

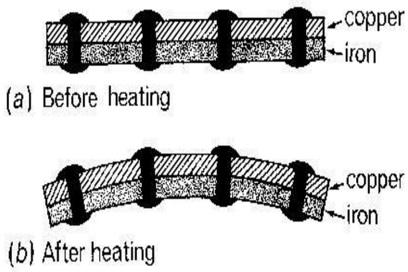
(c) THERMAL EXPANSION OF MATTER
This is the increase in size of matter in all directions whenever matter is heated.

1. Expansion of solids.
Expansion of solids can be illustrated using a metal ball with a ring as shown below.



-The metal ball passes through the ring when it is cold, but when heated, the ball doesn't pass through the ring any more, showing that it has expanded.
-It passes through the hole again when it cools, meaning that the metal contracts when it loses heat.

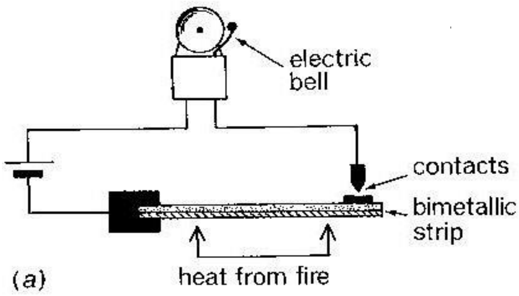
Bi- metallic strip
Different metals expand at different rates when equally heated;
This can be shown using a metal strip made of two metals such as copper and iron bounded tightly together (bi-metallic strip) when the bi metallic strip is heated, the copper expands more than iron and the strip bends as shown.



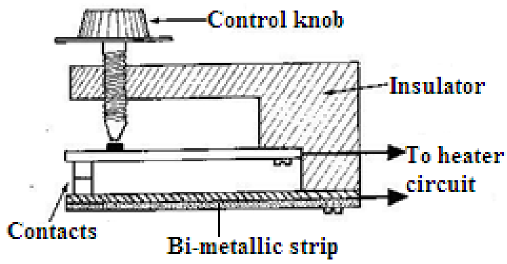
-When the bimetallic strip of iron and Brass is heated, it bends with brass on the outside of the curve.
-This is because Brass expands more than iron.

Uses of a metallic strip (application of expansion of solids)
Bimetallic strips are useful in the following devices by completing the metallic circuit.
i) Ringing alarm bells
ii) Thermostats

a) Fire alarm
Heat from the source makes the bi metallic strip bend and completes the electric circuit and the bell rings.



b) Thermostat
This is a device that makes temperature of appliances or room constant. The thermostat shown below uses a bi metallic strip in the heating circuit of a flat iron.



How an electric Iron works
-Setting the temperature: The control knob is set to the required temperature.

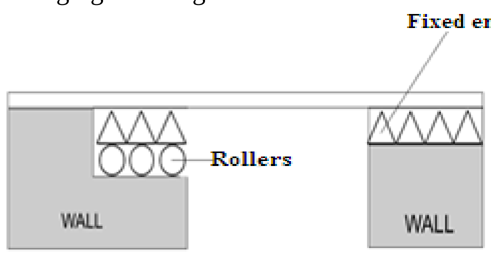
-Bimetallic strip heating: On reaching the required temperature, the bimetallic strip bends away breaking the circuit at contact C. This switches off the heater.
-Cooling bimetallic strip: On cooling just below the required temperature, the bimetallic strip makes contact and switches on the heater again. So a nearly steady temperature results.

-Knob: If the control knob is screwed more, the bimetallic strip has to bend more in order to break the heating circuit thus giving a high temperature

Disadvantage of expansion of expansion in our every day life

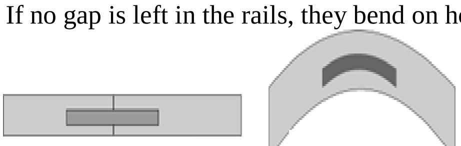
- Steel bridges

Bridges are constructed with one end fixed and the other side is placed on rollers in order for the structure to expand or contract freely with changing temperature without damaging the bridge.



- Railways:

Railway lines are constructed with gaps between the consecutive rails in order to allow free expansion of the rails is the temperature increases.
If no gaps are left between rails, the rails buckle during a hot day.
If no gap is left in the rails, they bend on hot days.



Cold day Hot day

- Electricity Transmission cables

The wires which are used for the transmission of electricity or telephone wires are usually left sagging in order to allow them free expansion and contraction.

Linear expansivity
Linear expansivity of a material is the fraction of its original length by which it expands per Kelvin rise in temperature.

$$\text{Linear expansivity} = \frac{\text{Linear expansion}}{\text{Original length} \times \text{Temperature rise}}$$

$$\propto \; = \frac{\Delta \boldsymbol{l}}{\boldsymbol{l_0} \times \Delta\boldsymbol{\theta}}$$

Where ; $\Delta \boldsymbol{l} = \boldsymbol{l_1} - \boldsymbol{l_0}$ ***and*** $\Delta\boldsymbol{\theta} = \boldsymbol{\theta_1} - \boldsymbol{\theta_0}$
Where ; $l_0 =$ original length
$l_1 =$ New length
$\theta_0 =$ Initial temperature
$\theta_1 =$ Final temperature

The S.I unit of linear expansivity is **K^{-1}**or **$^0C^{-1}$**

Examples:
1. In an experiment to measure linear expansivity of a metal, a rod of this metal is 800mm long is found to expand 1.36mm when the temperature rise from 15ºc to 100ºc.

Solution
$\Delta \boldsymbol{l} = (\boldsymbol{l_1} - \boldsymbol{l_0}) = 1.36$ mm
$l_0 = 800$mm

$\theta_0 = 15^0$C; $\theta_1 = 100^0$C; $\Delta\theta = 85$K

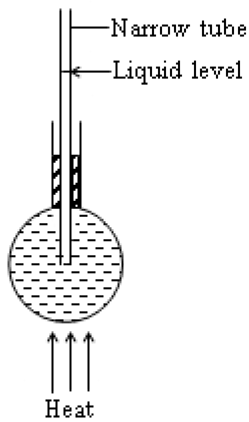
$$\propto \; = \frac{1.36}{800 \times 85} = 0.00002\text{K}^{-1}$$

Exercise:
1. A metal rod has a length of 100cm at 200ºc. At what temperature will its length be 99.4cm if the linear expansivity of rod is 0.00002K^{-1}. [Ans: $\theta_1 = 173$K]

2. A steel bridge is 2.5m long. If the linear expansivity of the steel is $1.1 \times 10^5 \text{C}^{-1}$.How much will it expand when the temperature rises by 5^0C? [Ans: $\Delta \boldsymbol{l} = 1.375 \times 10^{-2}$cm]

2. Expansion of liquids
Liquids expand when they are heated. Different liquids expand by different amount when equally heated.
Liquids expand much more than solids because according to the kinetic theory, liquid molecules are far apart compared to the solids and the intermolecular forces are weaker in liquids.

Experiment to demonstrate expansion of water.

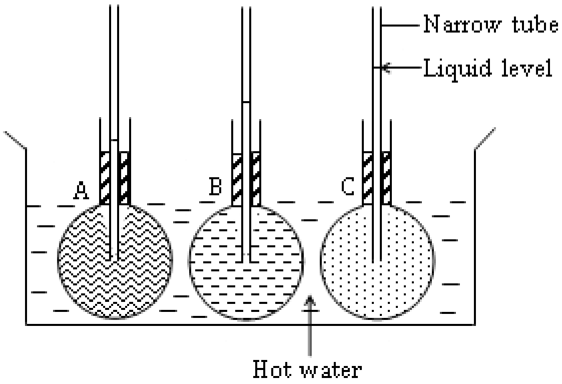


-Fill the flask completely with coloured water. Pass the narrow tube through the hole of the cork and fix the cork tightly to the flask.
-Note the first level of water on a narrow tube
-Heat the bottom of the flask and observe the new level of water on the capillary tube. Initially there will be a momentary drop of the water level in the tube then after wards the level rises.
-Therefore liquids expand when heated since there was a rise in the levels of water in the capillary tube.

Explanation
-When the flask is heated, the flask first receives heat before the water in it so the flask expands and its volume increases

causing the slight fall in level. -However, when heat reaches the water, the volume of water expands more than the increase in volume of the flask.

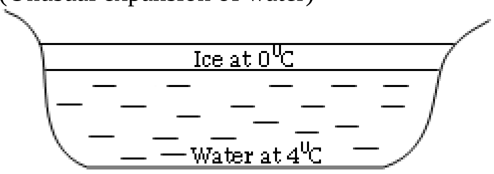
Comparing expansion of different liquids



-Three identical flasks A, B and C are filled with alcohol, kerosene and water respectively.
-Fit a narrow capillary tube in each flask through the cork, cool flasks to the same temperature, adjust the levels such that they are equal and mark the original levels.
-Place the flasks in a trough of hot water
-After some time, the liquid levels rise to different levels. This shows that different liquids expand differently when heated through the same temperature range.
Liquid C expands more than B and more than A in that order.

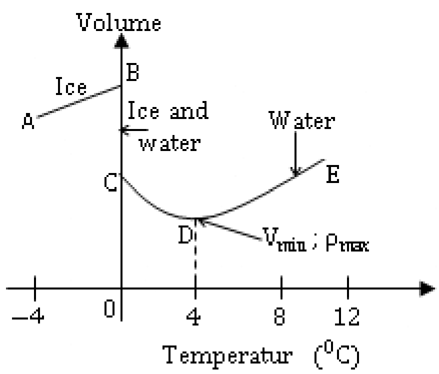
Application of expansion property of liquids
This property is used in thermometer; the liquids used include alcohol and mercury.

Anomalous expansion of water
(Unusual expansion of water)



For all solids expect ice, when heated, they melt to form liquids. They expand just after melting but ice which melts at 0^oc to form water contracts until 4^oc. Water is thus exceptional or anomalous in the range 0^oc to 4^oc.

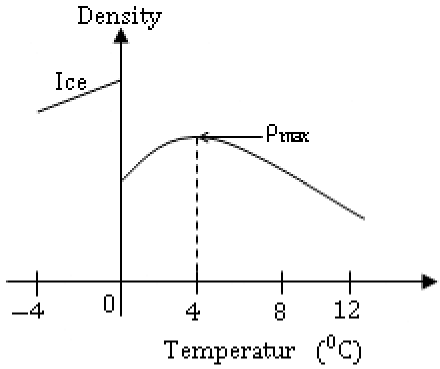
Sketch of volume against temperature.



From the sketch, it is noted that water has its minimum volume at 4^oc.

AB: As the temperature rises ice expands.
CB: The ice is melting to form water at 0^oc
CD: As the temperature rises, the formed water at 0^oc contracts until 4^oc.
DE: At 4^oc the water expands just like other liquids do.

Sketch of density against temperature.



-Since density is mass/volume but mass is unaltered by warming.
-It is only volume which decreases between 0^oc to 4^oc.
-It follows that water has its maximum density at 4^oc. From the sketch it is noted that ice is less dense than water.
-This is because for any given mass at 0^oc the volume of ice is greater than the volume of water. This is why ice is less dense than water.
-When ice is mixed with water, ice floats on water because when ice melts to form water, density increases as volume decreases until 4^oc.Therefore, ice is less dense than water.

Note: During very cold weather, pipes of water burst because at 0^oc when water freezes, considerable expansion occurs resulting in increase in volume.

Biological importance of abnormal expansion
The unusual expansion of water has some biological importance in the preserving of aquatic life during cold weather.

a) Water at the top cooling
During cool weather, water at the top of the sea cools first, contracts and being denser to the bottom. The warmer and less dense water rises to the surface to be cooled.

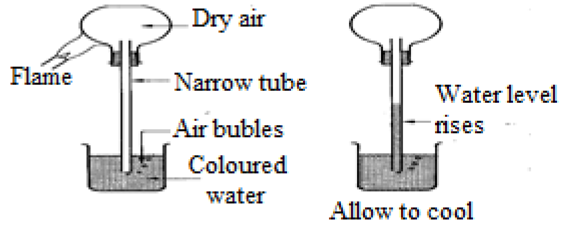
b) At 4^oc
When all the water is at 4^oc the circulation stops.

c) Temperature below 4^oc
When the temperature of water surface falls below 4^oc, it becomes less dense and remains at the top, eventually forming a layer of ice at 0^oc.
The lower layer of water at 4^0c can only lose heat by conduction. So in deep water there will be always water beneath the ice in which fish and other aquatic life can thrive.

Explanation of unusual expansion of water by kinetic theory
-The expansion of water between 4^oc and 0^oc is due to the breaking up of groups of water molecule below 4^oc and formation of groups of water molecules above 4^oc which require a large volume. -So the anomalous expansion of water at 4^oc is because water molecules bond together differently above and below 4^oc.

Expansion of gases
A gas expands when heated almost 10,000 times more than solids.
The greater expansion of gasses is due to very weak intermolecular forces which can be broken easily.

Experiment to demonstrate expansion in gases



In the above set up the flask is slightly heated.
Air bubbles will be seen coming out from the other end of the tube
This shows that air expand when heated.
In the second set up, when the source of heat is removed and the flask is allowed to cool by pouring cold water, the level of water will rise. This shows that air contracts when cooled.

Alternatively
When hands are rubbed together thoroughly and held around the flask as shown above, bubbles of air start coming out of water. This is because the heat produced by the hands was enough to cause the air in the flask to expand. When the hands are removed and flask left to cool, the water rises in the tube. This is because cooling the air contracts and pressure of the inside are becomes less than the atmospheric pressure.

Application of expansion of air.
Hot air balloon
Expansion of air is used in hot air balloon. When air in the balloon is heated, it expands and becomes less dense and as a result the balloon rises up.

Exercise 1: See UNEB Past papers.

1. 1988 Qn.12	6. 1999 Qn.9	11. 1989 Qn.2
2. 1988 Qn.18	7. 2004 Qn.11	12. 1994 Qn.1
3. 1988 Qn.31	8. 2004 Qn.33	13. 1998 Qn.3
4. 1991 Qn.4	9. 2006 Qn.17	14.1998 Qn.5
5. 1994 Qn.33	10.2007 Qn.36	15.

(d) GAS LAWS
Gases when heated will show a significant change in pressure volume and temperature unlike solids and liquids which show insignificant change in volume.
Gas laws are laws which express the relationships between Pressure, (P), Volume (V) and Temperature (T) of a fixed mass of a gas.

1. Boyle's law
Boyle's law states that the volume of fixed mass of gas at contact temperature is inversely proportional to its pressure.

Mathematically;

$$P \propto \frac{1}{V} \text{at constant temperature.}$$

$P = k\frac{1}{v}; \Leftrightarrow PV = k; \Leftrightarrow \mathbf{PV = constant}$

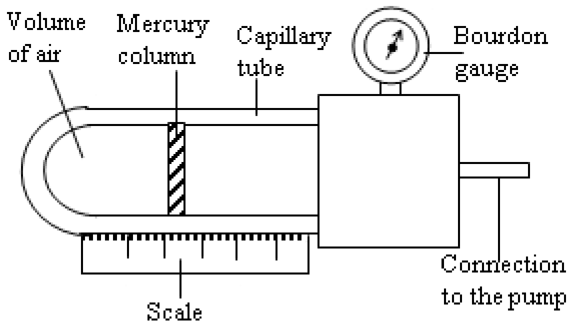
$\mathbf{P_1V_1 = P_2V_2 = constant}$

Example: 1
The pressure of a fixed mass of gas is 5artmospheres when its volume is 200cm^3. Find its pressure when the volume
(i) Is halved
(ii) Is doubled
(iii) Is increased by $1\frac{1}{2}$ times provided temperature remains constant.
Solution
(i)$P_1V_1 = P_2V_2$
$5 \times 200 = P_2(100)$
$P_2 = 10$ atmospheres

(ii) $P_1V_1 = P_2V_2$
$5 \times 200 = P_2(400)$
$P_2 = 2.5$ atmospheres

(iii) $P_1V_1 = P_2V_2$
$5 \times 200 = P_2(300)$
$P_2 = 3.333$ atmospheres
.
When pressure is doubled the volume is halved or vice versa

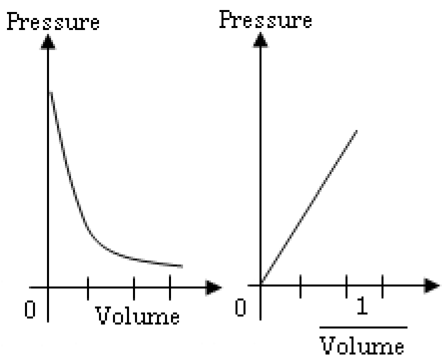
Experiment to verify Boyle's law



Trap dry air in the capillary tube using the mercury column.
-The pressure is varied using a bicycle pump and its value, P read from the Bourdon gauge and recorded.
-For each vale of P, the length, l of the air column is measured from the scale and recorded. This is the volume of the air.
-The procedures are repeated for different values of P and the results tabulated.

Pressure, P (Pa)	Volume, V(m^3)
-	-
-	-

-A graph of P against V is plotted



Example 1:
The volume of a fixed mass of gas at constant temperature when the pressure is 76mHg. Calculate the volume when the pressure is 38 cmHg.
the volume when the pressure is 38 cmHg.

Solution
(i)$P_1V_1 = P_2V_2$
$150 \times 76 = V_2(38)$
$V_2 = 300\text{cm}^3$

Note: from the above example, it is found when pressure halved the volume doubles.

Example:2
The volume of a fixed mass of gas at constant temperature increases from 300cm^3 to 500cm^3 . Find the new pressure if the initial pressure was 70cmHg.

Solution

$v_1 = 300\text{cm}^3, P_1 = 70\text{cmHg},$ $v_2 = 500\text{cm}^3; P_2 = ?$
$P_1V_1 = P_2V_2 \Leftrightarrow 70 \times 300 = P_2 \times 500$ $21000 = 500P_2$ $P_2 = 42\text{cmHg}$

Example:3
The pressure of a fixed mass of 0.5litres of a gas is 30cmHg. Find the volume if the pressure increases to 70cmHg.

Solution

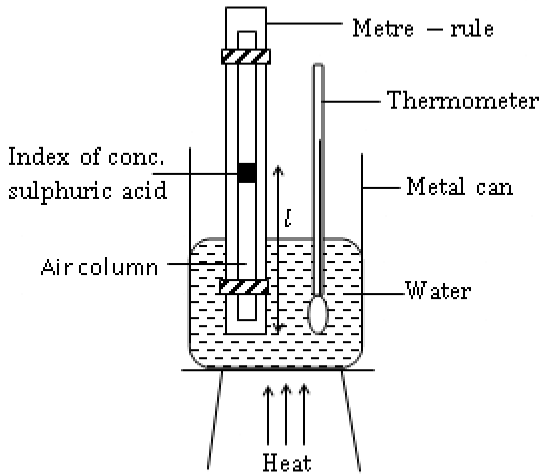
$v_1 = 0.5\text{litres}, P_1 = 30\text{cmHg},$ $v_2 = ?;\quad P_2 = 70\text{cmHg}$
$P_1V_1 = P_2V_2 \Leftrightarrow 30 \times 0.5 = 70 \times V_2$ $15 = 70V_2$ $V_2 = 0.211\text{litres}$

2. Charles' Law
Charles' law states that the volume of a fixed mass of a gas at constant pressure is directly proportional to the absolute temperature.
$V \propto T$at constant pressure.

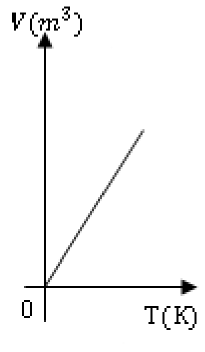
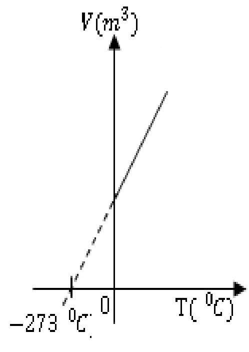
$$\mathbf{\frac{V}{T} = constant}$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2} = \text{constant}$$

Experiment to verify Charles's law



-Trap dry air using the index of concentrated sulphuric acid in a capillary tube. Tie the tube on the metre-rule using a rubber band.
-Place the apparatus in a metal can containing water and heat the water slowly while stirring gently.
-Read and record the length, l of the trapped air column and the temperature, T.
-Repeat the procedures for different temperatures and tabulate the results.
-Plot a graph of l against temperature, T.

A graph of v against T	A graph of V against T
	

Observation:
-The graph is a straight line through the origin.
-In the second graph, at273^0C, the gas occupies zero volume.
This temperature is called **absolute zero**.

Conclusion:
-The graph shows that l (which is proportional to volume), is directly proportional to the
absolute temperature at constant pressure. This verifies charles' law.

Absolute temperature is the Kelvin temperature scale which has zero value coinciding with -273 ^{0}C.
Absolute temperature is also called thermodynamic temperature. On this scale temperature is measured in Kelvin (K)
Where temperature 0^{o}C in Kelvin is obtained from temperature; $\theta^0c = (\theta + 273)\text{K}$
e.g. temperature of -73^{0}c
$T = (-73^0\text{C} + 273)$
$T = 200\text{K}$

Absolute zero is the temperature of 273^{o}c at which the volume of the gas would become zero as the gas is cooled. However, the volume of the gas can not actually shrink to zero. This is because the gas first liquidifies, then turns to solid before the temperature of 273^{o}c is reached.

The volume-temperature and pressure-temperature graphs for a gas are straight lines. This is because gasses expand uniformly with temperature. So equal temperature increase cause equal volume or pressure increases.

Example 1
The volume of a fixed mass of gas at constant pressure is 400cm^3 at a temperature of -73^{o}c. Calculate the volume when the temperature is raised to 27^{o}c.
Solution

$v_1 = 400\text{cm}^3, T_1 = (-73 + 273) = 200\text{K},$ $v_2 = ?;\quad T_2 = (27 + 273) = 300\text{K}$
$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Leftrightarrow \frac{400}{200} = \frac{V_2}{300} \Leftrightarrow V_2 = 600\text{cm}^3$

Example 2
The volume of a fixed mass of gas at a given pressure is 1.5m^3 at a temperature of 300K. Calculate the temperature when the volume will be 0.5m^3 at the same pressure.
Solution

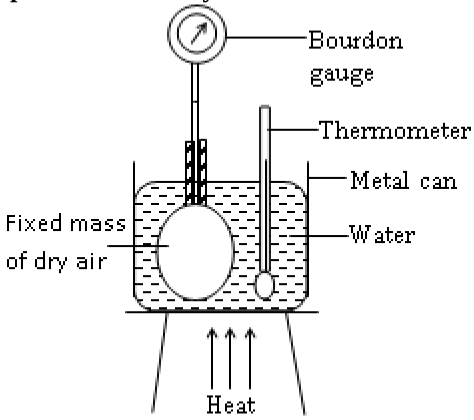
$v_1 = 1.5\text{m}^3, T_1 = 300\text{K},$ $v_2 = 0.5\text{m}^3, T_2 = ?$
$\frac{V_1}{T_1} = \frac{V_2}{T_2} \Leftrightarrow \frac{1.5}{300} = \frac{0.5}{T_2} \Leftrightarrow T_2 = 100\text{K}$

3. Pressure law.
The pressure of a fixed mass of gas at constant volume is directly proportional to its absolute temperature.
P $\propto$ T: at constant Volume.

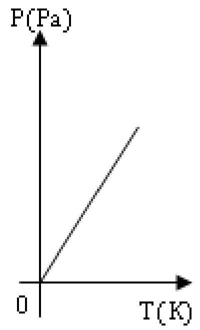
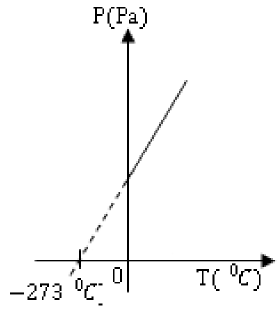
$$\frac{\mathbf{P}}{\mathbf{T}} = \mathbf{constant}$$

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

Experiment to verify Pressure law



Procedure:
-The apparatus is set up as shown above. The rubber tubing from the flask to the pressure gauge should be as short as possible.
-The flask containing dry air is placed in water in a can such that water is almost to the top of its neck.
-The can is heated from the bottom while stirring and the pressure, P is then recorded for different temperature values.
-The heating is stopped to allow steady gauge reading for each reading taken.
-The results are tabulated and a graph of pressure against temperature plotted.

For temperature in K	For temperature in ^{0}C
	

Observation:
-A straight line graph touching the temperature axis at -273^{o}C verifies pressure law.

Example 1
The pressure of gas in a cylinder is 15atm at 27℃.
(i) what will be the pressure at 177℃?
(ii) at what temperature will the pressure be 10 atmospheres?
Solution
(i)

$P_1 = 15\text{atm.}, T_1 = 27 + 273 = 300\text{K},$ $P_2 = ?, T_2 = 177 + 273 = 450K$
$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Leftrightarrow \frac{15}{300} = \frac{P_2}{450} \Leftrightarrow P_2 = 22.5\text{atm.}$

(ii)

$P_1 = 15\text{atm.}, T_1 = 27 + 273 = 300\text{K},$ $P_2 = 10\text{atm.}, T_2 = ?$
$\frac{P_1}{T_1} = \frac{P_2}{T_2} \Leftrightarrow \frac{15}{300} = \frac{10}{T_2} \Leftrightarrow T_2 = 200\text{K.}$

Equation of state
The combination of the three gas law equations forms a single equation called the equation of state. Or the general gas law.
It is an equation that expresses the relationship between Volume, V, pressure, P and temperature, T. It is given by the formula;

$$\frac{\mathbf{PV}}{\mathbf{T}} = \mathbf{constant}$$

$$\frac{\mathbf{P_1V_1}}{\mathbf{T_1}} = \frac{\mathbf{P_2V_2}}{\mathbf{T_2}}$$

Example 1
Air in a 2.5 litre vessel, at 127^{o}c exert a pressure of 3 atmospheres. Calculate the pressure that the same mass of air would exert if contained in a 4 litre vessel at -73^{o}c.

Solution

$V_1 = 2.5\text{litres.}, T_1 = 127 + 273 = 400\text{K},$ $P_1 = 3\text{atm}$ $V_2 = 4\text{litres}\quad, T_2 = -73 + 273 = 200\text{K}$

$P_2 = ?$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Leftrightarrow \frac{3(2.5)}{400} = \frac{4P_2}{200} \Leftrightarrow P_2 = 1.08\text{atm.}$

Example 2
A bicycle pump contains 50cm^3 of air at 17^{0}C and a pressure of one atmosphere. Find the air pressure when it is compressed to 10cm^3 and its temperature rises to 27^{0}C.
Solution

$V_1 = 50\text{cm}^3., T_1 = 17 + 273 = 290\text{K}, P_1 = 1\text{ atm}$ $V_2 = 10\text{cm}^3, T_2 = 27 + 273 = 300\text{K}, P_2 = ?$
$\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2} \Leftrightarrow \frac{1(50)}{290} = \frac{10P_2}{300} \Leftrightarrow P_2 = 5.17\text{atm.}$

Standard temperature and pressure (S.T.P)
This is the physical condition of temperature equal to 0°C and pressure is equal to 76cmHg at S.T.P, one mole of any gas occupies a volume of 22.4*l*.

Gas laws and kinetic theory.
Kinetic theory of matter states that, matter is made up of small particles called atoms or molecules that are in a constant random motion and the speed of movement of the particles is directly proportional to temperature.
-The theory considers the molecules of a gas to be like elastic spheres.
-Each time one of the molecules strikes the wall of the container it rebounds.
-The force produced on the on the wall by a molecule is the momentum change per second. So the gas pressure due to all bombarding molecules is proportional to their average total momentum per second (Force) normal to the wall.

Kinetic theory can be used to explain the cause of; -Gas pressure
-Boyle's law
-Charles's law
-Pressure law

a) Causes of gas pressure.
-Gas molecules are in constant random motion colliding with each other and bombarding the walls of the container.
-As they bombard the walls of the container, they exert a force on the walls. These forces cause gas pressure.

Boyle's law
-At constant temperature, the average speed of gas molecules is constant.
-When the volume of the container decreases, the rate of collision and bombardment increases resulting in increase of force exerted on the walls and increase in pressure.
-Likewise increase in volume at constant temperature result in decrease in pressure.

Charles 's law.
-When temperature of gas molecules increases, they move faster.
-To maintain the pressure constant, the volume of gas must increase so that molecules travel further between collisions with the walls.
-This results in fewer collisions per second.

Pressure law.
-When the temperature of gas increases, molecules move faster
-Raising the temperature of a fixed mass of gas at constant volume increases the average kinetic energy of the molecules so that the molecules make more frequent collisions with walls at high velocity.
- This decreases the rate of bombardment (few molecules collide), resulting in decrease in gas pressure.

b) Effect of Temperature on pressure
-When a gas is heated and its temperature rises, the average kinetic energy of the molecules increases and the average speed of the molecules increases.
-The frequency of the collisions of the molecules with the walls of the container increases hence the pressure of the gas increases.
-If the container is flexible, the volume of the gas increases in order to maintain the pressure constant.
-If the volume of the gas is to remain constant the pressure of the gas increases due to more frequent and more violent collisions of the molecules with the walls.
-The above explanation is used to explain why a balloon inflated with air bursts when left in sunshine.
-This is because the temperature rises yet volume remains constant so the pressure increases due to more frequent and more violent collision of the molecules with the walls.

Absolute zero is the temperature at which the molecules have their lowest possible kinetic energy.

Exercise 2: See UNEB Past papers.

1. 1997 Qn.3	6. 1989 Qn.13	11. 2006 Qn.15
2. 1998 Qn.6	7. 1992 Qn.6	12. 1989 Qn.7
3. 2003 Qn.4	8. 2000 Qn.33	13. 1991 Qn. 10
4. 2007 Qn.43	9. 2002 Qn.12	14.
5. 2001 Qn.3	10.1993 Qn.3	15.

(e) MEASUREMENT OF HEAT (QUANTITY OF HEAT)

(a). Heat Capacity

Heat capacity is the quantity of heat required to raise the temperature of a body by 1 Kelvin.

In general, the amount of heat required to raise the temperature of a substance by one Kelvin. The S.I. unit of heat capacity is Joules per Kelvin ($\mathbf{JK^{-1}}$).

$$\text{Heat Capacity, } \mathbf{C} = \frac{\text{Quantity of Heat}}{\text{Temperature Channge}} = \frac{\mathbf{Q}}{\Delta\boldsymbol{\theta}}$$

(b). Specific Heat Capacity

The word specific refers to a unit quantity of physical property.

Specific Heat Capacity is the quantity of heat required to raise the temperature of a 1Kg mass of a substance by 1K.

The S.I unit of specific heat capacity is Joules per kilogram Kelvin () or Joules per kilogram per Kelvin ($\mathbf{JKg^{-1}K^{-1}}$).

$$\text{Specific Heat Capacity} = \frac{\text{Quantity of Heat}}{\text{Mass} \times \text{Temp. Channge}}$$

$$C = \frac{Q}{m\Delta\theta}$$

$$\text{Heat Energy} = \text{Mass} \times \text{S.H.C} \times \text{Temp. change}$$

$$\textbf{Heat Energy} = \mathbf{mC\Delta\theta}$$

Where $\Delta\theta$ is the temperature rise from initial temperature $\theta_1$to final temperature, θ_2.

Then$\Delta\ \boldsymbol{\theta} = (\theta_2 - \theta_1)$

m = mass of substance, C= specific heat capacity.

$$\text{Heat capacity} = \text{mass} \times \text{Specific Heat Capacity}$$

NOTE:

When using H $= \mathbf{mC\Delta\theta}$ **;**

1. The mass, m must be in in S.I unit (Kg).
2. In questions with the phrase "the temperature rises by …^{0}C or the temperature rose by…^{0}C; the temperature value given is the change in temperature, $\boldsymbol{\Delta\theta}$**.**

Example:

If the temperature of substance change from 20^{o}c to 40^{o}c. Then the temperature rise is;

$\Delta\ \boldsymbol{\theta} = (\theta_2 - \theta_1) = (40 - 20) = 20^0$C

Note: The value of C is different for different substances. The table shows values of specific heat capacities of some common substances.

Substance	Specific Heat Capacity ($\mathbf{JKg^{-1}K^{-1}}$)
1.Water	4200
2.Ice	2100
3.Aluminium	900
4.Copper	400
N.B:The high specific heat capacity of water makes water a very good liquid for cooling machines.	

Importance of the high specific heat capacity of water

The high specific heat capacity of water makes the temperature rise and fall to be slower for water.

-This is one of the major reasons why water is used in the cooling system of engines and radiator of central heating system.

-The other reason why water is used is because it is cheaper and available.

The specific heat capacity of water is $4200\text{JKg}^{-1}\text{K}^{-1}$ and that of soil is about $800\text{JKg}^{-1}\text{K}^{-1}$. This results in the temperature of the sea to rise and fall more slowly than that of land.

The specific heat capacity of water being $4200\text{JKg}^{-1}\text{K}^{-1}$ means that heat of 4200J is required by 1kg of water to raise its temperature by 1K.

Islands are surrounded by water as they experience much smaller changes of temperatures from summer to winter because the specific heat capacity of water is high so that temperature rises and falls more slowly.

Example 1

How much heat is needed to rise the temperature from 30^{0}c to 0^{o}c for an iron of 5kg. Specific heat capacity of iron is 440J/KgK.

Solution:

$\boldsymbol{\Delta\theta} = (\theta_2 - \theta_1) = (40 - 30) = 10^0\text{C}$

$$\begin{aligned}\textbf{Heat Energy} &= \mathbf{mC\Delta\theta}\\ &= 5 \times 440 \times 10\\ &= 22000\text{J}\end{aligned}$$

Example 2: (2000 Qn. 4)

When a block of iron of mass 2Kg absorbs 19KJ of heat, its temperature rises by 10^{0}C. Find the specific heat capacity of iron.

Solution:

$\text{Q} = 19\text{KJ} = 19 \times 1000 = 19000; \boldsymbol{\Delta\theta} = 10^0\text{C}; \text{C?}$

$\textbf{Heat Energy}, \mathbf{Q} = \mathbf{mC\Delta\theta}$

$19000 = 2 \times \text{C} \times 10$

$19000 = 20\text{C}$

$\text{C} = 950\text{JKg}^{-1}\text{K}^{-1}$

Example 3: (2003 Qn. 13)

Find the amount heat required to raise the temperature of a 0.5Kg salt solution from -5^0C to 15^0C. Specific heat capacity of salt solution is $4000\text{JKg}^{-1}\text{K}^{-1}$.

Solution:

$\text{Q} =?\ \text{m} = 0.5\text{Kg}; \theta_1 = -5\ ^0\text{C},\ \theta_2 = 15\ ^0\text{C};$

$\Delta\ \boldsymbol{\theta} = (\theta_2 - \theta_1) = (15 - -5) = 20\ ^0\text{C}$

$$\begin{aligned}\textbf{Heat Energy}, \mathbf{Q} &= \mathbf{mC\Delta\theta}\\ &= 0.5 \times 4000 \times 20\\ &= 40000\text{J}\end{aligned}$$

Example 4: (1992 Qn. 4)

Find the amount heat required to raise the temperature of a 20g of water from 30^{0}C to 60^{0}C. Specific heat capacity of water is $4200\text{JKg}^{-1}\text{K}^{-1}$.

Solution:

$\text{Q} =?\ \text{m} = 20\text{g} = \frac{20}{1000} = 0.02\text{Kg};$

$\boldsymbol{\Delta\theta} = (\theta_2 - \theta_1) = (60 - 30) = 30\ ^0\text{C}$

$$\textbf{Heat Energy}, \mathbf{Q} = \mathbf{mC\Delta\theta}$$
$$= 0.02 \times 4200 \times 30$$
$$= 2520\text{J}$$

Example 5: **UNEB 1997. Qn. 15**

Calculate the specific heat capacity of paraffin if 22000 joules of heat are required to raise the temperature of 2.0 Kg of paraffin from 20^0Cto 30^0C.

CALORIMETRY

Calorimetry is the measurement of heat exchanged.

The device used in calorimetry is a calorimeter. It is usually made of copper.

The calorimeter is lagged with an insulator and placed in a jacket with a plastic cover which has two holes for a thermometer and a stirrer.

Methods of Measuring Specific Heat Capacity

(i) Method of mixtures

(ii) Electrical Method (not on syllabus)

Describing the method of mixture

-The method of mixture involves mixing a solid with a liquid at different temperature but the specific heat capacity of either solid or liquid should be known.

-In this method a hot substance is mixed with a cold substance and then stirred. Then heat will flow from a hot substance to the cold substance until both are at the same temperature.

-If no heat is lost to the surrounding then heat lost by the hot substance = heat gained by cold substance.

NOTE:

1.-If the heat capacity of the calorimeter (or container) is NOT neglected, then heat lost by the hot object is gained by both the calorimeter and its content.

-Both the calorimeter and its content always have the same temperature values. Thus

$$\begin{pmatrix}\text{Heat lost by}\\ \text{hot body}\end{pmatrix} = \begin{pmatrix}\text{Heat}\\ \text{gained}\\ \text{by cold}\\ \text{body}\end{pmatrix} + \begin{pmatrix}\text{Heat}\\ \text{gained by}\\ \text{calorimeter}\end{pmatrix}$$

$$(\mathbf{m_s C_s \Delta\theta}) = (\mathbf{m_l C_l \Delta\theta}) + (\mathbf{m_c C_c \Delta\theta})$$

2. If the heat capacity of the calorimeter is neglected, then the heat gained by the calorimeter is neglected and is not included in the calculation.

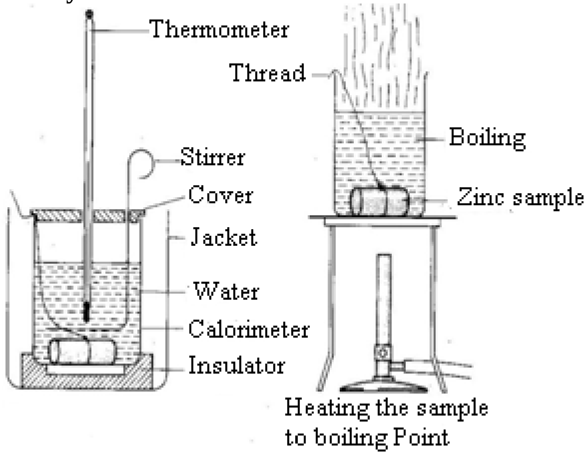
$$\begin{pmatrix}\text{Heat lost by}\\ \text{hot body}\end{pmatrix} = \begin{pmatrix}\text{Heat gained}\\ \text{by cold body}\end{pmatrix}$$

$$(\mathbf{m_s C_s \Delta\theta}) = (\mathbf{m_l C_l \Delta\theta})$$

Where, $\mathbf{m_s}, \mathbf{m_l}, \mathbf{m_c}$ = masses of hot body, cold body and calorimeter respectively

$\mathbf{C_s}, \mathbf{C_l}, \mathbf{C_c}$ = Specific Heat Capacity of hot body, cold body and calorimeter respectively

Experiment to determine the specific heat capacity of a solid by method of mixture



Procedure

-Put water of mass m_1 in a container of heat capacity c_1

-Put calorimeter and its contents in a calorimeter jacket and record their initial temperature θ_1

-Meanwhile, put the solid of mass m in boiling water in a beaker as shown in figure (i) above for some minutes. Record the boiling point θ_2

-<u>Quickly</u> transfer the solid from boiling water to the calorimeter using a string.

-Begin to stir until the <u>final steady</u> temperature θ_3 is obtained (the heat shield is to prevent the heating from boiling water to reach the calorimeter).

-Assume negligible heat to the surrounding.

$$\begin{pmatrix}\textbf{Heat lost by}\\ \textbf{hot body}\end{pmatrix} = \begin{pmatrix}\textbf{Heat}\\ \textbf{gained}\\ \textbf{by cold}\\ \textbf{water}\end{pmatrix} + \begin{pmatrix}\textbf{Heat}\\ \textbf{gained by}\\ \textbf{calorimeter}\end{pmatrix}$$

$$(\mathbf{m_s C_s \Delta\theta}) = (\mathbf{m_w C_w \Delta\theta}) + (\mathbf{m_c C_c \Delta\theta})$$

$$m_s C_s(\theta_3 - \theta_2) = m_w C_w(\theta_2 - \theta_1) + m_c C_c(\theta_2 - \theta_1)$$

$$C_s = \frac{m_w C_w(\theta_2 - \theta_1) + m_c C_c(\theta_2 - \theta_1)}{m_s(\theta_3 - \theta_2)}$$

Knowing values of C_1,M_1, M_2, C_2,M and temperature changes, specific heat capacity of a solid C_s can be obtained from the above expression.

Precautions

- The specimen must be transferred as fast as possible but with care to avoid splashing of water from calorimeter.
- The calorimeter must be insulated and placed on an insulating stand in a constant temperature bath.
- The calorimeter must be polished on its inner and outer surface to reduce heat loss by radiation.
- Stirring must be done to ensure uniform distribution of heat.

NOTE:

To determine the specific Heat capacity of the liquid, the same procedure above is used. However in this case, a solid of known specific heat capacity is used and C_l is made the subject of the formula.

$$m_s C_s(\theta_3 - \theta_2) = m_i C_l(\theta_2 - \theta_1) + m_c C_c(\theta_2 - \theta_1)$$

$$C_l = \frac{m_s C_s(\theta_3 - \theta_2) - m_c C_c(\theta_2 - \theta_1)}{m_l(\theta_2 - \theta_1)}$$

Example 1:
A piece of metal of mass 0.5kg is heated to 100ºc and then placed in 0.4kg of water at 10ºc. If the final temperature of the mixture is 30ºc. calculate the specific heat capacity of the metal.
(The S.H.C of water is $4200JKg^{-1}K^{-1}$)

Solution:

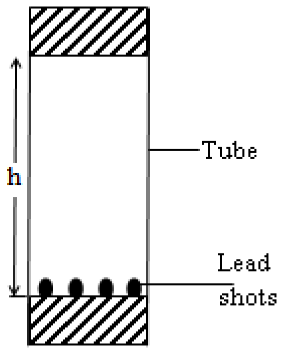
$\theta_3 = 100^0C; m_s = 0.5kg$ $\theta_2 = 30^0C;\ \ m_w = 0.4kg$ $\theta_1 = 10^0C;$
Assume negligible heat to the surrounding. $\begin{pmatrix}\text{Heat lost by}\\ \text{hot body}\end{pmatrix} = \begin{pmatrix}\text{Heat gained}\\ \text{by cold water}\end{pmatrix}$ $m_sC_s(\theta_3 - \theta_2) = m_wC_w(\theta_2 - \theta_1)$ $0.5 \times C_s \times (100 - 30) = 0.4 \times 4200(30 - 10)$ $35C_s = 0.4(4200)(20)$ $C_s = 960JKg^{-1}K^{-1}$

Note:
Liquid take up the volume of the container when filled so when a liquid is filled in a container the volume of the container is equal to the volume of liquid filling it.

$$\begin{pmatrix}\text{Mass of}\\ \text{liquid}\end{pmatrix} = \begin{pmatrix}\text{volume of}\\ \text{liquid}\end{pmatrix} \text{x} \begin{pmatrix}\text{density of}\\ \text{liquid}\end{pmatrix}$$

Example 2: UNEB 1993. Qn. 3(d)
A copper block of mass 250g is heated to a temperature of 145^0C and then dropped into a copper calorimeter of mass 250g containing $250cm^3$ of water at 20^0C.
(i) Calculate the maximum temperature attained by the water. (S.H.C of water is $4200JKg^{-1}K^{-1}$).
(ii) Sketch a graph to show the variation of temperature of water with time.

Solution:
Finding Specific Heat Capacity by Mechanical method



-Lead shots of measured temperature θ_1 and mass "m" are placed in a tube as shown above. When the tube is inverted, they fall through distance "h". so potential energy of the lead shots is **mgh**.
-This energy becomes kinetic energy which in turn becomes internal molecular energy when the lead shots are brought to rest. The internal molecular energy is heat energy which rises the temperature of lead shot from $\theta_1$toθ_2.
- Heat energy gained by the lead shots is equal to the potential energy lost by lead shot.

$$\mathbf{mc(\theta_2 - \theta_1) = mgh}$$

When the tube is inverted N times then the total potential energy is calculated as **Nmgh** so that heat gained is equal to potential energy lost.

$$mc(\theta_2 - \theta_1) = Nmgh$$
$$c(\theta_2 - \theta_1) = Ngh$$
$$\mathbf{c = \frac{gh}{(\theta_2 - \theta_1)}}$$

Where **N** is the number of time the tube is inverted. **g** is acceleration due to gravity and **h** is the distance through which the lead shots have fallen.

The distance "h" is the same as the length of the tube. This method is more advantageous than the method of mixtures because here the mass of substance is not required.

Example:
A tube length 10cm contains leads shots. If the tube is inverted 1000 times such that the temperature of the shots changes from 40ºc to 100ºc. calculate the specific heat capacity of the lead shots.

$h = 10cm = 0.1m; g = 10ms^{-2}; N = 1000times$
$c = \frac{gh}{(\theta_2 - \theta_1)} = \frac{1000 \times 10 \times 0.1}{100 - 40}$ $= \frac{1000}{60}$ $= 16.7JKg^{-1}K^{-1}$

Example:
A tank holding 60kg is heated by 3KW electric immersion. If the specific heat capacity is 4200J/kgk. Calculate the time taken for the temperature to rise from 10ºc to 60ºc.

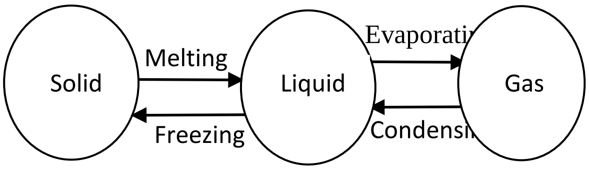
Solution:

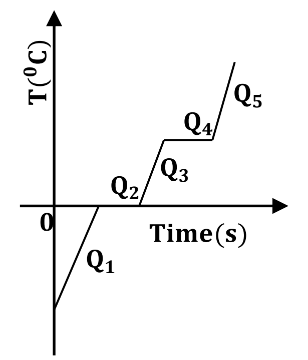
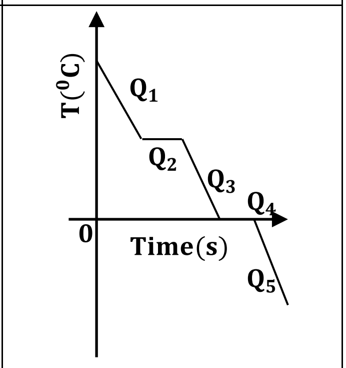
m=60kg P=3KW =3 x 1000W=3000W
$Energy = Power \times Time$ $mc(\theta_2 - \theta_1) = Pt$ $60 \times 4200 \times (60 - 10) = 3000t$ $t = 4200s$

LATENT HEAT (HIDDEN HEAT)
(a) Latent Heat
Latent heat is the quantity of heat absorbed or released at constant temperature by a substance during change of state.
Specific latent heat is the heat required to change one kilogram of substance from one state of matter to another without changing its temperature.

When a substance changes state from solid to liquid or liquid to solid liquid to gas the temperature remains constant although heat is supplied.

This can be explained by the kinetic theory.
When a solid is changing in state there is no temperature change because the supplied heat energy is being used by molecules to break away the intermolecular force holding them in one state.
Latent heat therefore is the heat which causes no change in temperature but changes the state, say solid to liquid, liquid to solid or liquid to gas.



<table>
<tr><td>(a) Heating Curve</td><td>(b) Cooling curve</td></tr>
<tr><td></td><td></td></tr>
<tr><td colspan="2">Q = Quantity of heat,
m = mass,
l_f = Latent heat of fusion,
l_v = Latent heat of vapourisation
c = Specific heat capacity
$\Delta\theta$ = Change in temperature</td></tr>
<tr><td>$\mathbf{Q_1}$: Temperature of ice increasing
$\mathbf{Q_1 = mc\Delta\theta}$

$\mathbf{Q_2}$: Ice changing to water
$\mathbf{Q_2 = ml_f}$

$\mathbf{Q_3}$: Temperature of water increasing
$\mathbf{Q_3 = mc\Delta\theta}$

$\mathbf{Q_4}$: water changing to vapour
$\mathbf{Q_4 = ml_v}$

$\mathbf{Q_5}$: Temperature of steam increasing
$\mathbf{Q_5 = mc\Delta\theta}$</td><td>$\mathbf{Q_1}$: Temperature of steam decreasing
$\mathbf{Q_1 = mc\Delta\theta}$

$\mathbf{Q_2}$: Steam condensing
$\mathbf{Q_2 = ml_v}$

$\mathbf{Q_3}$: water cooling
$\mathbf{Q_3 = mc\Delta\theta}$

$\mathbf{Q_4}$: water changing to ice
$\mathbf{Q_4 = ml_f}$

$\mathbf{Q_5}$: Ice cooling
$\mathbf{Q_5 = mc\Delta\theta}$</td></tr>
</table>

(b) Types of latent Heats

(i) Latent heat of fusion; $\mathbf{L_v}$

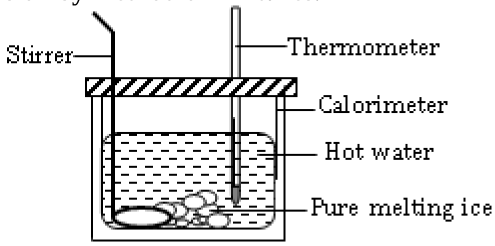
Latent heat of fusion is the quantity of heat required to change the state of a substance from solid to liquid at constant temperature.

Specific Latent heat of fusion is the quantity of heat required to change the state of a 1kg mass of substance from solid to liquid at constant temperature.

The S.I unit is a $\mathbf{Jkg^{-1}}$

$$\boxed{Q = mL_f}$$

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



-Pour pure hot water of known mass, $\mathbf{m_{Hw}}$and specific heat capacity $\mathbf{C_w}$ in a well lagged calorimeter of mass, $\mathbf{m_c}$and specific heat capacity $\mathbf{C_c}$.

-Record the initial temperature of,$\theta_1$of hot water.

-Place small pieces of pure melting ice at 0^0C into the calorimeter and stir the mixture gently until all the ice melts.

- Read and record the final temperature of,$\theta_2$of the mixture in the calorimeter.

-Re weigh the calorimeter and its content to determine the mass of melted ice $\boldsymbol{m_i}$from the formula;

$$m_i = (m_i + m_{Hw} + m_c) - (m_{Hw} + m_c)$$

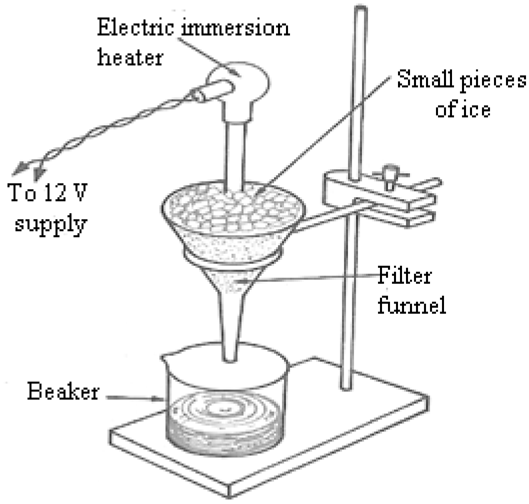
-Heat lost by hot water and calorimeter is equal to heat gained by ice and cold water from ice

$$\boldsymbol{m_{Hw}C_w\Delta\theta + m_cC_c\Delta\theta = m_il_f + m_wC_w\Delta\theta}$$

$$\begin{bmatrix} m_{Hw}C_w(\theta_1 - \theta_2) \\ +m_cC_c(\theta_1 - \theta_2) \end{bmatrix} = m_il_f + m_wC_w(\theta_2 - 0)$$

$$l_f = \frac{\begin{bmatrix} \mathrm{m_{Hw}C_w}(\theta_1 - \theta_2) \\ +\mathrm{m_cC_c}(\theta_1 - \theta_2) \end{bmatrix} - \mathrm{m_wC_w}(\theta_2 - 0)}{m_i}$$

Experiment to determine the specific latent heat of fusion by Electrical method.



Procedures:

a) Placing heater;

An electric heater of known power “p” is placed in filter funnel.

b) Packing small pieces of ice

Small pieces of ice are packed around the electric heater.

c) Switching on and timing;

The heater is switched on for a known time “t” and mass “m” of water collected in the beaker is weighed and determined from the formula:

$$\begin{pmatrix}\text{Mass of} \\ \text{melted ice}\end{pmatrix} = \begin{pmatrix}\text{Mass of empty} \\ \text{beaker + water}\end{pmatrix} - \begin{pmatrix}\text{Mass of} \\ \text{beaker}\end{pmatrix}$$

Conclusion:

The specific latent heat of fusion of ice, L_f is calculated from the formula;

$$Pt = mL_f$$

Assumption;

- No heat is absorbed from the surrounding.
- All heat supplied by the heater has been absorbed by the ice only.

Significance of high value of specific latent heat of fusion [$L_f = 340,000 Jkg^{-1}$]

Ice is often used as a cooling agent e.g. ice cubes are added to juice to keep it cold.

(ii) Latent heat of vapourisation

Latent heat of vapourisation is the quantity of heat required to change the state of a substance from liquid state to gas at constant temperature.

Specific Latent heat of fusion is the quantity of heat required to change the state of a 1kg mass of substance from liquid state to a gas at constant temperature.

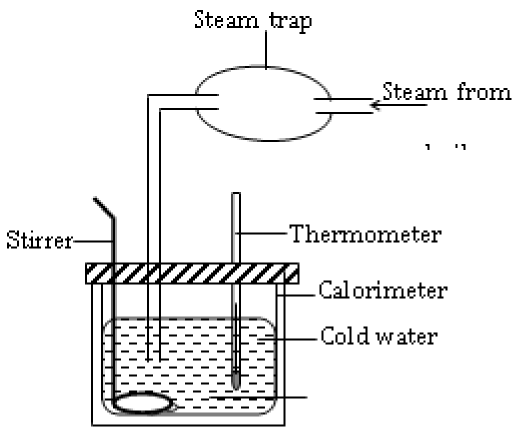
The S.I unit is a Jkg^{-1}

$$\boxed{Q = mL_v}$$

Importance of the very high value of specific latent heat of vapourization of steam [$L_v = 2,260,000 Jkg^{-1}$]

- ✓ Because of high value, steam is used as a heating agent e.g. In cookers (cooking)
- ✓ Can be used for sterilizing medical tools e.g. blades, forceps, e.t.c.

Experiment to determine the specific latent heat of vapourization by method of mixtures.



-Pour pure cold water of known mass, m_{cw} and specific heat capacity C_w in a well lagged calorimeter of mass, m_c and specific heat capacity C_c.

-Record the initial temperature of, θ_1 of cold water.

-Pass steam from boiling pure water at 100^0C into cold water in the calorimeter for some time and stir the mixture gently until all the temperatures are steady.

- Read and record the final temperature of, θ_2 of the mixture in the calorimeter.

-Re weigh the calorimeter and its content to determine the mass of melted ice m_s from the formula;

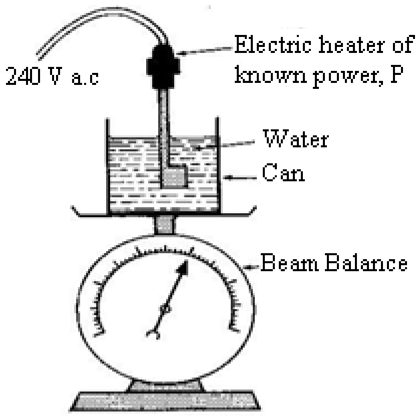
$$m_s = (m_s + m_{cw} + m_c) - (m_{cw} + m_c)$$

-Heat lost by hot steam and condensed water from steam is equal to heat gained by cold water and calorimeter

$$m_s l_v + m_s C_w \Delta\theta = m_{cw} C_w \Delta\theta + m_c C_c \Delta\theta$$

$$l_v = \frac{\begin{bmatrix} m_{cw}C_w(100-\theta_2) \\ +m_cC_c(\theta_2-\theta_1) \end{bmatrix} - m_sC_w(\theta_2-\theta_1)}{m_s}$$

Determination of specific latent heat of vaporization of steam by electrical method



Procedures:

a)

Weigh the mass of water and the beaker and record it as m_1.

b) Placing heater;

An electric heater of known power "p" is placed in the water in a can placed on top of a beam balance.

c) Switching on and timing;

The heater is switched on for a known time "t" and Weigh the mass of water and the beaker again and record it as m_2.

d) Finding mass of steam

The mass "m" of steam escaped is determined from the formula:

$$\begin{pmatrix} \text{Mass of} \\ \text{steam} \end{pmatrix} = (m_1) - (m_2)$$

Conclusion:

The specific latent heat of vapourisation of steam L_v is calculated from the formula;

$$Pt = mL_v$$

Latent heat and kinetic theory

(a) Latent heat of fusion.

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

The average K.E of molecules remaining constant because melting takes place at constant temperature.

(b) Latent heat of vaporization;

During change of state from liquid to vapour, (Boiling) at constant temperature, the heat supplied weakens the intermolecular forces of attraction, the molecular spacing increase, so that they gain freedom to move about independently.

As a result, the heat supplied is used to overcome these forces resulting in gain molecular potential energy but not their kinetic energy and also the work to expand against atmospheric pressure.

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

Specific latent heat of vaporization is always greater than L_f because for molecules of a liquid to escape, they require a lot of heat which increases the K.E in order to overcome the intermolecular forces of attraction.
While for latent heat of fusion very low amount of heat is required to weaken the intermolecular forces of attraction.

Effect of latent heat of vaporization
When steam at 100°c condenses on your body, it produces more serious burn than one would have from an equal mass of water at 100°c because when steam condenses latent heat is given out.

How to apply the formula in calculations
The following should be noted;
1. When applying the heat formula for change of state from either solid to liquid or liquid to solid the value of specific latent heat of fusion should be used.
2. The substance must either be at the melting point temperature for solid to liquid or at freezing point temperature for liquid to solid.

a) For a solid at melting point changing to liquid at freezing point.
Example I: How much heat is required to melt 10g of ice at 0°c given specific latent heat of fusion is 3.36×10^5 J/Kg.

Solution
$\text{Heat} = mL_f$
$\text{Heat} = \left(\frac{10}{1000}\right) \times (3.36 \times 10^5)$
$\text{Heat} = 336000\text{JKg}^{-1}$

b) When the solid is not at the melting point changing to a liquid at freezing point
In this case heat energy for changing the temperature to melting point is required. The heat for change the solid to liquid is applied, so heat energy required = Heat for change of temperature to melting point.+ Heat for change of state
$\text{Heat} = mc\Delta\theta + mL_f$
$\text{Heat} = mc(\theta_2 - \theta_1) + mL_f$
Where: m is mass the substance
C is the specific heat capacity of the solid
θ_2 is the melting temperature of the solid
θ_1 is the initial temperature of the solid.

Example 2:
How much heat is required to change 10g mass of ice at –10°c to water at 0°c. Given that the specific heat capacity of ice is 2100J/KgK. and the special latent fusion of ice is 3.36 x 10^5 J/Kg.

Solution
$\text{Heat required} = mc(\theta_2 - \theta_1) + mL_f$
$$\text{Heat required} = \left(\frac{10}{1000}\right)(2100)(0 - -10) + \left(\frac{10}{1000}\right)(3.36 \times 10^5)$$
$\text{Heat required} = 336000 \text{ J}$

(c) For a solid not at melting point to a liquid not at freezing point.
Heat required = Heat for change of temperature of solid to melting point + Heat for change of state from solid to liquid + Heat for change of temp at melting point to a given temperature.
$\text{Heat} = mc_1\Delta\theta_1 + mL_f + mc_2\Delta\theta_2$

WHERE
m is mass of the solid which is also the same as the mass of the liquid formed
$\Delta\theta_1$ is the change in temperature of the solid from its initial temperature to melting temperature.
$\Delta\theta_2$ is the change in temperature of the liquid formed from temperature to the final temperature of the liquid.
C_1 is the specific heat capacity of a liquid
C_2 is the specific heat capacity of the solid
L_f is the specific latent heat of fusion

Example
10g of ice at -10°c is heated to water at 30°c given that the S.H.C of ice is 2100 J/KgK, the S.H.C of water 4200J/KgK. The specific latent heat of fusion of water is $3.36 \, x \, 10^5$J/Kg. Calculate the heat energy supplied.

Solution:
States involved
i) Solid at -10°c ii) solid liquid at melting point 0°C
iii) Liquid at 30°C

$m = 10\text{g} = 0.01\text{kg}$;
$\theta_2 = 0^0\text{C}$;
$\theta_1 = -10^0\text{C}$;

$$\binom{\text{Heat}}{\text{supplied}} = mc_1\Delta\theta_1 + mL_f + mc_2\Delta\theta_2$$
$$\binom{\text{Heat}}{\text{supplied}} = 0.01(2100)(0+10) + 0.01(336000) + 0.01(4200)(30-0)$$
$$\text{Heat supplied} = 210 + 3360 + 1260 = 4830 \text{ J}$$

Example
A 3kw electrical heater is left on for two minutes when its placed in a container packed with ice. If 100g of ice was melted to water, calculate the specific latent heat of fusion of ice.

Solution:
$P = 3KW = 3000W; m = 100g = 0.1Kg; t = 2min$

Solution
$\text{Heat} = mL_f$
$pt = mL_f$

$3000 \times 120 = 0.1 \times L_f$
$360000 = 0.1L_f$
$L_f = 3600000 \text{ Jkg}^{-1}$

Note:
When the body changes state from liquid to solid, the same amount of latent of fusion is given out.

Example

When the 1.5kw heater was switched on for 26 minutes, the top balance recorded that the mass of the beaker was reduced by 1kg. Calculate the specific latent heat of vaporization of water.

Solution:

$P = 1.5KW = 1500W; m = \text{mass lost as steam} = 1kg$; $t = 26min = 1560s$
$Heat = mL_v$ $pt = mL_v$ $1500 \times 1560 = 1 \times L_v$ $2340000 = L_v$ $L_v = 2340000\ Jkg^{-1}$

Note:
If it's a change of state from liquid to gas (vapour) or gas to liquid then the specific latent heat of vaporization should be used.

Exercise

1. Calculate the mass of steam at 100°c needed to raise temperature of water by 1kg from 20°c to 80oc. Specific heat capacity of water is 4000J/Kgk.
[Ans: $m = 0.10$ Kg]

2. Calculate the heat required to convert 5kg of ice at -20^{0}C to steam at 100^{0}C.
[Given that the S.H.C of ice is 2100 J/KgK, the S.H.C of water 400J/KgK. The specific latent heat of fusion of water is $3.4\,x\,10^5$J/Kg and the specific latent heat of vapourizationis $2.3\,x\,10^6$J/Kg.
[Ans: $Q = 15{,}510{,}000$ J]

3. Musa was carrying out an experiment. He heated 200g of copper metal block to 98^{0}C. He then transferred it quickly to 300g of water in a copper calorimeter of mass 100g at 30^{0}C. Calculate the final temperature of the mixture.
{Specific heat capacities of water and copper are 4200J/KgK and 400J/KgK respectively}

4. Two bath taps H and C deliver hot and cold water respectively at the same rate into a bath tab. Tap H is opened for 20 seconds while tap C is opened for 35 seconds.
If the initial temperatures of water from H and C are 75^{0}C and 24^{0}C respectively, find the temperature of the water in the bath tab assuming the heat capacity of the bath bat to be negligible.
A: 12.0 B: 24.0 C: 42.5 D. 56.5

5. See **UNEB**

1989 Qn. 33	2001 Qn.34	1988 Qn.3
2006 Qn.8	2007 Qn.8	2000 Qn.3
1987 Qn.14	**Section B**	1992 Qn.8
1988 Qn.19	1988 Qn.5	
1999 Qn.15	1998 Qn.2	

<u>The heat received by a substance depends on the following factors:</u>

- Temperature
- Mass
- Nature of substance

f). VAPOURS

(i) Vapour is the gaseous state of a substance below its critical temperature i.e.
Critical temperature (T_c) is the minimum temperature above which the gas cannot be liquidized no matter how much pressure is applied.

(ii) Saturated vapour is the vapour which is in thermal dynamic equilibrium with its own liquid i.e. whose rate of evaporation = rate of condensation.

(iii) Un saturated vapour is the vapour which is not in thermal dynamic equilibrium with its own liquid i.e. whose rate of evaporation ≠ rate of condensation.

(iv) **Supper saturated vapour** is the vapour whose rate of evaporation > its rate of condensation.

(v) Thermal dynamic equilibrium is the liquid's thermal state at which its rate of evaporation is equal to its rate of condensation.

(vi)Vapour pressure is the pressure exerted on the walls of the container by the vapour molecules.

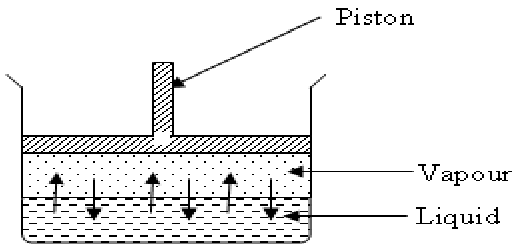
(vii) Saturated vapour pressure (s.v.p) is the pressure exerted by vapour which is in thermal dynamic equilibrium with its own liquid.

(viii) Un saturated vapour pressure is the pressure exerted by vapour which is not in thermo dynamic equilibrium with its own liquid
.

(ix) Supper saturated vapour pressure is the pressure exerted by vapour whose rate of evaporation > its rate of condensation.

(x) Dew point is defined as temperature of saturated atmospheric air.
NB: A cloudy film forms on screens of cars being driven in rain because of the condensation of the excess water vapour in atmospheric moist air as a result of exceeding its dew point.

Kinetic theory explanation for the occurrence of saturated vapour pressure (s.v.p)



- ✓ When a liquid in a closed container is heated, the energy which goes into it becomes mechanical energy to the molecules.
- ✓ Some of the liquid molecules get enough kinetic energy and break the intermolecular bonds and escape from the surface of the liquid and occupy the space just above it.
- ✓ These molecules constitute what we call **vapour** and the pressure they exert to the walls of the container as they collide with themselves and the walls of the container is called vapour pressure.

Vapour pressure is the pressure exterted by the escaping molecules of the vapour from the surface of the liquid.

- ✓ When these molecules bounce off from the walls of the container, they strike the liquid surface and re-enter the liquid until when a state of thermal dynamic equilibrium is attained i.e. (rate of evaporation = rate of condensation).
- ✓ In this state, the vapour is said to be saturated exerting saturated vapour pressure and before this state, vapour is un saturated (with rate of condensation > rate of evaporation) exerting un saturated vapor pressure**.**

Saturated vapour pressure (s.v.p) is the pressure exerted by vapour which is in thermal dynamic equilibrium with its own liquid.

NB:
Saturated vapours do not obey ideal gas laws because its mass changes due to condensation or evaporation as conditions change yet gas laws only apply to a constant mass of a gas.
It should be noted that saturated vapor occurs for a very short time and constant temperature (boiling point).

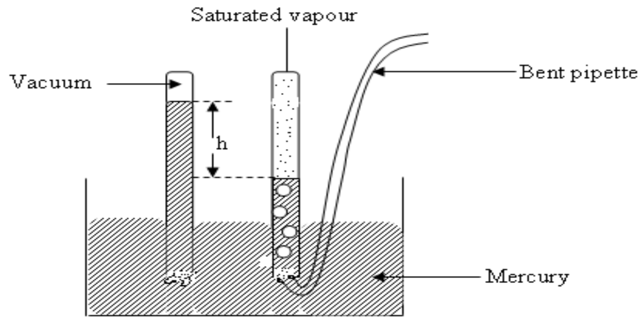
Comparison of vapour pressure

Saturated vapour.	**Un saturated vapour**.
It does not obey ideal gas laws.	It obeys ideal gas laws.
It is achieved at thermal dynamic equilibrium.	Its rate of evaporation ≠its rate of condensation.
Its pressure remains constant at particular temperature.	Its pressure increases with increase in temperature.

Determining saturated vapor pressure
Bent-pipette method
This method is used to determine the **s.v.p** of a volatile liquid at a particular temperature.

- **Procedure.**

Two barometers A and B are filled with mercury and inverted over a trough of mercury as shown. At first the mercury is at the same level.
The liquid whose **s.v.p** is to be determined is introduced with the help of a bent pipette in the vacuum space above the mercury level in one of the barometric tubes as shown below.



Observation
Some of the liquid evaporates immediately and the mercury column falls by "h".

Explanation
This is because the introduced lquid evaporates and forms a vapour which exerts a pressure on the mercury causing the column to fall.
.
When mercury has stopped dropping, the vapour is said to be in dynamic equilibrium, thus saturated vapour.
The pressure **$h\rho g$** is the **s.v.p** of the volatile liquid and **ρ** is its density.

Merits of mercury for this experiment

- Mercury is very dense compared to many liquids
- Mercury is opaque thus easily seen and read.

If too much water is introduced on top of mercury column
Observation
Some water evaporates and some remains on top of the mercury column.

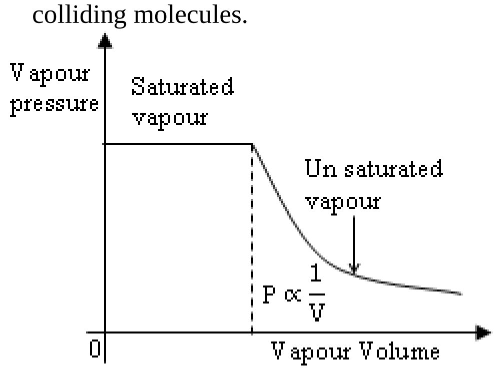
Explanation
Some water remains on the top because the space above becomes a saturated vapour so that the rate at which molecules leave the liquid surface is equal to the rate at which other molecules return to the liquid.

Effect of compression on a saturated vapour
The saturated vapour is compressed by lowering the tube.

Observation
The height "h" of mercury column remains constant but amount of water on top of the mercury column increases.

Explanation
The height "h" remains constant because saturated vapour pressure is not affected when the vapour is compressed. However, the amount of water increases because more vapour condenses when the vapour is compressed.

More Explanation:
- ✓ A reduction in vapour volume of saturated vapour mainly leads to an equal reduction in the number of vapour molecules above the liquid surface.
- ✓ Since s.v.p is achieved at constant temperature (boiling point), the vapour remains in thermal dynamic equilibrium.
- ✓ This means that the force per square meter (pressure) exerted on the walls of the container remains constant due to an equal reduction in the surface of the walls for colliding molecules.



Effect of expansion on saturated vapour
The saturated vapour is expanded by raising the tube
Observation

The height “h” of the column remains but the amount of water on top of the column decreases.

Explanation

The height “h” remains constant because the expansion of the saturated vapour becomes unsaturated on expansion so more water evaporates.

Vapour pressure and temperature

Effect of temperature on saturated vapour

When a saturated vapour is heated, it increases with temperature.

Although saturated vapour increases as temperature increases, a saturated vapour does not obey Boyle’s law and Charles’s law because;

- ✓ The mass of a saturated vapour is not fixed with temperature change but varies with temperature changes.
- ✓ The volume of saturated vapour is independent of pressure.

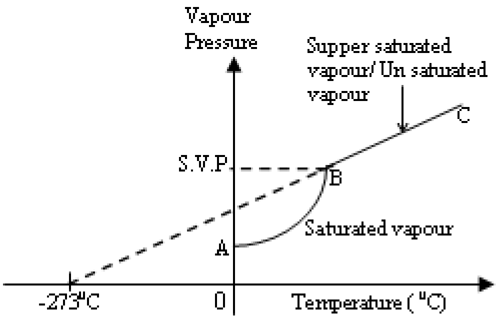
The mass of unsaturated vapour depends on the pressure. The mass of unsaturated vapour can be fixed while temperature changes.

More Explanation:

- Initially vapour pressure increase slowly with increase in temperature exponentially because fewer molecules are energetic enough to leave the liquid surface but as the liquid’s boiling point is approached, vapour pressure rapidly increases i.e. un saturated vapour pressure.
- At boiling point vapour pressure remains constant (saturated vapour pressure) since vapour is saturated.

- Heating the liquid beyond its boiling point results into supper saturated vapour whose rate of evaporation is greater than its rate of condensation and vapour pressure (un saturated vapour pressure) increases linearly with increase in temperature due to increased multiple collisions of vapour molecules with the walls of the container

Variation of pressure with temperature of saturated vapour



Explaining the graph

AB-Saturated vapour increases with increases in temperature, but does not obey the gas laws because:

(i) The volume of saturated vapour is independent of pressure.

(ii) The mass of a saturated vapourcannot be fixed as temperature changes.

BC-unsaturated vapour increase as temperature increases and obeys Boyle’s law and Charles’ law because:

(i) Volume of unsaturated vapour depends on the pressure

(ii) Mass of unsaturated vapour can be fixed when temperature changes.

Definition of saturated vapour pressure

A saturated vapour pressure is the pressure of a vapour which is in dynamic equilibrium with its liquid or solid.

Saturated vapourpressure and boiling point

A liquid will only boil when its saturated vapour pressure is equal to the atmospheric pressure.

What happens when a liquid boils?

When a liquid is heated its temperature rises. This makes the saturated vapour pressure to increase until it becomes equal to the atmospheric pressure.

At this stage further addition of heat, cause bubbles of the vapour to form inside liquid. This is boiling; therefore boiling point is the temperature at which saturated vapour pressure becomes equal to the external atmospheric pressure.

From the above it will be noted that the boiling point of a liquid depends on altitude because boiling occurs only when the saturated vapour pressure becomes equal to atmospheric pressure which depends on altitude.

Dew point

Dew point is the temperature at which the water vapourpresent in air is just sufficient to saturate it.

MELTING POINT, BOILING POINT AND EVAPORATION

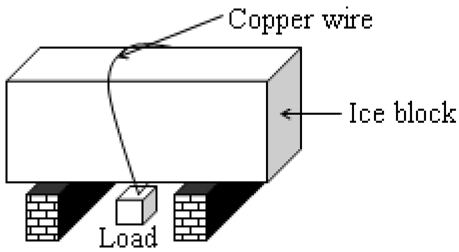
(a) Melting

This is defined as the process by which a solid turns to liquid at constant temperature called melting point i.e.

Melting point is constant temperature at which a solid substance liquidifies at constant atmospheric pressure.

Freezing point is constant temperature at which a molten substance solidifies at constant atmospheric.

Effect of pressure on melting point



When pressure is increased by the weighted copper wire

- Observation

The weighted copper wire passes through the block of ice without cutting it into two pieces.

- Explanation

This is because increasing pressure by the weighted copper wire lowers the melting point of ice, so the copper wire sinks through water and water which is no longer under pressure refreezes and gives out latent heat to the copper wire to enable melting of ice below.

In general increasing pressure decreases the melting point of solid and decreasing pressure increases the melting point.

Effect of impurities on the melting point
Impurities like salt lower the melting point of solid. E.g. the temperature of a well stirred ice water mixture is normally 0°c but when an impurity such as salt is added it may fall to -20°c.

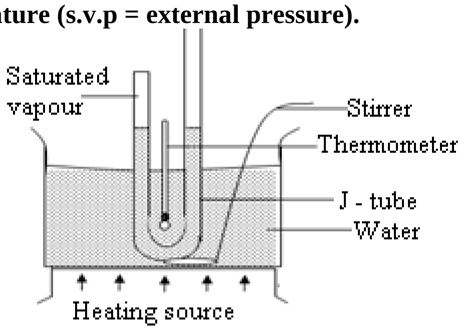
(b) Boiling
Boiling is a change of state from liquid to vapour that occurs within the liquid at constant temperature called boiling point.

Boiling point is the constant temperature of a liquid at which its saturated vapour pressure is equal to external atmospheric pressure.

Steam point is the constant temperature at which (pure water ↔vapuor) at 760mmHg. It is 100℃.

NB:
It should be noted that boiling of any liquid occurs only when its saturated vapor pressure equalizes with external pressure implying that when a liquid is boiling, there is change of state thus occurring constant temperature called boiling point.

Experiment to show that boiling occurs at constant temperature (s.v.p = external pressure).



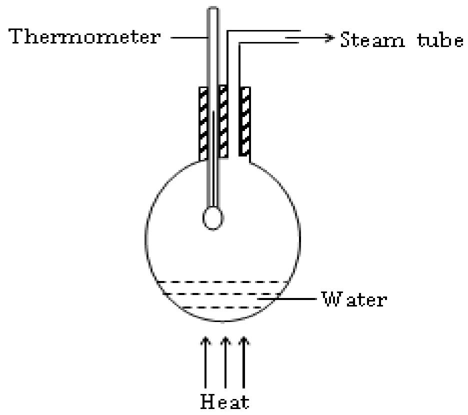
- **W**ater is trapped in a closed end of J-shaped tube and the tube is placed in a beaker containing water being heated from the base as it is stirred to ensure uniform distribution of heat throughout the liquid.
- When water in the beaker starts boiling, its vapour escapes and exerts pressure on water in the open limb of the J- shaped tube.
- At this point the thermometer reading remains constant and water in the J- shaped tube levels up indicating that saturated vapor pressure is equal to external pressure.

Effect of pressure on boiling point
The boiling point of a liquid is directly proportional to the pressure above the liquid.
❖ If the pressure above the liquid is increased, the boiling point of the liquid rises. This is because more external pressure compresses the water molecules into the liquid. This requires more heat energy to break such molecules, hence increasing the boiling temperature.

❖ But if the pressure above the liquid is decreased the boiling point of the liquid is lowered.

❖ In a pressure cooker, food cooks more quickly because the pressure of steam above water in the cooker can rise to twice the normal atmospheric value.

Experiment to show the effect of pressure on boiling points



✓ When heating is stopped, the tube is closed and the flask is cooled by cold water.

Observation
✓ Water starts to boil again through there is no heating.

Explanation
✓ This is because when the flask is cooled the water vapour or steam above the water condenses resulting in the pressure above to decrease. This decreases the boiling point.

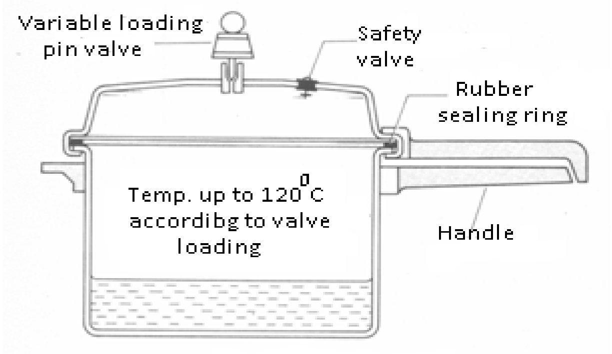
NOTE: Cooking has nothing to do with whether water is boiling or not. Boiling here is just a mere physical phenomenon that can be seen.
Cooking depends on two factors; Time and temperature.
$\textbf{Cooking (Hard boiling)} = \textbf{Time} \times \textbf{Temperature}$

Thus from the above, cooking to occur;
❖ At reduced temperature, increase the cooking time
❖ Very quickly, increase the cooking temperature.

The Pressure cooker
❖ Up on a mountain, the air pressure is low so water boils at a temperature less than 100°c. This is because the pressure on the surface of the water decreases on the mountain therefore cooking takes longer.

❖ If we raise the boiling point of water we can reduce the time taken to cook food. This is possible using a pressure cooker.

Pressure cookers are useful in places where atmospheric pressure is low like at the top of a mountain (high altitudes).



Cooking with a pressure cooker is faster than ordinary cooking because most of its top surface is covered leaving just a small opening to let out vapour.
This covering reduces the space of escape for vapour molecules which increase the pressure inside due to random collisions of vapour molecules thus raising the boiling point to about 120ºC, hence faster cooking due to much heat.

Effect of impurities on boiling point
Impurities such as salt when added to a liquid e.g. water the boiling point of the liquid rises.
Addition of impurities raises the boiling point of a liquid. This is because; impurities absorb some of the supplied heat making the liquid to boil at a higher temperature than its normal boiling point thus faster cooking.

(c) Evaporation
This is defined as the process by which a liquid turns to vapour molecules which occurs at the liquid surface. It takes place at all temperatures but it is greatest when the liquid is at its boiling point.
So evaporation is the conversion of a liquid into its gaseous state.

Rate of evaporation
This is the rate at which molecules of a liquid escape from the liquid surface per second.
The rate of evaporation of a liquid is increased by;
- Increasing the surface area of the liquid e.g. same amount of water put in a basin and cup exposed to the same drought, one in a basin reduces faster than that in a cup.
- Increasing the temperature of the liquid since increase in temperature directly increases the average kinetic energy of the molecules escaping.
- Providing drought which removes the vapour molecules from the liquid surface before returning to it e.g. water exposed to direct sunshine evaporates faster than that under a shade.
- Reducing the pressure of the air above the liquid surface (atmospheric pressure) e.g. evaporation is faster on a mountain than on a leveled ground.

Factors affecting evaporation

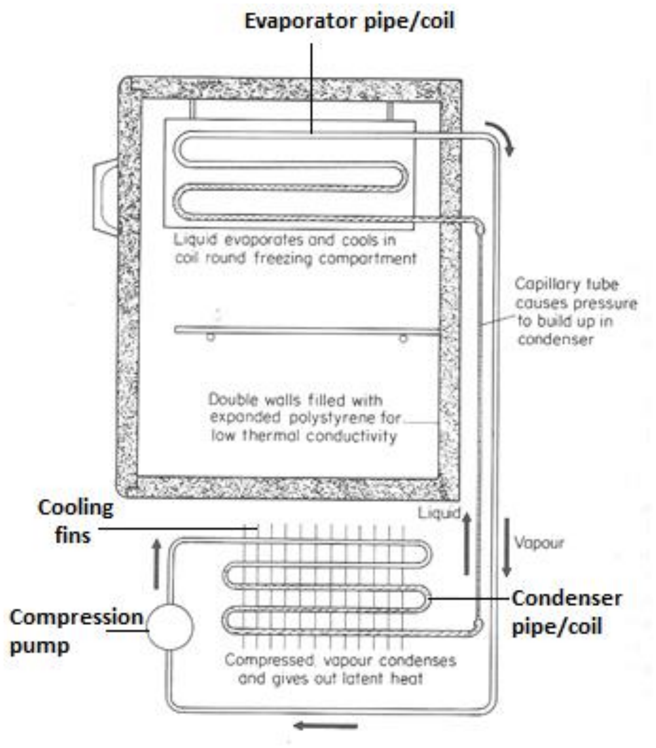
Factor	**Effect/Explanation**
Surface area	Increasing the surface area increases the rate of evaporation. Explanation This is because the increased surface area makes more molecules to be at the surface of the liquid where they can easily escape.
Temperature	Increasing temperature increases the rate of evaporation. Decreasing temperature decreases the rate of evaporation. Explanation This is because more molecules will move faster enough to escape from the surface of the liquid. This is because fewer molecules will move fast enough to escape from the surface of the liquid.
Drought (Air current)	The rate of evaporation increases when there is too much wind blowing over the liquid surface. Explanation Because wind blows away the energetic molecules that have already escaped from the liquid. This gives chance for more molecules to escape.
Pressure	High pressure above the liquid surface means there is a high exertion on the liquid surface thus preventing molecules from escaping
Concentration of the liquid vapour in air	If the air already has a high concentration of the substance evaporating, then, such substance will evaporate very slowly.
Intermolecular forces	The stronger the forces keeping the molecules together, the more energy needed to put them apart and escape. Hence the slower the rate of evaporation.

Explanation of evaporation according to the kinetic theory (How evaporation causes cooling).
- ✓ At a particular temperature, molecules of a liquid have an average speed but some molecules are moving faster than other.
- ✓ Evaporation occurs when faster moving molecules reach the surface and escape from the attractions of all the molecules.
- ✓ At the same time the slower molecules remain in the liquid causing the average kinetic energy of the molecules to fall.
- ✓ This causes cooling as temperature falls with falling averages kinetic energy.

Cooling
This is defined as the continuous fall of temperature of a body placed in drought until when it attains an equilibrium state.
Cooling as a result of evaporation is seen in:
- ❖ Panting of dogs
- ❖ Making ice by evaporation of a volatile liquid
- ❖ Refrigerators

THE REFRIGERATOR
A refrigerator is a cooling appliance which uses the mechanism that transfers heat from it to the external environment.
It is used in preservation of;
- ✓ Food – in homes and supermarkets.
- ✓ Blood – in blood banks in hospitals.
- ✓ Medicines – in pharmacies/hospitals/health centres.

How it works principle
A refrigerator works on the principle that heat is taken in at one point and given out at another point by the refrigerating substance (**Freon**) as it is pumped around the circuit.



Compressor/Pump:
1. Freon (a volatile liquid) or the refrigerant is compressed by the pump against the expansion valve, its pressure rises, and pushes it into the coils (cooling fins) on the outside of the refrigerator.

Condenser and cooling fins:
2. When the hot high pressure gas in the coils meets the cooler air temperature of the outside the cabinet, it is condensed to a liquid.

3. Now in liquid form at high pressure, the refrigerant cools down as it flows into the coils inside the freezer and the fridge. It dissipates all the latent heat to the surrounding by the cooling fins.

Evaporator:
4. The refrigerant absorbs the heat from the material contents inside the freezing box, cooling down the surrounding air and hence the contents.

5. Lastly, the refrigerant evaporates to a gas, and then flows back to the compressor, where the cycle starts again.

Functions of the main parts of refrigerator
Pump/Compressor
- ❖ The pump removes the vapour formed in the freezer
- ❖ The pump forces the vapour into the heat exchanger.

Heat exchanger or Condenser
It is where the vapour is compressed and liquefies giving out latent heat of vaporization.

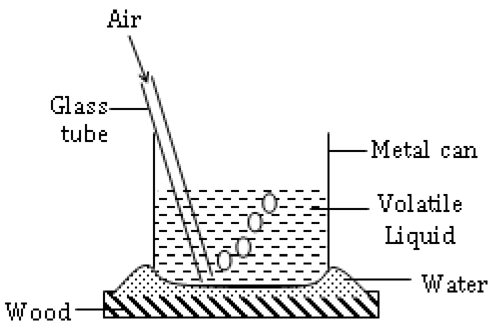
Cooling fins
The cooling fins give out the latent heat of vaporization to the surrounding air.
Note: The cooling fins are painted black so that they can quickly give or emit heat radiations.

Differences between evaporation and boiling

Evaporation	**Boiling**
i) Occurs at any temperature	Occurs at a fixed temperature called boiling point
ii) Occur at the surface of the liquid. No bubbles	Occurs within the liquid. Bubbles appear
iii) Depends on the surface area	Does not depend on the surface area
iv) Can occur even when atmospheric pressure is not equal to saturated vapour pressure	Occurs only when atmospheric pressure is equal to saturated vapour pressure
v) Causes cooling	Does not cause cooling

However evaporation and boiling are similar in that:
- ❖ Both evaporation and boiling need latent heat of vaporization.
- ❖ Both evaporation and boiling involve change of state from liquid to gas.

Making ice by evaporation of a volatile liquid like ether



Procedures:
- ✓ Place a metallic can filled with a volatile liquid like ether on a film of water at the top of a wooden block.
- ✓ Blow air current through a glass tube or straw as shown above.

Observation:
- ✓ The water underneath the can freezes and turns to ice.

Explanation:
- ✓ When a current of air is bubbled through ether, the ether evaporates in the bubbles which carry it to the surface and burst.
- ✓ So the bubbling of air through ether results in increasing the rate of evaporation. This rapid change of state from liquid to vapour requires latent heat which is conducted through the beaker from the water below it causing it to cool and form ice.

Note: The metallic can may be replaced by a beaker.

Application of good and bad conductors
i) Frying and cooking pans are made of metals because metals allow heat to pass through them easily.
ii) A metal always feels cold when touched on a cold day because it removes heat from the body and transfers it away very fast.
This shows that metals are good conductors of heat as they draw the heat from the body

iii) A handle of a frying pan is made of insulators such as wood or plastic because they are poor conductors.

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

3. OPTIC

3. OPTICS (LIGHT)

<u>Definition:</u>
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 $3.0\text{x}10^8$ 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:

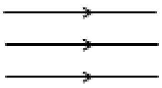
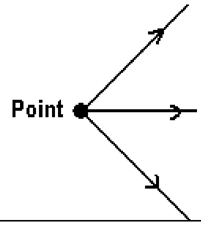
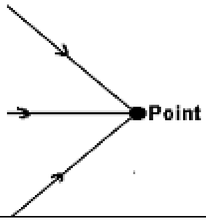
(i) <u>Transparent Medium</u>
A media which allows almost all of the light to pass through it and allows objects to be seen. E.g. colourless water, paraffin and colourless glass.

(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 

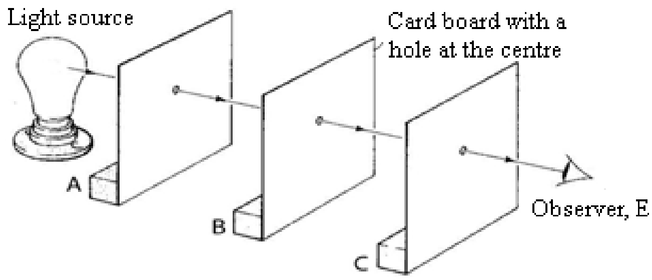
RECTILINEAR PROPAGATION OF LIGHT

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

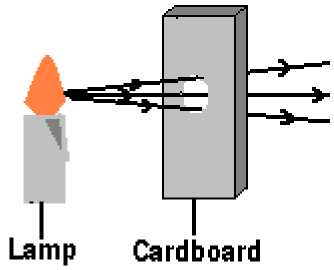
A shadow is a region of darkness formed when an opaque object obstructs the path of light.

Shadows are formed because light travels in a straight line.

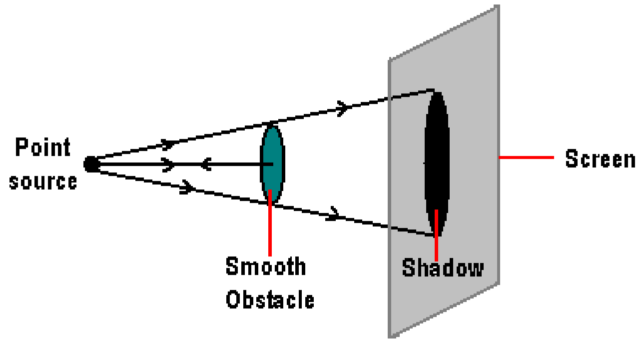
Shadow formation

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.

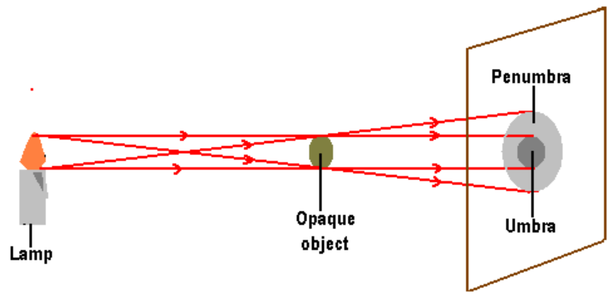


For a point source, a sharp shadow is formed, i.e. the shadow is also equally dark all over.

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

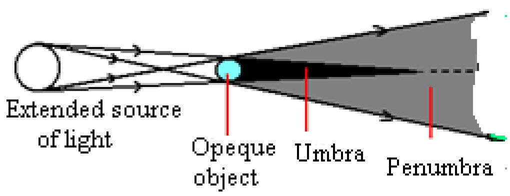
A region of shadow where no light reaches at all.

Penumbra

A region of the shadow where some light reaches.

Note:

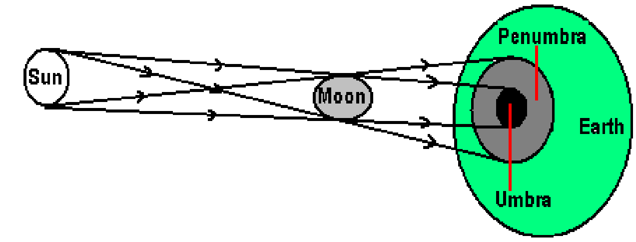
For an extended source: When the opaque object is moved near the source, the size of umbra decreases, but the size of penumbra increases. When the object is moved near the screen, the size of umbra increases, but the size of penumbra decreases.



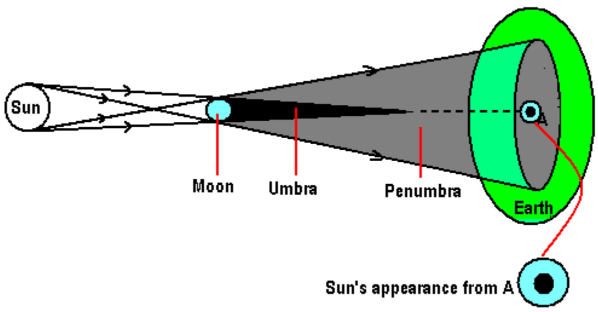
The umbra may fail to reach the screen if the opaque object is very far away from the screen

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.

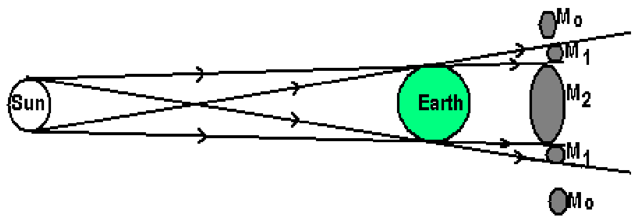


❖ ***Annular Eclipse:***
Annular eclipse of the sun occurs when the sun is very far from the earth and the moon is between the earth and the sun, such that the tip of the umbra is the one that reaches the earth's surface. From one place on the earth, the sun is represented by the appearance of a ring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

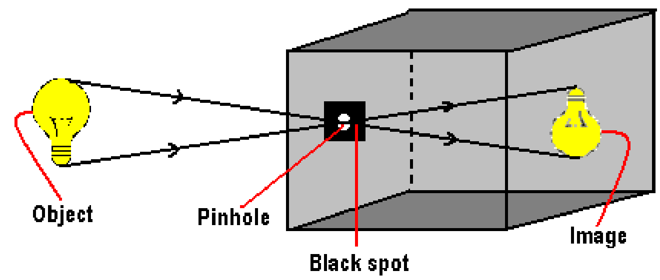


Note: Total eclipse of the moon lasts longer than total eclipse of the sun because for the moon, the earth which is in the middle is larger than the moon for the sun.

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 $M = \frac{\text{Image distance, V}}{\text{Object distance, U}}$ $M = \frac{10\text{ cm}}{150\text{ cm}} = \frac{1}{15} \ldots.(i)$ But also; $M = \frac{\text{Image height, h}}{\text{Object height, H}}$ $M = \frac{5\text{ cm}}{H} \quad \ldots.(ii)$ 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 Qn.22	2000 Qn. 34	2002 Qn. 27	2006 Qn. 29	2006 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.

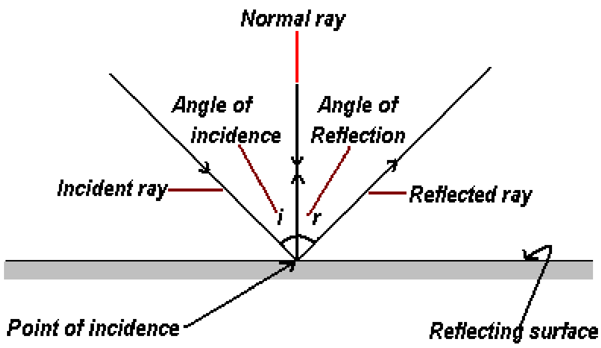
Types of Rays
(i) ***Incident rays;*** is a ray of light from the light source falling onto/striking the reflecting surface

(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.

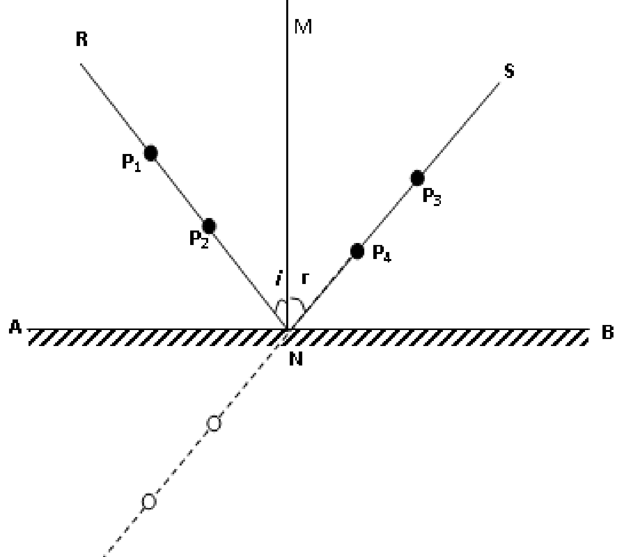
✓ Angle of incidence (i)
This is the angle that the incident ray makes with the normal at the point of incidence.

✓ 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.

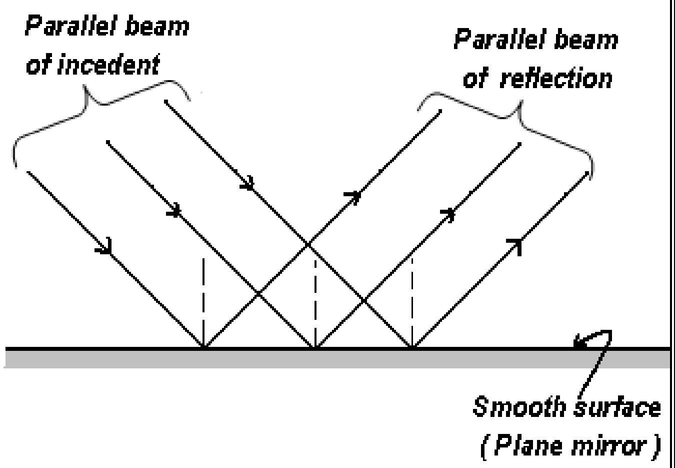
Observation:
✓ Angle **i** = angle **r.**
✓ The incident ray, the normal and the reflected ray at the point of incidence all in the same plane.

Conclusion: hence verifying the laws of reflection

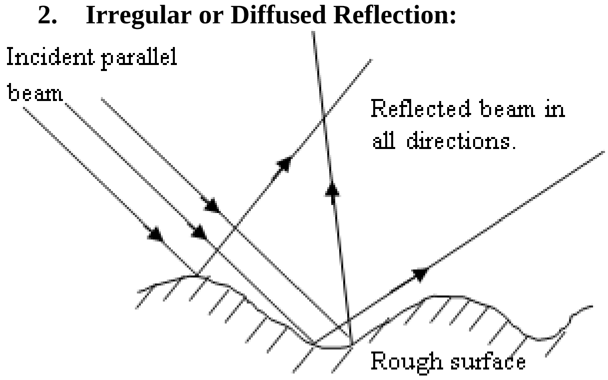
Types of Reflection

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.



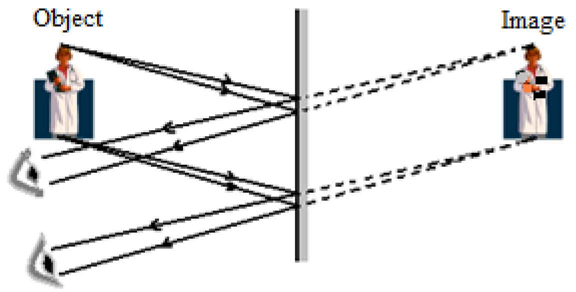
2. **Irregular or Diffused Reflection:**



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.

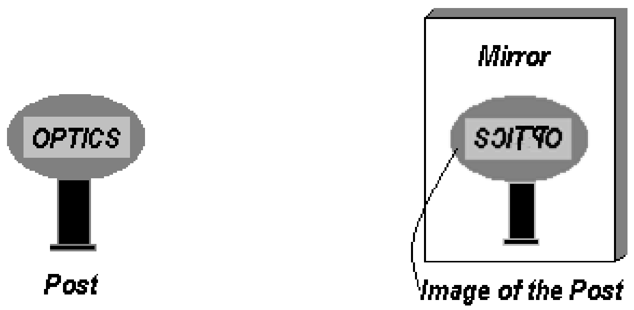
Explanation of virtual image in plane mirror:

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.

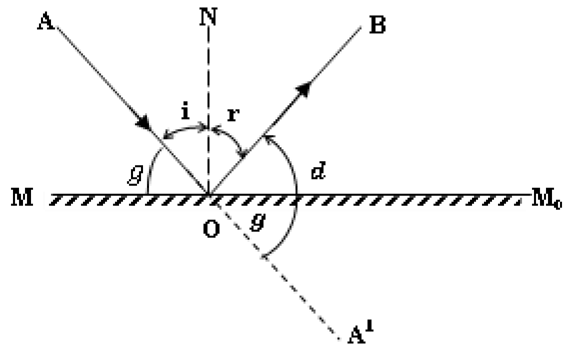
Lateral Inversion:

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;

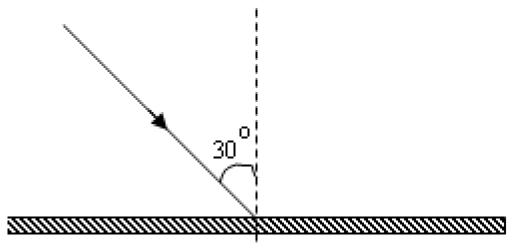
$(90 - i) = g$ (Vertically opposite angles)

$d = g + g$

$d = 2g$

Example

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



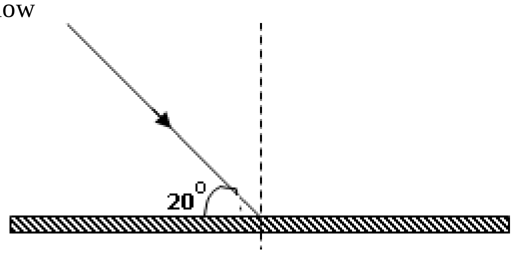
Find the:

(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

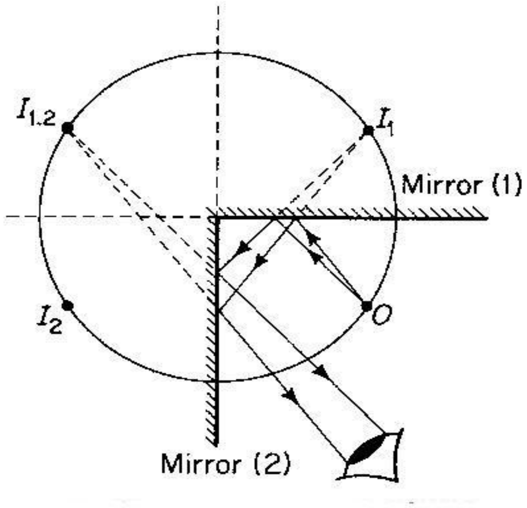
$n = \left(\frac{36}{\theta} - 1\right)$

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

$\theta = 4.5^0$

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

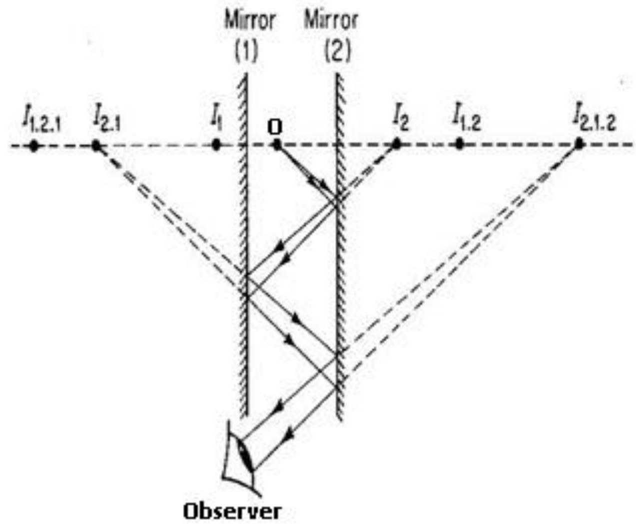
(i) **Image formed in two plane mirrors inclined at 90^0**



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.



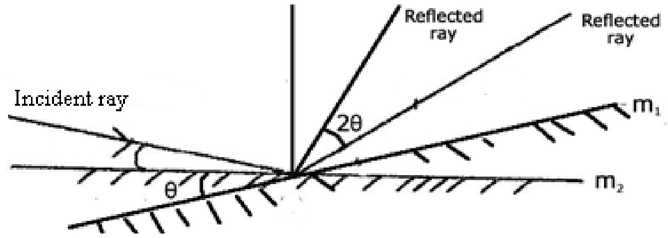
-The object O, gives rise to image I_1, on mirror m_1 and I_2 on m_2 .I_1 acts as virtual object to give an image $I_{(1,2)}$ in mirror m_2 just as I_2 gives an image $I_{(2,1)}$ in mirror $m_{1.}$ $I_{(1,2)}$ in mirror m $I_{(1,2)}$ gives $I_{(1,2,1)}$ after reflection in m_1 while $I_{(2,1,2)}$ after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

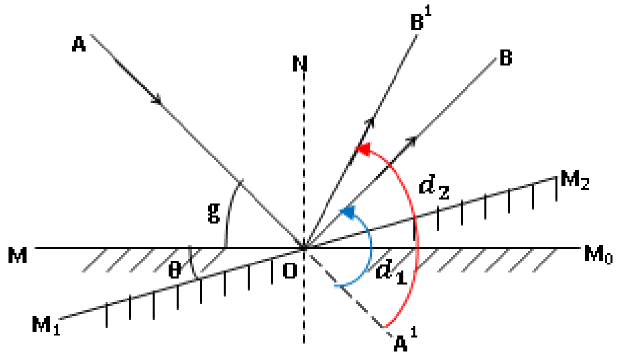
ROTATION OF REFLECTED RAY BY ROTATING THE MIRROR



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

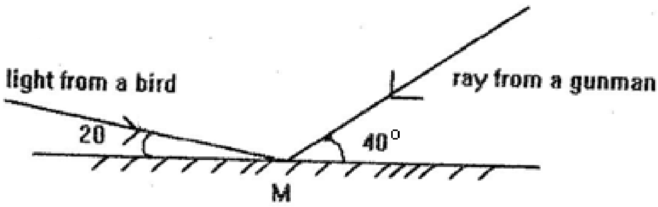
But;

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?

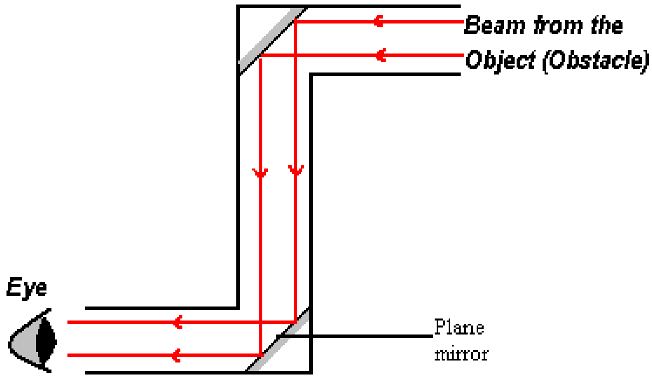
b) An object is placed 6cm from a plane mirror. If the object is moved further, find the distance between the object and its image.

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.

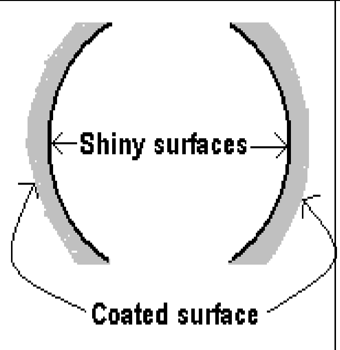
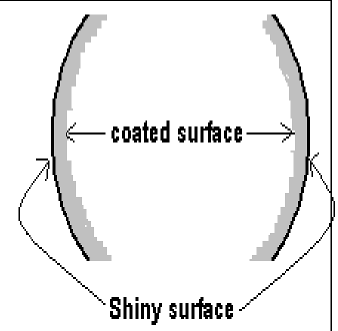
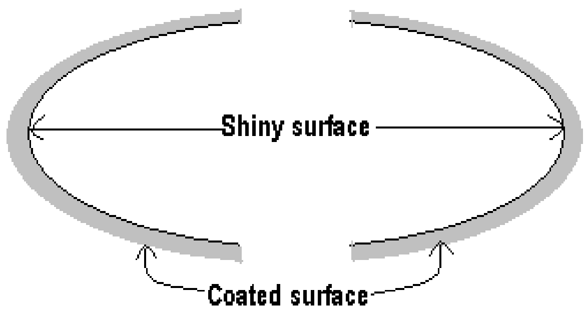
Principal axis.
This is the straight line joining the pole to the centre of curvature.

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

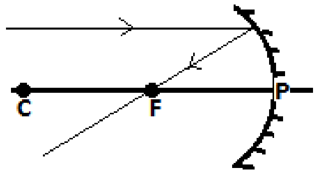
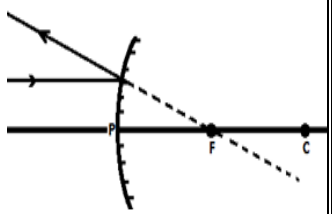
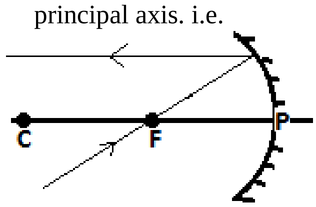
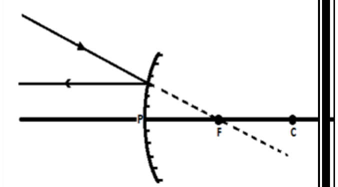
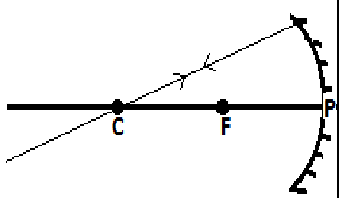
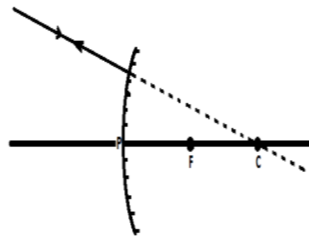
A concave mirror is the type of curved mirror in which the reflecting surface is curved inwards.

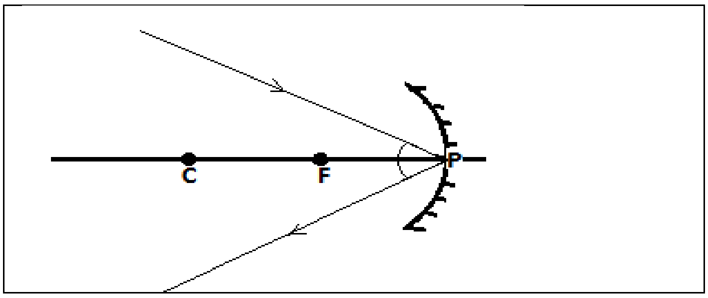
Uses of concave mirror
- ✓ Used in astronomical telescopes.
- ✓ Used for shaving because it magnifies the object.
- ✓ Used as solar concentrators.
- ✓ Used by dentists for magnification i.e Dentist mirror.
- ✓ Used in car head lamps , torches

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.

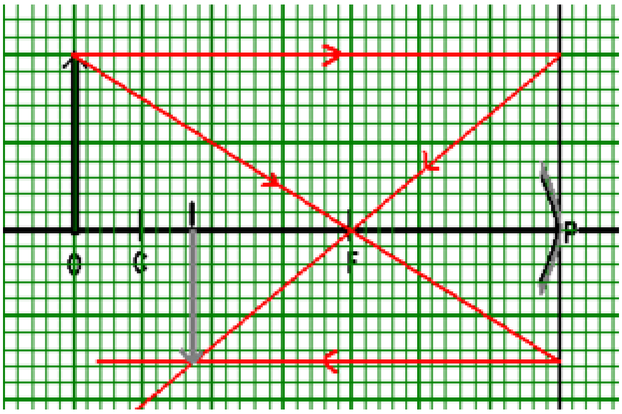
Useful rays used in construction of ray diagrams.

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.

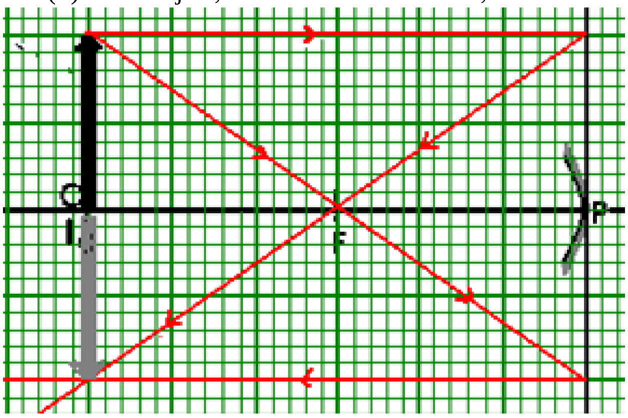
(i) Object, O beyond the centre of curvature, C.



The image, I formed is;

- ❖ Position: Between F and C
- ❖ Nature : Real and Inverted
- ❖ Size : Diminished

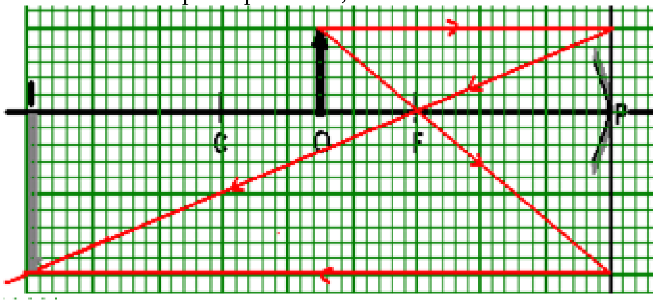
(ii) Object, O at centre of curvature, C.



The image, I formed is;

- ❖ Position: At C
- ❖ Nature : Real and Inverted
- ❖ Size : Same size as the object

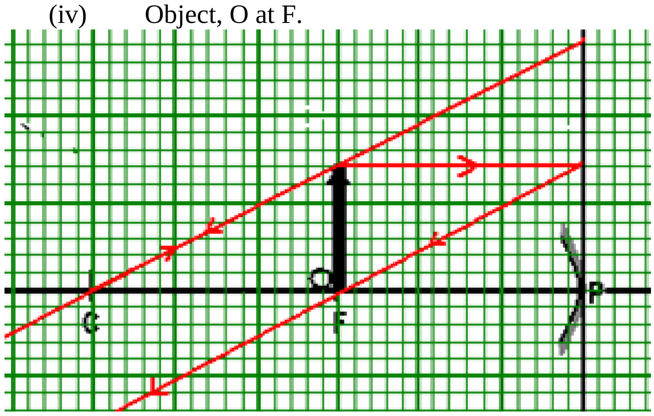
(iii) Object, O between centre of curvature, C and the principal focus, F



The image, I formed is;

- ❖ Position: Beyond C
- ❖ Nature : Real and Inverted
- ❖ Size : Magnified

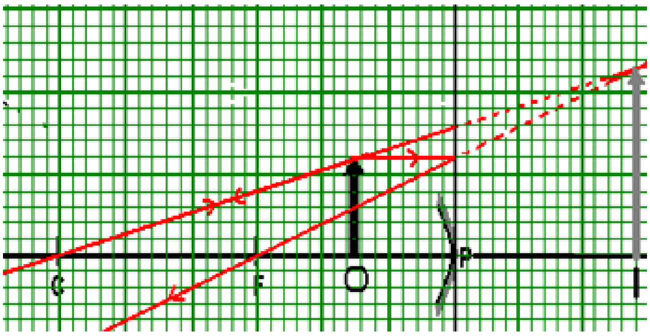
(iv) Object, O at F.



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**

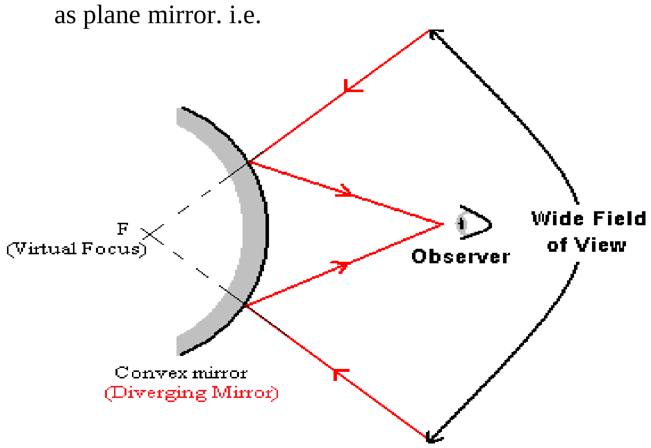
Convex mirror is a type of curved mirror in which the reflecting surface curves outward.

Uses of convex mirror

Convex mirrors are used as;

i) security mirrors in supermarket
ii) driving mirrors

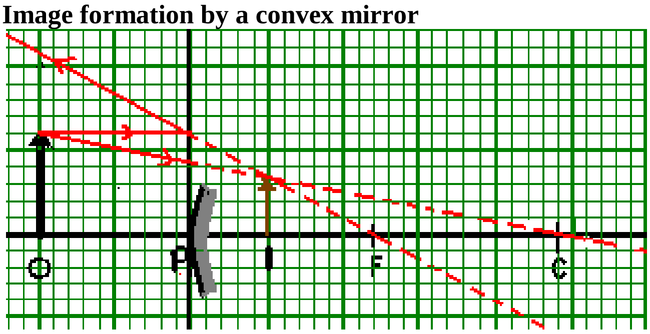
This is **because** a convex mirror;
- ✓ Gives an erect (upright) virtual image of the objects.
- ✓ Provides a wider field of view than other mirrors such as plane mirror. i.e.



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

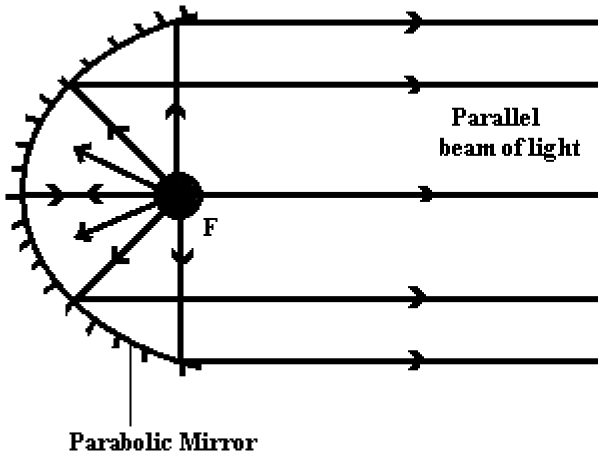


Characteristics of the image, I formed by convex mirror.
Irrespective of the position of the object, the images formed in convex mirrors are;
- ❖ Position: Behind the mirror
- ❖ Nature : Virtual and upright (erect)
- ❖ Size : Diminished

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.

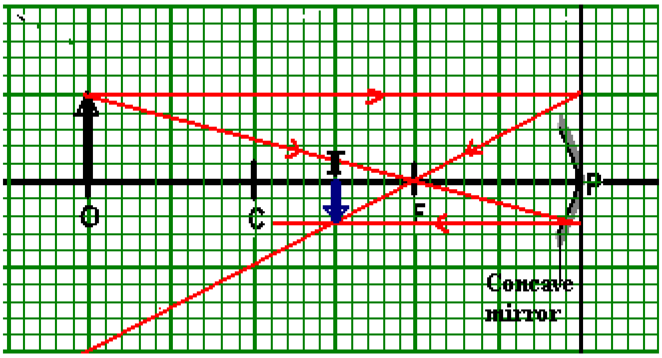
$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{h}{H}$$

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**	❖ $10\text{cm} \rightarrow \frac{10}{10} \rightarrow 1\text{cm}$
Horizontal axis	**1 : 10 cm**	❖ $60\text{cm} \rightarrow \frac{60}{10} \rightarrow 6\text{cm}$ ❖ $20\text{cm} \rightarrow \frac{20}{10} \rightarrow 2\text{cm}$



Position:

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

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

Size:

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

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

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.

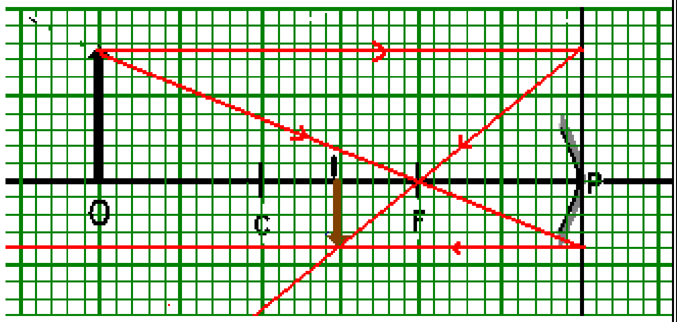
(i) Use a ray diagram to locate the position and size of the image on the graph paper.

(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**	❖ $1.5\text{cm} \rightarrow \frac{1.5}{1} \rightarrow 1.5\text{cm}$
Horizontal axis	**1 : 2 cm**	❖ $4\text{cm} \rightarrow \frac{4}{2} \rightarrow 2\text{cm}$ ❖ $12\text{cm} \rightarrow \frac{12}{2} \rightarrow 6\text{cm}$



(i) Position:

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

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

Size:

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

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

(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

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

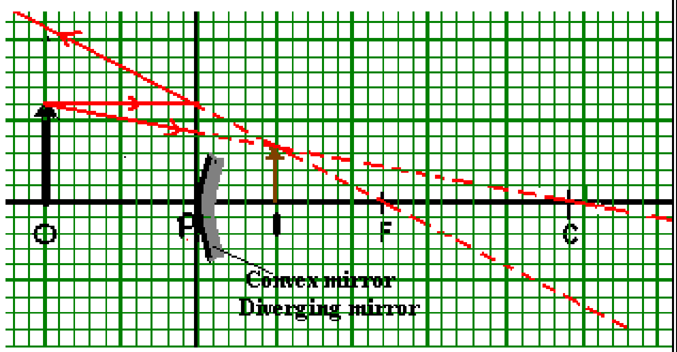
Example 3:

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



(i) Position:

The image distance as measured from the scale drawing is 1cm; using the above scale,

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

$$= \ 5\ cm$$

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.

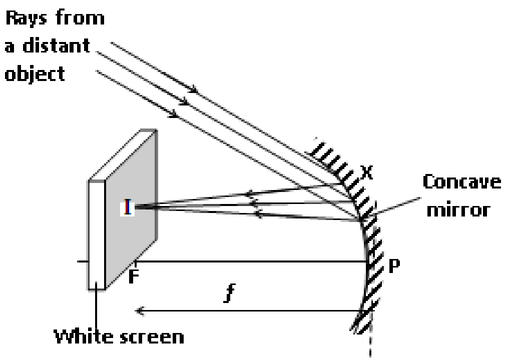
4. When an object is 42cm from a concave mirror, the object and the image are of the same height. What is the focal length of the mirror?

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.

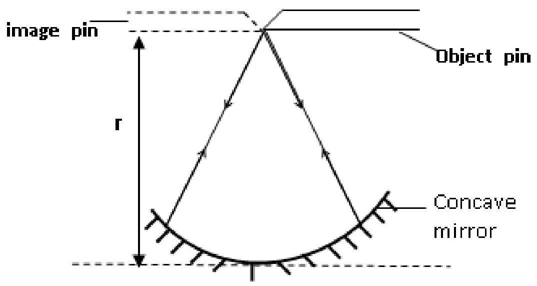
Determining the focal length of Concave mirrors

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.**

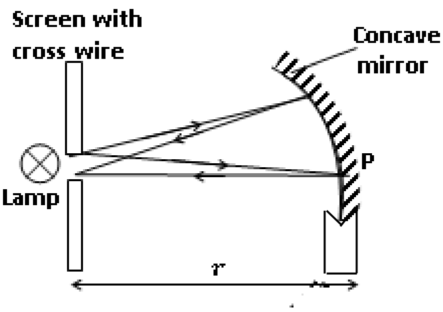


A concave mirror is placed horizontally on a bench. An optical pin is clamped horizontally on a retort stand so that the tip lies along the principal axis of the mirror.

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.

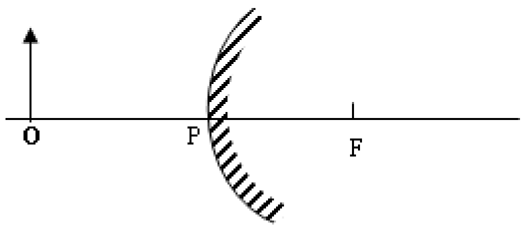
Exercise: See UNEB Paper I:

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.

(ii) Calculate the magnification.
(d) State the reasons for use of convex mirrors in vehicles.

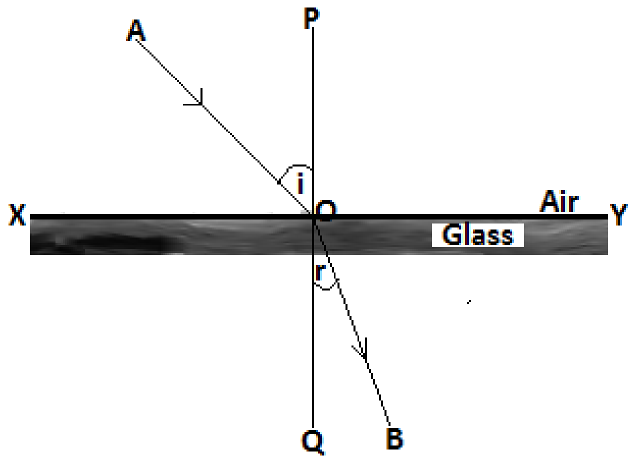
4. UNEB 2002 Paper 2 Qn. 5
(c) With the aid of a diagram, explain why a parabolic mirror is most suitable for use in car head lights.
(d) List **three** uses of concave mirrors

REFRACTION OF LIGHT

Definition:
Refraction is the bending of light ray(s) as it passes from one transparent medium to another of different densities.

Refraction is the change in speed of propagation of light due to change in optical density.
When light propagating in free space is incident in medium, the electrons and protons interact with the electric and magnetic fields of the light wave. This result in the slowing down of a light.

Illustration.



Refraction occurs because light travels at different speed in the different media.

Description

(a) Rays and lines

Ray AO is called incident ray.
This is the ray that fall/strikes the boundary at the normal in the first medium.

Ray OB is called the refracted ray.
Refracted ray is the ray that leaves the boundary at the normal in the second medium and o the opposite side of the incident ray.

Line PQ is called the normal.
The normal is an imaginary line at right angle to the boundary and separates the incident ray and the refracted ray.

Line XY is called the boundary.
The boundary is the line that separates the two media. It is the line where refraction occurs.

(b) Angles

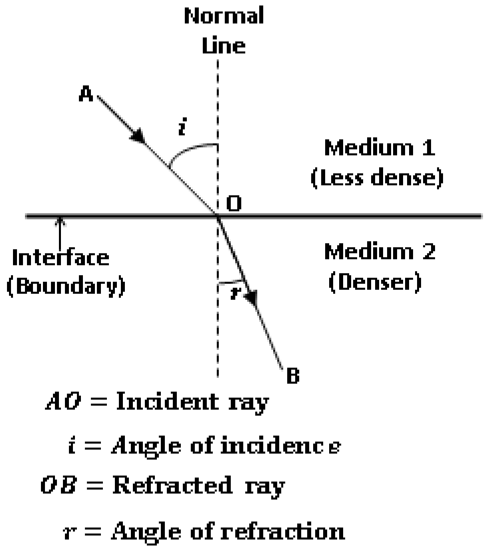
Angle, i is the angle of incidence.
This is the angle formed between the incident ray and the normal.

Angle, r is called angle of refraction.
The angle of refraction is the angle formed between the refracted ray and the normal.

NOTE: The light ray is refracted towards the normal when it travels from a less dense medium to a denser medium and then refracted away from the normal if it travels from a denser medium to a less dense medium.

Principle of Reversibility of light
It states that if a light ray (path) after suffering a number of refractions is reversed at any stage, it travels back to the source along the same path with the same refraction.

Law of refraction
When light passes from one medium to another, say from air glass part of it is reflected back into the previous medium and the rest passes through the second medium with its direction of travel changed.



Generally, if light is incident from a less dense medium, to a more optically dense medium, its speed reduces and it is refracted towards the normal at the point of incidence.
However, if light travels from a denser to a less dense medium, its speed increases and it is refracted away from the normal.

Laws of Refraction
Law 1. The incident ray, refracted ray and the normal at point of incidence all lie on the Same plane.

Law 2. For any two particular media, the ratio of the sine of angle of incidence to sine of angle of refraction is constant.

i.e.$\frac{\sin i}{\sin r} = \textbf{aconstant}(\cap)$

The constant ratio $\frac{\sin i}{\sin r}$ is called the refractive index for light passing from the first to second medium.

Hence; $_1\cap_2 \quad = \frac{\sin i}{\sin r}$

Definition:
Refractive Index is the ratio of sine of angle of incidence to the sine of angle of refraction for a ray of light traveling from one medium to another of different densities. i.e.
If light travel from air to glass, then the refractive index of glass with respect to air is given by;

$$_{air}\cap_{glass} \quad = \frac{\sin i}{\sin r}$$

It can also be defined as the ratio of the speed of light in one medium to the speed of light in another medium.

Hence; $_1\cap_2 \quad = \frac{v_1}{v_2} = \frac{\text{Speed of light in medium 1.}}{\text{Speed of light in medium 2}}$

If medium 1 is a vacuum, we refer to the ratio as the **absolute refractive index of medium 2**, denoted by $\mathbf{n_2}$.

If medium 1 is a vacuum, then;

$$\cap_2 = \frac{C}{v_2} = \frac{\text{Speed of light in vacuum.}}{\text{Speed of light in medium 2}}$$

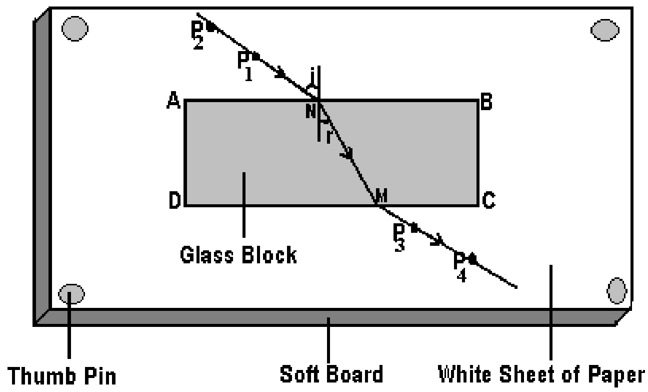
$Where, \boldsymbol{C} = 3.0 \times 10^8 \boldsymbol{ms}^{-1}$

Note: For practical purposes, $\cap_{\mathbf{Vacuum}} \quad = \cap_{\mathbf{Air}} \quad = 1$

DETERMINATION OF REFRACTIVE INDEX

Apparatus:
- Rectangular Glass Block
- Four Optical Pins and 4 thumb pins
- Soft Board
- White Sheet of Paper
- Mathematical Set

Set up

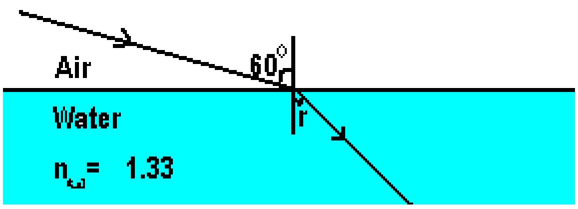


Procedure
a) Place the rectangular glass block on the white sheet of paper stuck on the soft board.
b) Trace the outline of the glass block on the white sheet of paper.
c) Remove the glass block and draw a normal at N.
d) Using a protractor, measure from the normal the angle of incidence, i = 20^o to draw the incident ray of the angle measured and pin two optical pins P_1 and P_2 on the ray drawn.
e) Replace the glass block back to its outline and aim from face DC to fix pins P_3 and P_4 such that they appear to be in line with the images of P_1 and P_2.
f) Remove the glass block and draw a line through P_3 and P_4 to face DC.
g) Draw a line from normal to meet the line trough P_3 and P_4 to measure the angle of refraction, r.
h) Repeat the procedure d) to g) for i = 30^o, 40^o, 50^o, 60^o and 70^o.
i) Tabulate your result in a suitable table including values of sin i and sin r.
j) Plot a graph of sin i against sin r and determine the slope n of the graph.

Conclusion
- ❖ The graph sini against sinr is a straight line this verifies Snell's law.
- ❖ The slope of the graph is the refractive index of the glass block.

Example 1:
A ray of light travels from air into water at angle of incidence of 60°. Calculate the angle of refraction given that the refractive of water is 1.33.

Solution
Given; i = 60° n = 1.33 r = ?
Ray Diagram



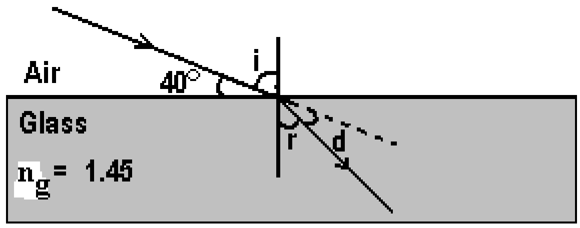
From Snell's law
$\cap_{air} \sin i_{air} = \cap_{water} \sin i_{water}$
$1 \sin 60 = 1.33 \sin r$

$$\sin r = \left(\frac{0.866}{1.33}\right)$$

$$r = \sin^{-1}\left(\frac{0.866}{1.52}\right)$$
$$r = 41.7^0$$

Example 2:
A ray of light traveling through air strikes glass at an angle of 40° to the surface. Given that the refractive index of glass is 1.45, find the;
(i) Angle of refraction
(ii) Angle of deviation (angle through which the ray is bent from its original direction).

Solution
Given; ϴ = 40° n = 1.45 r = ?
Ray diagram



Where; r = angle of refraction
d = angle of deviation

From the angle properties
$40^0 + i = 90^0$
$i = 90^0 - 40^0$
$i = 50^0$

From Snell's law
$\cap_{air} \sin i_{air} = \cap_{water} \sin i_{water}$
$1 \sin 50 = 1.45 \sin r$

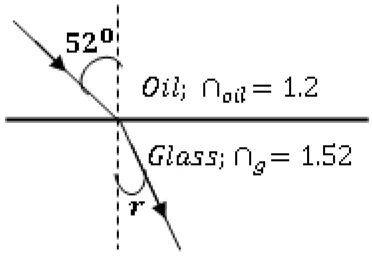
$$\sin r = \left(\frac{0.766}{1.45}\right)$$

$$r = \sin^{-1}\left(\frac{0.766}{1.45}\right)$$
$$r = 31.9^0$$

Angle of deviation, d
From the diagram,
$r + d = i$
$31.9^0 + d = 50^0$
$d = 18.1^0$

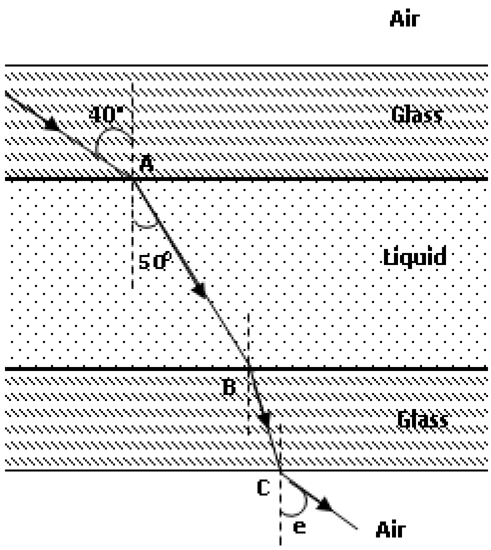
Examples 3:
If the angle of incidence in oil is52^0, find the angle of refraction in glass for a ray of light travelling from oil to glass. ($\cap_{oil} = 1.2$ and $\cap_{glass} = 1.52$)

Solution:



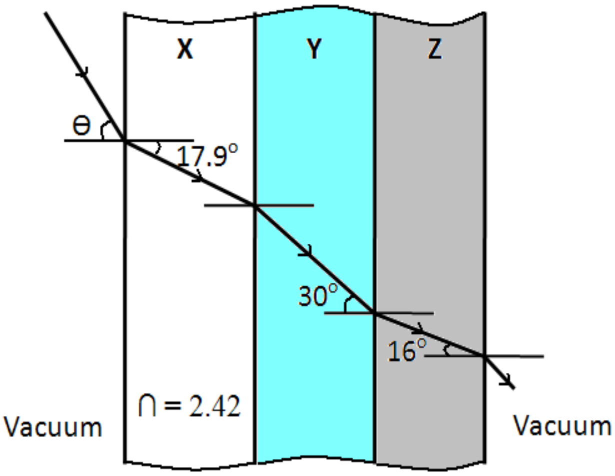
Using Snell's law;
$\cap \sin i = \text{constant}$
$\cap_{oil} \sin i_{oil} = \cap_{glass} \sin i_{glass}$
$1.2 \sin 52 = 1.52 \sin r$
$$\sin r = \left(\frac{0.9456}{1.52}\right)$$
$$r = \sin^{-1}\left(\frac{0.9456}{1.52}\right)$$
$$r = 38.47^0$$

Examples: 4
The diagram bellow shows a liquid sandwiched between two glass slabs of refractive index 1.5. A ray of light begins from the upper glass slab and it latter emerges into air.



Find the;
(i) Refractive index of the liquid.[$n_L = 1.26$]
(ii) Angle of emergency in air. [$e = 74.6^0$]

Example 5:
White light was observed to travel from vacuum through multiple boundaries of transparent media X, Y and Z, parallel to each other as shown below. Calculate the;
(i) Angle ϴ
(ii) Refractive index of Y
(iii) Speed of light in X
(iv) Refractive index of Z with respect to X



Real and Apparent Depths

Real depth

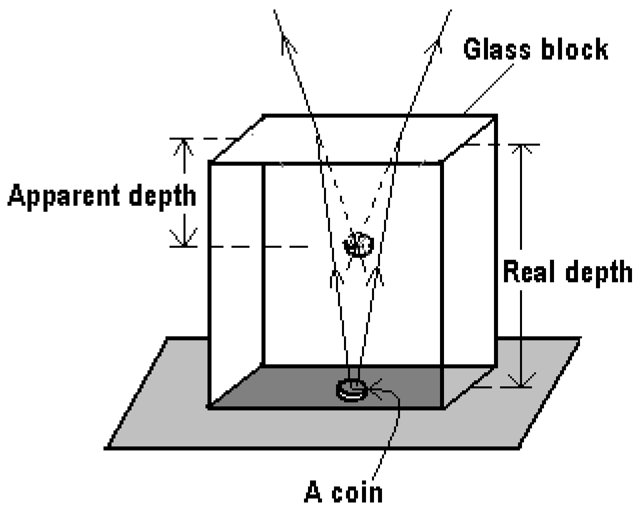
Real depth is the depth where the object is actually placed or laying under the transparent medium of different optical density to the surrounding medium. i.e. Real depth is the actual height of the medium in its desired dimension.

Apparent depth

Apparent depth is the depth where the object appears to be when observed through the transparent medium of different optical density to the surrounding medium.

The real and apparent depth of an object viewed through a transparent material can be used to determine the refractive index of the transparent material.

Illustration of real depth and apparent depth

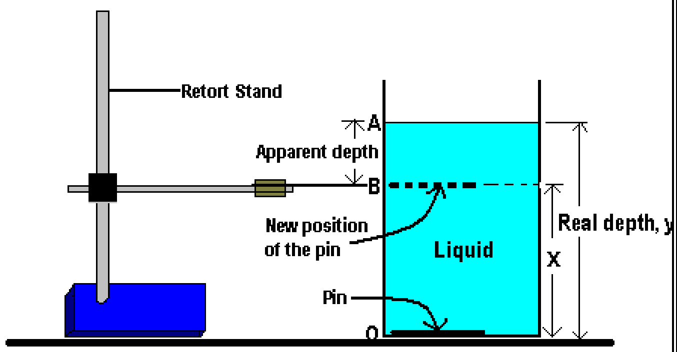


Determination of refractive index of Liquid using real depth and apparent depth.

Apparatus:

Beaker, Retort stand, Pins, Liquid, Half metre rule

Diagram:



Procedure:

Pour liquid in a beaker and measure the height, y (real depth) of the liquid in the beaker

Place a pin at the bottom of the beaker with its point touching the side of the beaker.

Support another pin on the clamp at the side of the beaker using plasticine.

Observe from the edge of the beaker and adjust the pin on the clamp until it appears to be on the same level with the pin in the beaker.

Now measure the height, x from the bottom of the beaker where the pin in liquid appears to determine the apparent.

Divide the real depth of the pin in liquid by the apparent depth of the same pin to determine the refractive index, n of the liquid.

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{y}{y - x}$$

Example: 1

A pin placed at the bottom of the liquid appears to be at a depth of 8.3 cm when viewed from above. Find the refractive index of the liquid if the real depth of the liquid is 11 cm.

Solution

Given, Real depth = 11 cm

Apparent depth = 8.3 cm

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{11}{8.3}$$

$$n = 1.33$$

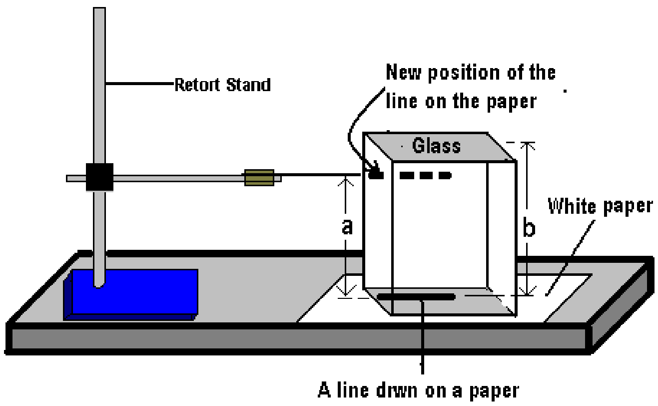
Determination of refractive index of glass using real depth and apparent depth.

Apparatus:

Glass block, Retort stand, optical Pin, White sheet of paper

Half metre rule

Diagram:



Procedure:
Draw a line on a white sheet of paper and place a glass block a above it as shown.
Look down at the edge of the glass perpendicular to the tip of the line drawn on the paper.
Adjust the search pin on the clamp until it is at the same level as the line drawn on the paper. Ensure no parallax i.e. the pin and the image of the line should appear to be one on moving the head to and fro the line of observation.
Measure the distance, a and b respectively to determine the apparent depth of the line
Refractive index of the glass block is then obtained from;

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{b}{b-a}$$

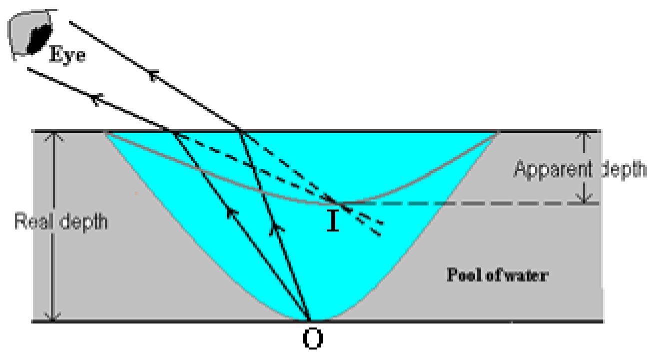
Example: 2
A glass block of height 9 cm is placed on a coin of negligible thickness. The coin was observed to be at 3 cm from the bottom of the glass block when viewed from above. Find the refractive index of the glass.
Solution

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{9}{9-3} = \frac{9}{6}$$

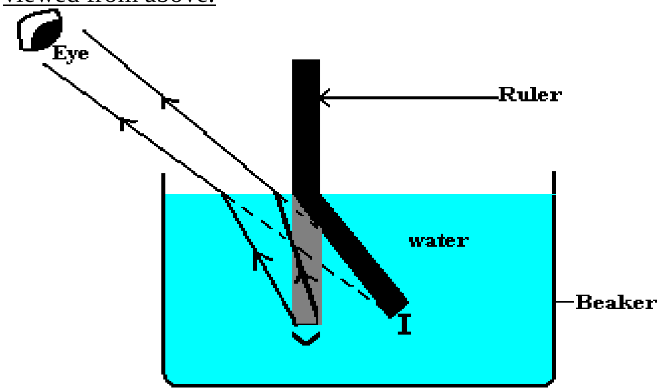
$$n = 1.5$$

Effects of refraction:
(i) A swimming pool appears shallower that its actual depth



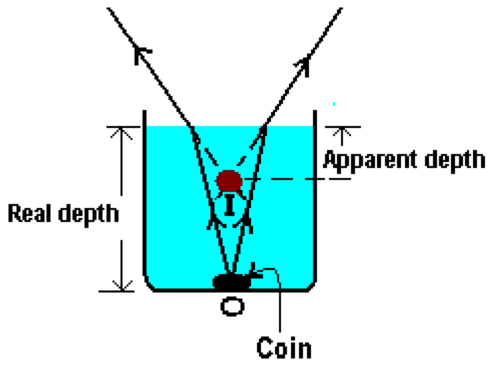
Explanation
This is because light rays from the bottom are refracted away from the normal at the water to air boundary.
These rays appear to come from the point I not O, so at the point I the pool appear shallower than it is.

(ii) A ruler placed in a glass of water appears bent when viewed from above.



Explanation
Rays of light from the point V of the ruler pass from water to air and are bent away from the normal as it emerges to the less dense medium. As it enters the eye, it appears to be coming from the point I above V.

(iii) A coin or even written mark placed at the bottom of water in a beaker or basin appears to be on top when viewed from above.

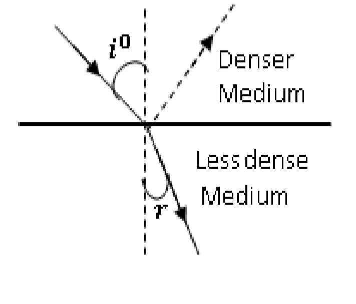


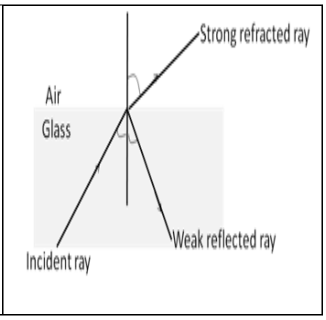
Explanation
This is due to refraction of light from the coin at O. As light passes through the water to air boundary, the ray is refracted away from the normal in air and appear to be originating from the point I (apparent depth) above the actual point O (Real depth) at the bottom of the container.
This effect and explanation is also factual for an object or mark under other medium like glass block and even glass prism.

(iv) Twinkling of the stars in the sky at night.

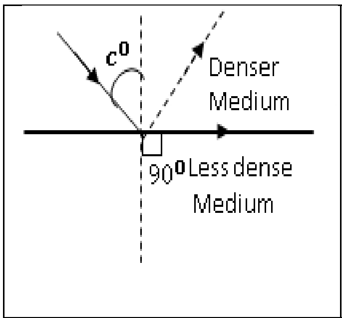
TOTAL INTERNAL REFLECTION AND CRITICAL ANGLE

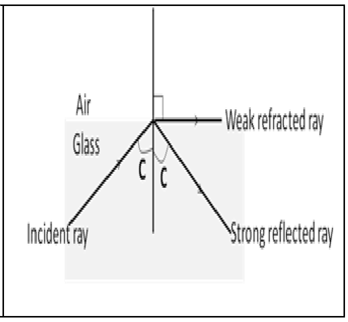
Consider monochromatic light propagating from a dense medium and incident on a plane boundary with less dense medium at a small angle of incidence. Light is partly reflected and partly refracted.





As the angle of incidence is increased gradually, a stage is reached when the refracted ray grazes the boundary between the two media.

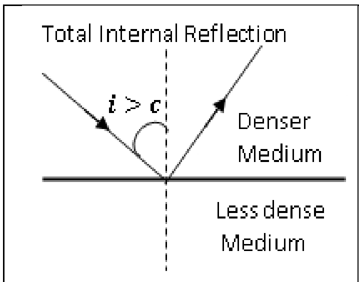


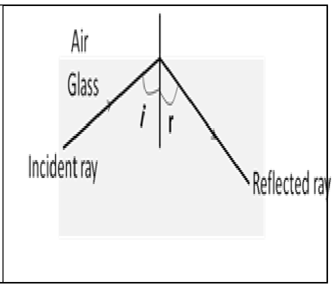


The angle of incidence **c** is called the <u>critical angle.</u>

Hence **critical angle** is the angle of incidence in a denser medium which makes the angle of refraction in a less dense medium 90°.

When the angle of incidence is increased beyond the critical angle, the light is totally internally reflected in the denser medium. Total internal reflection is said to have occurred.





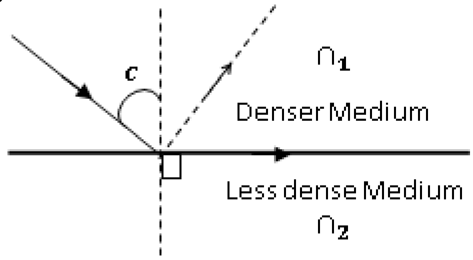
Hence **Total Internal Reflection** is the process where all the incident light energy is reflected back in the optically denser medium when the critical angle is exceeded.

Conditions for Total Internal reflection to occur.

(i). Light must be moving from an optically denser medium (e.g glass) to a less dense medium (e.g air).

(ii). The angle of incidence in the optically denser medium must exceed (greater than) the critical angle. **[$i > c$].**

Relationship between critical angle, c, and refractive index, n



Using Snell's law:

$\cap_1 \sin i_1 = \cap_2 \sin r_2$

$\cap_1 \sin c = \cap_2 \sin 90$

$$\sin c = \frac{\cap_2}{\cap_1}$$

If the lens dense medium is air or a vacuum;

$$\mathbf{\sin c} = \frac{1}{\cap_1}$$

<u>Calculation involving critical angle and refractive index</u>

At critical angle, the angle of refraction is 90º i.e. r = 90º. And the ray is from more optically dense medium i.e glass to a less optically dense medium i.e. air. So,

From Snell's Law:

$\cap_g \ \sin i_g \ = \ \cap_{air} \sin r_{air}$

$\cap_g \sin C \ = \ \sin 90^o$; But $\sin 90^o \ = \ 1$

$\cap_g \sin C \ = \ 1$

$$\cap_g \ = \ \frac{1}{\sin C}$$

Where $\cap_{\boldsymbol{g}} =$ Refractive index of the glass and C is the critical angle.

Example: 1

Calculate the refractive index of the glass if the critical angle of the glass is 48º.

SOLUTION:

Give; C = 48o , $\cap_g = ?$

$From; \cap_g = \frac{1}{sin\boldsymbol{C}}$

$\cap_g = \frac{1}{sin 48^o}$

$\cap_g = \frac{1}{0.669}$

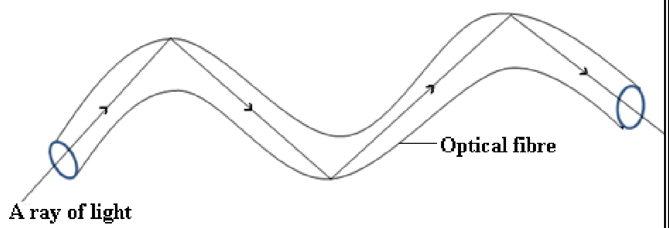
$\cap_g = 1.5$

Applications of total internal reflection

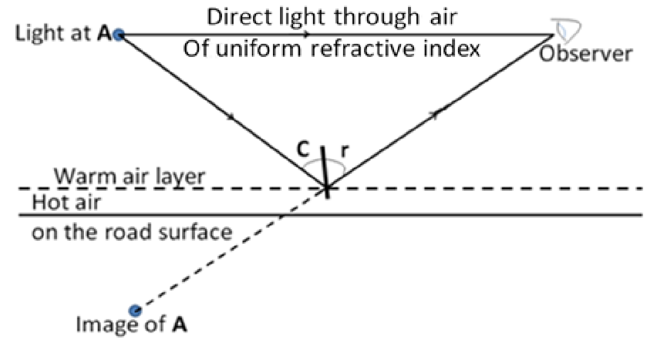
(i) Light pipes and Optical fibres

Light can travel and can be trapped by total internal reflection inside a bend glass tube and pipe along a curved path.

If several thousand rays are trapped together, a flexible light pipe is obtained that can be used to light up some awkward spot for inspection.



(ii) Mirage



Explanation

- ✓ Gradual refraction:

On a hot day light from the sky is gradually refracted away from the normal as it passes through layers of warm but less dense air near hot road.

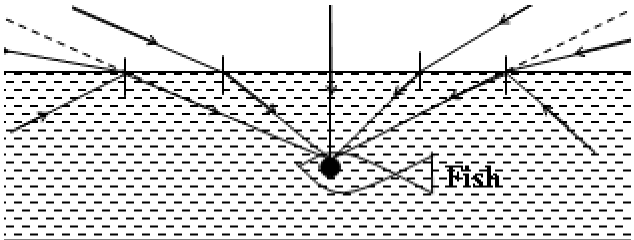
- ✓ Total internal reflection:

The refractive index of warm air is slightly smaller than that of cool air, so when light meets a layer at critical angle, it suffers total internal reflection thus to the observer the road appears to have a pool of water.

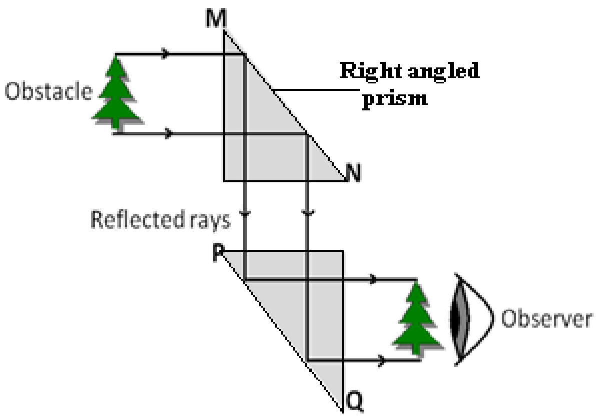
(iii) Fish's view:

The fish in water enjoys a wider field of view in that it views all objects under water and those above the water surface

Objects above the water surface are viewed as a result of refraction while those under the water surface are viewed as a result of total internal reflection. However this is only true if the water surface is calm.



(iv) Submarine periscope:

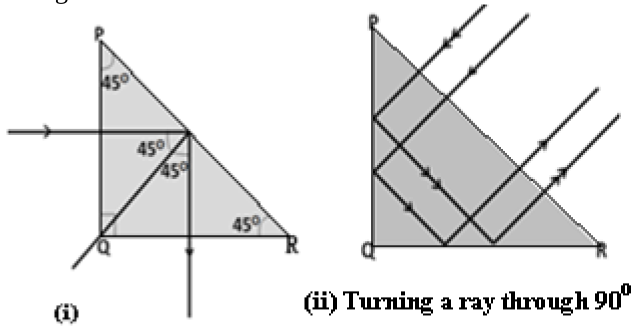


Light from a distant object meets the surface MN at 45°; so light is totally internally reflected downwards.

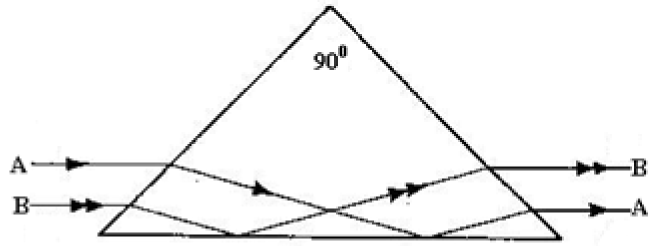
The reflected light is incident to the surface PQ where it is totally internally reflected to give the emergent light to the observer.

(v) Totally reflecting prism

The critical angle of a glass prism is **42°** and a ray is normally incident on face PQ thus un deviated i.e. not refracted. Total internal reflection occurs and a ray is turned through 90°.



(ii) Turning a ray through 90°



(iii) Turning a ray through 180°

The critical angle of glass is 42° and rays are incident normally on face PR. At face PQ, the rays are incident at 45° so total internal reflection occurs.

The use of prisms are preferred to plane mirror

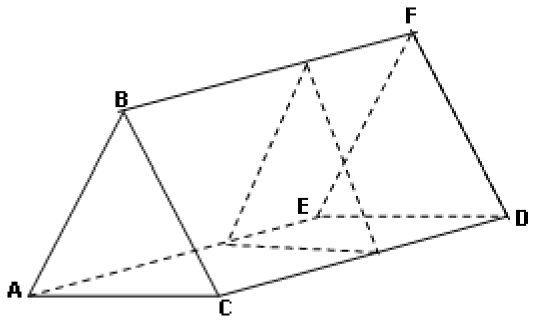
- ✓ Prisms produce clear image
- ✓ Prisms do not tarnish and deteriorate as mirror.

However, plane mirrors are not used in submarine periscope because:

- Several images of one object are formed at the back by plane mirror due to multiple reflection inside the glass i.e. plane mirror produces blurred images.
- Plane mirrors absorbs more light than prisms so the image produced is fainter.

REFRACTION THROUGH A TRIANGULAR PRISM

Refraction by glass prism



BF= Refracting edge

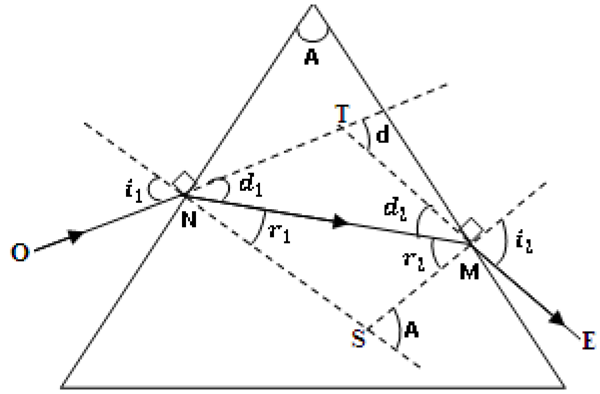
AB and BC = Refracting surface

AC and ED = Base

ABC and DEF = Principle section (or any other plane perpendicular to the refracting edge).

Angle ABC = Refracting angle or angle of the prism.

Representation of a Prism.



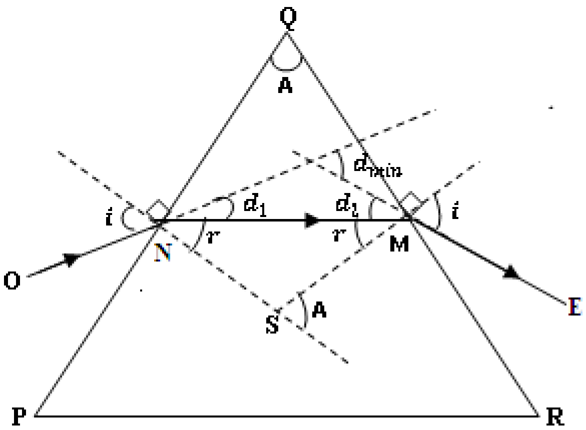
Rays: ON = Incident ray; Angle i_1 = angle of incidence
NM = Refracted ray; Angle r_1 = angle of refraction
ME = Emergent ray; Angle i_2
= angle of emergence
Lines: NS and MS = Normal lines on either sides.
Angle A = angle of the prism or refracting angle.

Deviation of light by a prism
Considering Deviation at N,
$i_1 = r_1 + d_1 \Leftrightarrow d_1 = i_1 - r_1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (i)$
Considering Deviation at M,
$i_2 = r_2 + d_2 \Leftrightarrow d_2 = i_2 - r_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (ii)$

From Triangle NMT:
$d = d_1 + d_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (iii)$
Putting equations (i) and (ii) into Equation (iii) gives:
$d = (i_1 - r_1) + (i_2 - r_2)$
$d = (i_1 + i_2) + (-r_1 - r_2)$
$d = (i_1 + i_2) - (r_1 + r_2) \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (iv)$

From Triangle NMS:
$A = r_1 + r_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (v)$
$\boldsymbol{d = (i_1 + i_2) - A} \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (vi)$

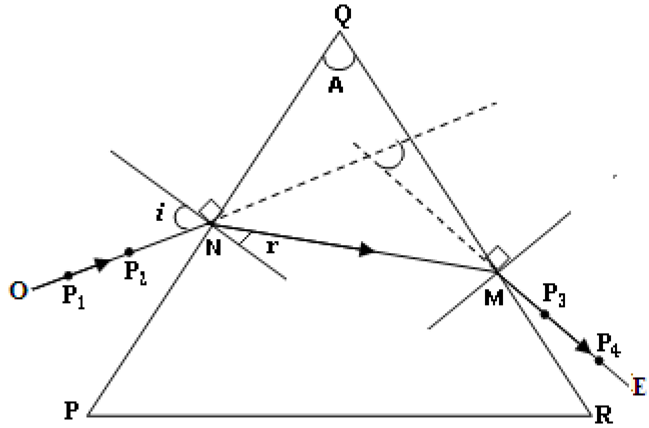
Minimum Angle of Deviation
Definition: is the smallest angle to which angle of deviation decreases when the angle of incidence is gradually increased.



Condition for minimum deviation position:
- ✓ Ray of light MN in the prism is parallel to the base of the prism.
- ✓ Incidence angle and emergency angles are equal.
- ✓ Light passes symmetrically rough the prism.

The angle of incidence, i = angle of emergency, e

Experiment to measure the refractive index of a triangular glass prism.

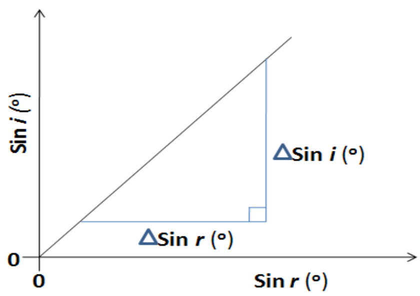


✓ Outline of the prism
The prism is placed on a paper and its outline ABC is drawn and then the prism is removed. Draw the normal at M and measure the angle of incidence, i. Place the pins P_1 and P_2 on the incident ray.

✓ Obtaining the refracted ray.
Replace the prism to its outline. By looking through the prism from side QR, pins $\mathbf{P_3}$ and P_4 are placed such that they are in a straight line with images of P_1 and P_2 in the prism.
Draw a line to join point N to M from which the angle of refraction on AC is measured.
✓ Repeating the procedures and tabulating the results
Repeat the procedures for different values of i and obtain different values of r.
Record the results in a suitable table including values of sin i and sin r as shown below
Table of result:

$i(^0)$	$r(^0)$	Sini	Sinr

✓ Plotting the graph
Plot a graph of sin i against sin r to determine the slope of the graph. Slope is the refractive index of the prism.



Note: For a light ray travelling in a medium like water to glass, then the refractive index of glass with respect to water is calculated from:

$${}_w\cap_g = \frac{\cap_g}{\cap_w} = \frac{\sin r_2}{\sin i_2}$$

In general, the refractive index of any medium X with respect to another first medium Y is given by:

$${}_Y\cap_X = \frac{\cap_X}{\cap_Y}$$

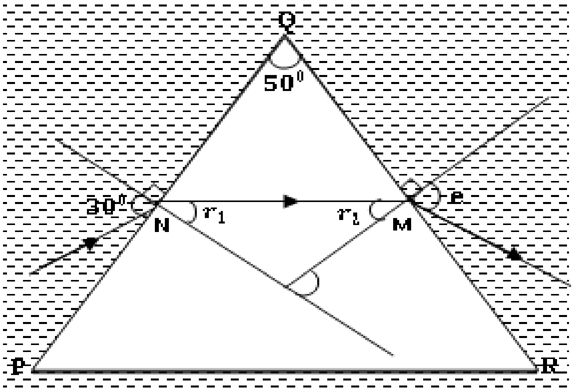
Where; $\cap_X$ = refractive in dex of X
$\cap_Y$ = refractive index of Y
For calculation, your are required to use;

$$\cap_Y \sin i_Y = \cap_X \sin r_X$$

Example 1:
A ray of light is incident on water – glass boundary at 41o. Calculate r if the refractive indices of water and glass are 1.33 and 1.50 respectively.
Solution:
Given; $\cap_g = 1.5$, $\cap_w = 1.33$, $\mathbf{i_w} = 41^o$ and $\mathbf{r_g} = ?$
From ; $\cap_Y \ sin\ i_Y = \cap_X \ sin\ r_X$

$$\cap_w \ sin\ i_w = \cap_g \ sin\ r_g$$
$$1.33 sin 41^o = 1.50 sin\ r$$
$$\sin r = \frac{1.33 \sin 41^o}{1.50}$$
$$r = \sin^{-1}\left(\frac{1.33 sin 41^o}{1.50}\right)$$
$$r = 35.5^o$$

Example:1
A ray of light propagating in a liquid is incident on a prism of refractive angle 50^0 and refractive index 1.6, at an angle of 30^0 as shown below.



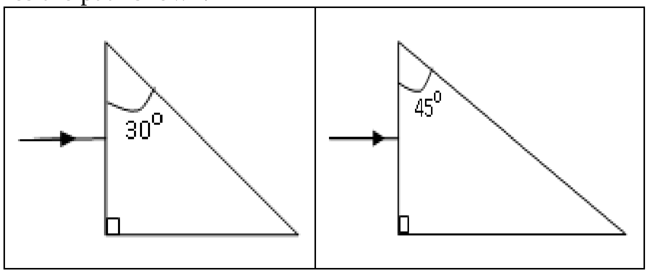
If light passes through the prism symmetrically, calculate the;
(i). Refractive index of the liquid.
(ii). Angle of deviation.

Solution.

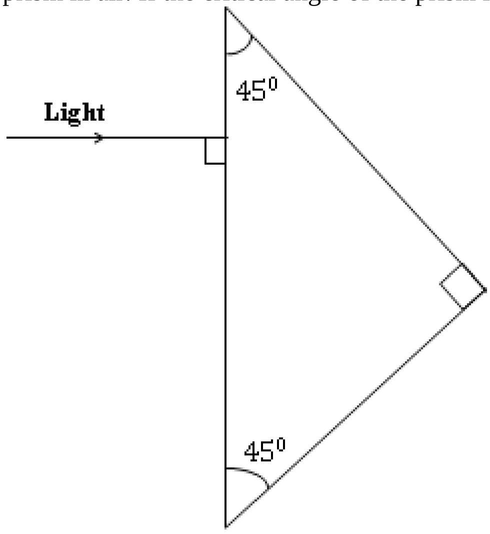
(i) Applying Snell's law at N: $\cap_L \sin i = \cap \sin r_1$ $\cap_L \sin 30 = 1.6 \sin r_1 \ldots (i)$ Applying Snell's law at M: $\cap \sin r_2 = \cap_L \sin e$ $1.6 \sin r_2 = \cap_L \sin e \ldots (ii)$ But, also; $r_1 + r_2 = A$ $r_1 + r_2 = 50 \ldots\ldots\ldots (iii)$ But since light passes through the prism symmetrically, then;	❖ $r_1 = r_2 = r$; Thus $2r = 50 \Leftrightarrow r = 25^0 \Leftrightarrow r_1 = r_2 = 25^0$ ❖ $e = i \Leftrightarrow e = 30^0$ Thus from equation (i); $\cap_L \sin 30 = 1.6 \sin r_1$ $\cap_L \sin 30 = 1.6 \sin 25^0$ $\cap_L = \frac{1.6 \sin 25^0}{\sin 30}$ $\cap_L = 1.35$

(ii).
$d = (i_1 + i_2) - A$
$d = (i + e) - 50$
$d = (30 + 30) - 50$
$d = 10^0$

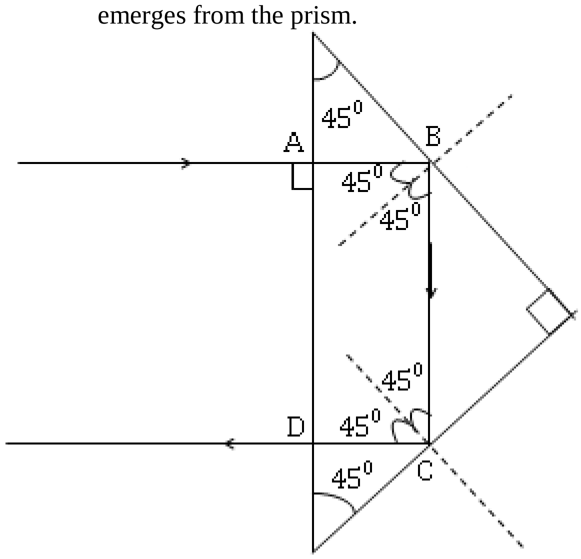
The figures below show two right angled prisms of refracting angles 30^0 and 45^0respectively. Rays of light are incident normally on the faces of the prisms below. Complete the diagrams to show the path taken by the incident ray through each prism hence explain why light takes the path shown.



The figure below shows light incident normally on a glass prism in air. If the critical angle of the prism is 42^0,



(i) Complete the diagram t o show the path of light as emerges from the prism.



At points B and C, light is moving from a denser to a less dense medium and angle of incidence is greater than the critical angle. [$45^0 > 42^0$]. Thus, total internal reflection occurs.
At points A and D, the incident light is not deviated because it is incident normally to the surface.

(ii) Calculate the refractive index of the glass prism
Applying Snell's law at B

$$\cap_Y \ sin\ i_Y = \cap_X \ sin\ r_X$$
$$n sin\ C = 1x\ sin\ 90$$
$$n \times sin\ 42 = 1 \times sin\ 90$$
$$n = 1.49$$

Trial Questions

1. A prism of refractive 1.5 and refractive angle 60^0 has an angle of refraction of 28^0 on the 1st face. Determine
   a) angle of incidence i [44.7^0]
   b) angle of refraction on 2nd face r_2 [$r_2 = 32^0$]
   c) angle of emergency i_2 [$i_2 = 52.6^0$]
   d) angle of deviation d [37.34^0]

2. Critical angle of a certain precious stone is $\mathbf{27^0}$. Calculate the refractive index of the stone.

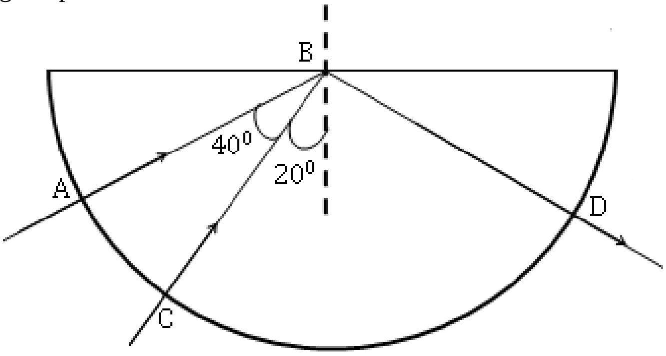
3. **See UNEB Paper I**

1994 Qn.40	1995 Qn.24	1996 Qn.1	1996 Qn.35

4. **UNEB 1990 Qn. 4**
(a) (i) State the laws of refraction.
(ii) What is meant by refractive index?
(b) Describe a simple experiment to determine the refractive of the glass of a triangular prism.
(c) The angle of refraction in glass is 320. Calculate the angle of incidence if the refractive index of glass is 1.5.

5. **UNEB 1996 Qn. 3 PII**
(a) What is meant by the following terms;
(i) Critical angle
(ii) Total internal reflection
(b) State; (i) two conditions for total internal reflection to occur.
(ii) One application of total internal reflection.

6. **UNEB 1993 Qn. 9**
The diagram below shows rays of light in a semi-circular glass prism of refractive index 1.5.



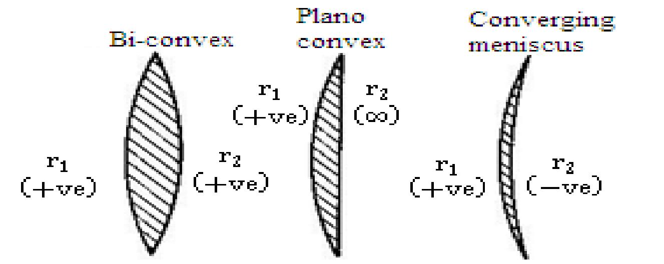
(a) Explain why ray AB;
(i) Is not refracted on entering the block at A.
(ii) Takes path BD on reaching B.
(b) Ray CB is refracted at B. Calculate the angle of refraction.

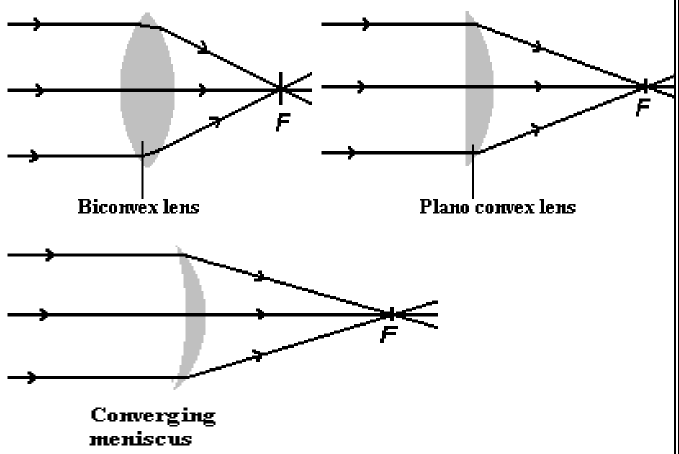
7. UNEB 1996 Qn. 4; UNEB 1987 Qn. 7; UNEB 2001 Qn.46

LENSES

Definition:
Lenses are spherical surfaces of transparent materials. The materials may be glass, plastics, water, etc.

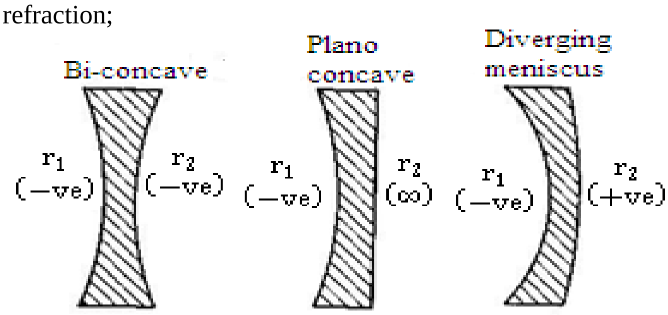
Types of Lenses:
(i) Converging Lenses (Convex Lens):
A convex lens is thick in the center. It is also called a converging lens because it bends light rays inwards. There are three examples if convex lenses, namely:

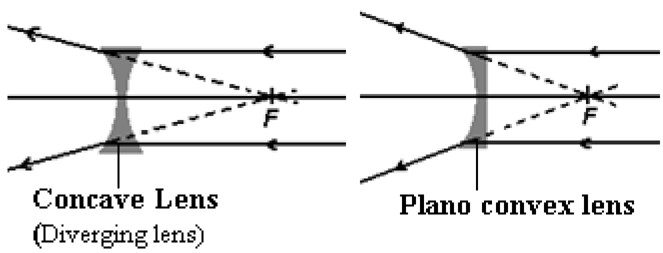


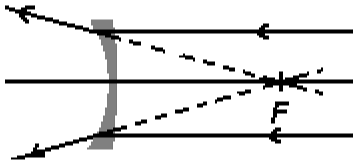


A converging lens (Convex lens) is one in which all parallel beams converge at a point (principle focus) after refraction.

(ii) Diverging Lens (Concave Lens):
A concave lens is thinnest in the central and spreads light out. A concave lens is also called a divergent lens because all rays that are parallel to the principal axis diverge after refraction;



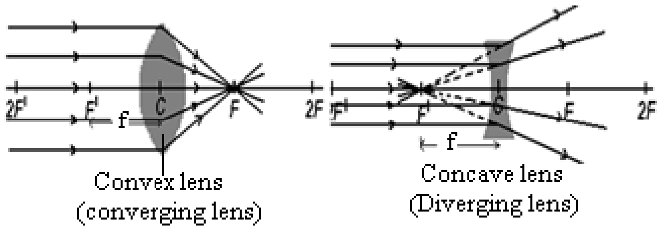




Diverging meniscus

In a diverging lens, refracted ray seems to come from the point after refraction.

Technical Terms:



- Pole of a lens:

Is the centered point of the surface of the lens through which the principal axis passes.

- Optical Centre: (C)

Is the point on the principle axis mid way between the lens surfaces. It is the centre of the lens at which rays pass un deviated.

- Principal Axis:

Is the line through the optical center of the lens on which the principal focus lies.

- Principal Focus, F:

<u>Convex lens.</u>
Is the point on the principal axis at which all rays parallel and close to the principal axis meet after refraction thru the lens.
<u>Concave lens.</u>
This is the point on the principal axis of a concave lens at which all rays parallel and close to the principal axis appear to diverge from after refraction thru the lens.

- Focal Length, f:

Is the distance between the optical center and the principal focus.

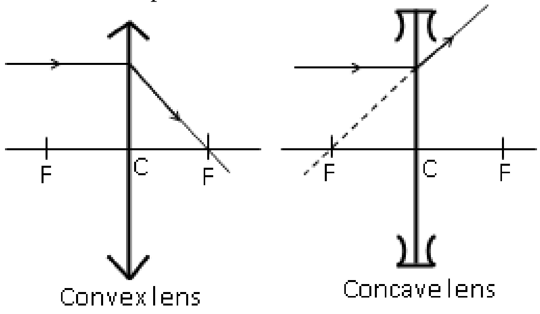
Note: The principal focus of a converging lens is real while that of a diverging lens is virtual.
Real principal focus is one at which actual rays meet after refraction.

1. <u>Centers of curvature</u>, 2F: Is the centre of the sphere of which the lens surfaces form part. OR It is a point on the principle axis where any ray through it hits the lens at right angles.

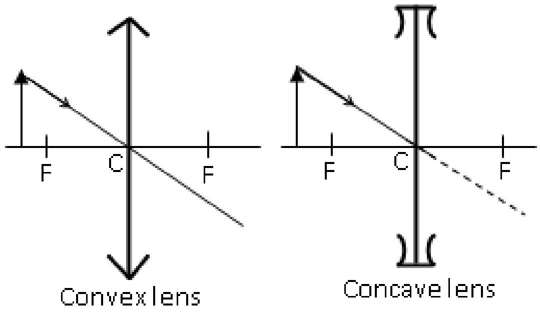
2. <u>Radius of curvature:</u> Is the radius of the sphere of which the lens forms part. OR It is the distance between the optical centre and the centre curvature of the lens.

<u>Ray Diagram for a Convex (Converging) Lens.</u>
In constructing ray diagram, 2 of the 3 principal rules are used.

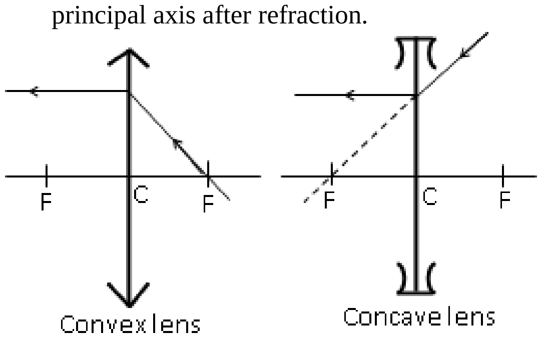
1. A ray parallel to the principal axis is refracted through the focal point.



2. A ray through the optical centre passes un deviated i.e. is not refracted.

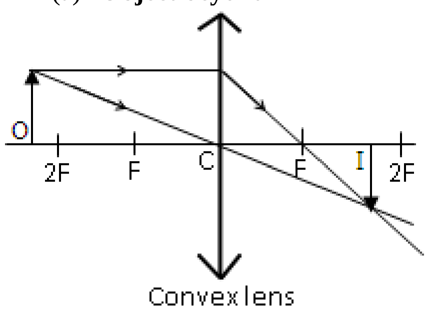


3. A ray through the principal focus emerge parallel to the principal axis after refraction.



Images formed by convex lenses:
The nature of the image formed in a convex lens depends on the position of the object from the lens.

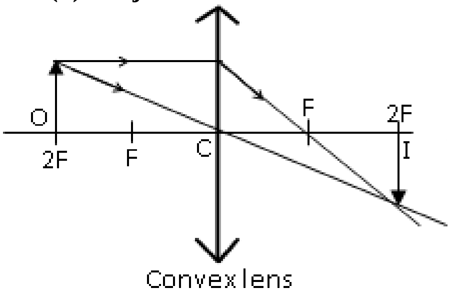
(a) **Object beyond 2F**



Characteristics of the image:

- Nature: Real and Inverted.
- Position: Between F and 2F.
- Magnification: Diminished

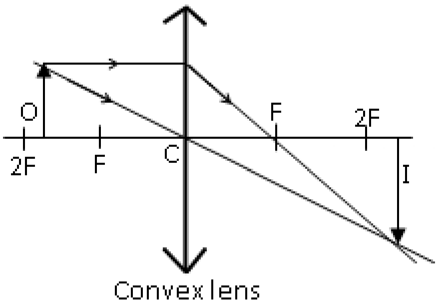
(b) Object at 2F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: At 2F.
- Magnification: Same size as object.

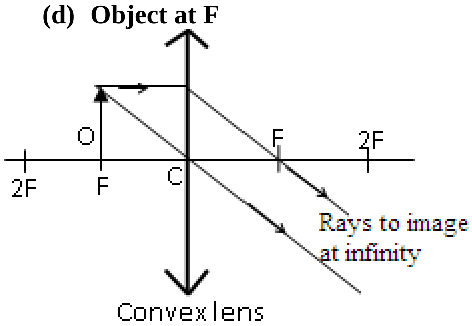
(c) Object between F and 2F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: Beyond 2F.
- Magnification: magnified.

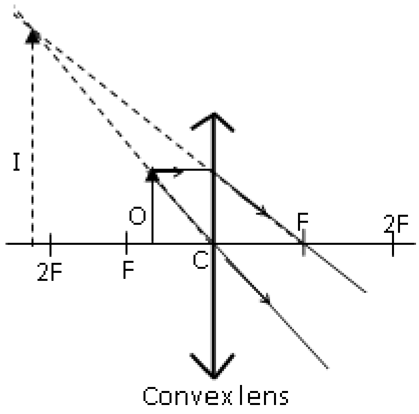
(d) Object at F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: At infinity.
- Magnification: magnified.

(e) Object between F and C



Characteristics of the image:

- Nature: Virtual and Upright or erect.
- Position: On the same side as the object.
- Magnification: magnified.

When the object is placed between F and C, the image is magnified and this is why the convex lens is known as a magnifying glass.

Summary of the useful rays

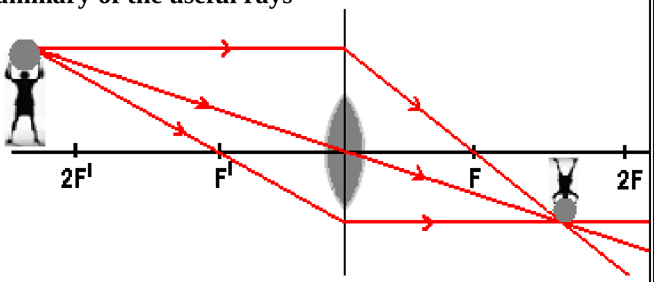
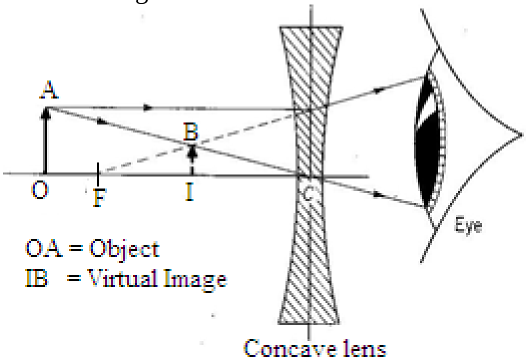
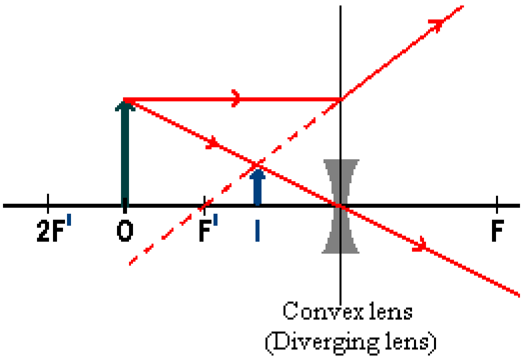


Image Formation in a Concave Lens

Irrespective of the position of the object, a concave lens forms an image with the following characteristics:

- Nature: Virtual and Upright or erect.
- Position: Between F and C.
- Magnification: Diminished.





Magnification of lens:

$$\text{Magnification, M} = \frac{\text{image height, h}}{\text{object height, H}}$$

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

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

The lens formula:

If an object is at a distance, u forms the lens and image, v distance from the lens, then focal length, f is given by:

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

This applies to both concave and convex.

Real is positive and virtual is negative sign convention:

According to this sign convention;

- All distances are measured from the optical centre of the lens 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 convex lens is real hence its focal length, f is positive while a concave lens has a virtual principle focus, F and so its focal length, f is negative.

Example 1:

An object of height 10cm is placed at distance 50cm from a converging lens of focal length 20cm. Calculate the;

(i) Image position.

(ii) image height

(iii) magnification

Solution:

Given, H = 10 cm, u = 50 cm, f = 20 cm

v = ? h = ?

Using the mirror formula; $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ $\frac{1}{20} = \frac{1}{50} + \frac{1}{v}$ $\frac{1}{20} - \frac{1}{50} = \frac{1}{v}$	$\frac{1}{v} = \frac{5-2}{100} = \frac{3}{100}$ $\frac{1}{v} = \frac{3}{100}$ $v = 33.33$ cm A real image was formed 33.33cm from the lens.

Using the definition of magnification, $M = \frac{h}{H} = \frac{V}{U}$ $\frac{h}{10} = \frac{33.33}{20}$ $h = 6.67$ cm	Magnification: $M = \frac{h}{H} = \frac{V}{U}$ $M = \frac{(\frac{100}{3})}{20}$ $M = 0.67$

Questions: (Students' Exercise)

1. An object is placed: a) 20 cm b) 5 cm, from a converging lens of focal length 15 cm. Find the;

(i) nature of the image in each case .

(ii) position, v of the image in each case.

(Va = 60cm ; Vb = 7.5)

(iii) Magnification, M of the image in each case.

(Ma = 3 ; Mb = 1.5)

2. A four times magnification virtual image is formed of an object placed 12cm from a converging lens. Calculate the;

(i) Position of the image (v = 48 cm)

(ii) Focal length of the lens (f = 10 cm) .

3. Find the nature and position of the image of an object placed 10cm from a diverging lens of focal length 15cm.

(Virtual : v = 6cm).

Finding position by graph (scale drawing):

Step I: Select a scale for drawing

Step II: Make a sketch of the drawing; this should include two major rays from a point on the object i.e.

- ✓ A ray parallel and closed to the principal axis should be refracted through the focal point for a converging lens while for a diverging lens, the ray parallel and closed to principal axis is refracted in such a way that is appears to come from the focal point.
- ✓ A ray through the optical center should be drawn un deviated.

Examples:

An object of height 10cm is placed at a distance of 50cm from a converging lens of focal length 20cm. Find by scale drawing the;

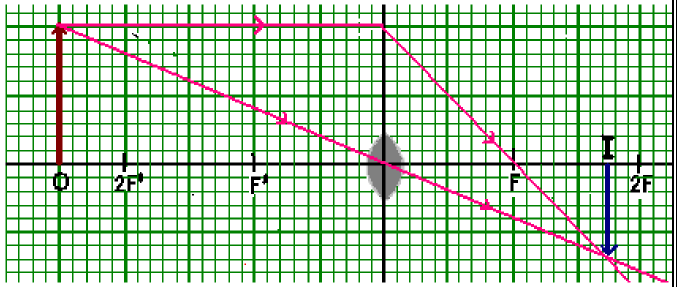
(i) Image position

(ii) Image height

(iii) Nature of the image formed

Solution

Axis	Scale	Conversion
Vertical axis	**1 : 5 cm**	❖ $10\text{ cm} \rightarrow \frac{10}{5} \rightarrow 2\text{cm}$
Horizontal axis	**1 : 10 cm**	❖ $50\text{cm} \rightarrow \frac{50}{10} \rightarrow 5\text{cm}$ ❖ $20\text{cm} \rightarrow \frac{20}{10} \rightarrow 2\text{cm}$



(i) <u>Position:</u>

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

$$\textit{Image distance} = (3.4\ x\ 10)\ cm$$
$$= 34cm$$

<u>Size:</u>

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

$Image\ height\ =\ (1.4\ x\ 5)\ cm$
$=\ 7\ cm$

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

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{34}{50} = 0.68$$

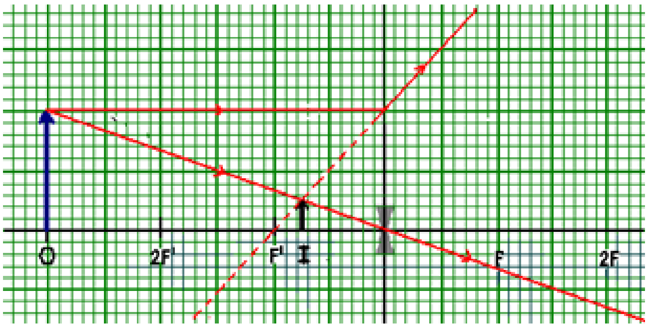
Or

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{7}{10} = 0.7$$

Example: 2
An object of the height 10cm is placed at a distance of 60 cm from a diverging lens of focal length 20cm. Find by scale drawing, the;
(i) Image position, v
(ii) Height, h of the image
(iii) Nature of the image
(iv) Magnification, M

Solution

Axis	**Scale**	**Conversion**
Vertical axis	**1 : 5 cm**	❖ 10 cm $\rightarrow \frac{10}{5} \rightarrow$ 2cm
Horizontal axis	**1 : 10 cm**	❖ 60cm $\rightarrow \frac{60}{10} \rightarrow$ 6cm ❖ 20cm $\rightarrow \frac{20}{10} \rightarrow$ 2cm



(i) Position:
The image distance as measured from the scale drawing is 3cm; using the above scale,
Image distance = (1.5 x 10) cm
= 15cm

Size:
The height of the image on the scale drawing is 0.8cm; using the scale,
Image height = (0.5 x 5) cm
= 2.5 cm

(ii) Nature:
The image formed is; Virtual, Upright and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{15}{60} = 0.25$$

Students' Exercise

1. An object 1cm tall stands vertically on principal axis of a converging lens of, focal length, f = 1cm, and at a distance of 1.7cm from the lens. Find by graphical construction, the position, size, magnification and nature of the image.

2. An object is 32.5 cm from a diverging lens of focal length 12 cm. by scale drawing;
   (i) Locate the numerical position and the height of the image formed.
   (ii) Calculate the ratio of image magnitude to object height.
   (iii) Describe the image formed using the result in (ii) above.

3. An object is placed 10 cm in front of a concave lens of focal length 20 cm to form an image. Determine the position, nature and magnification of the image using a ray diagram.

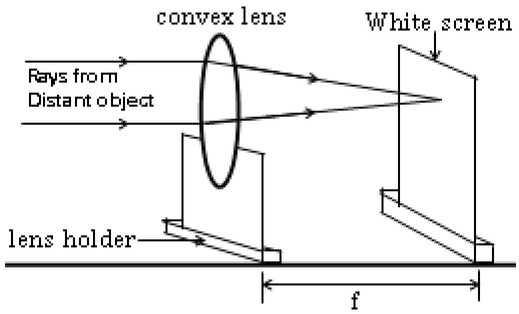
4. An object 5cm tall is placed 15 cm away from a convex lens of focal length 10cm. By construction, determine the position size and nature of the final image.

5. An object 5cm high is placed 20cm in front of a converging lens of focal length 15cm. Find the power of the lens and the magnification of the lens.

6. An object of height 20cm is placed vertically on the axis of a convex lens of focal length 10cm at a distance of 30cm from the lens. Use the graphical method to find the position, nature and magnification of the image.

Experiments to measure focal length of convex lens (Converging lens)

1. **Rough method**
(Using a distant object, e.g window)



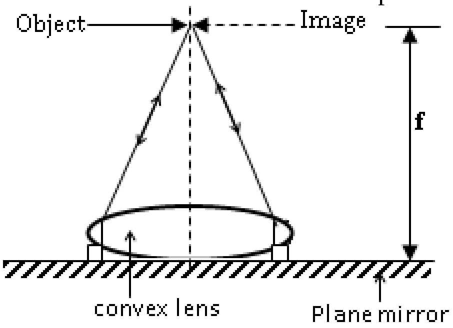
Position the lens and a white screen on a table as shown above.
Move the lens towards and away from the screen until a sharply focused image of the distant object is formed on the screen.
Measure the distance, f between the lens and the screen. It is approximately equal to the focal length of the lens used.

Note:
To improve the accuracy of the results, it is advisable that the experiment is repeated at least three times and the average focal length calculated.

f_1(cm)	f_2(cm)	f_3(cm)	f(cm)
a	b	c	$\frac{(a+b+c)}{3}$

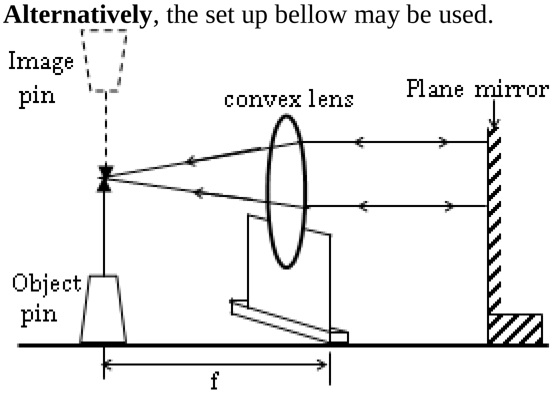
2. Plane mirror method and no parallax

A plane mirror M is placed on a table with its reflecting surface facing upwards. The lens L is placed top of the mirror.
An optical pin, O is then moved along the axis of the lens until its image I coincide with the object O, when both are viewed from above and there is no parallax.



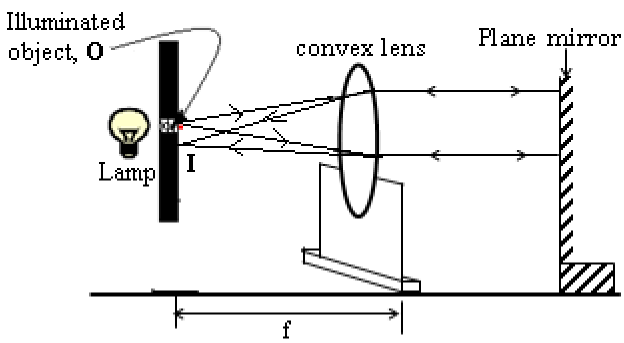
The distance from the pin O to the lens is thus measured and it is equal to the focal length, f, of the lens.

Alternatively, the set up bellow may be used.



NOTE: Rays from O passing through the lens are reflected from the plane mirror M and then pass through the lens a gain to form an image. When O and I coincides the rays from O incident on the mirror must have returned a long their incident path after reflection from the mirror. This happens if the rays are incident normally on the plane mirror, M. The rays entering the lens after reflection are parallel and hence the point at which they converge must be the principle focus.

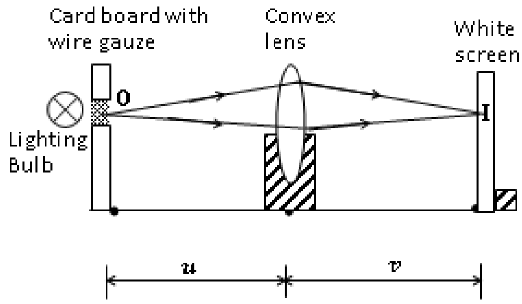
3. Using illuminated object and plane mirror



The position of the lens holder is adjusted until a sharp image of the object is formed on the screen alongside the object itself. The object will now be situated at the focal point (focal plane). The distance between the lens and screen is measured and this is the focal length f.

Note: The focal point or focal plane of a lens is a point or a plane through the principal focus at right angle to the principal axis. At this point, rays from any point on the object will emerge from the lens as a parallel beam and are reflected back through the lens.

4. Lens formula method



Using an illuminated object, O at a measured distance, u, move the screen towards and away from the lens until a clear image of the cross wires is obtained on the screen.
The image distance, v is measured and recorded.
The procedure is repeated for various values of u and the corresponding values of v measured and recorded.
The results are tabulated including values of $\frac{1}{u}$ *and* $\frac{1}{v}$.

u(cm)	v(cm)	$\frac{1}{u}(\text{cm}^{-1})$	$\frac{1}{v}(\text{cm}^{-1})$
-	-	-	-

The focal length can be calculated from the equation $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ and the average of the values obtained .

Power of a lens:

Power of a lens is the reciprocal of its focal length expressed in meters. The S.I of power of lens is dioptres (D).
Note: The Focal length of convex les is real so it's positive and hence its power is positive.
The focal length of a concave lens is virtual so it's negative hence its power is negative.

The power of the combination of lenses can be calculated from:

The power of the lens; $\mathbf{P} = \frac{\mathbf{1}}{\textbf{focal length in metres}}$

$$= \frac{\mathbf{1}}{\mathbf{f}}$$

$$\begin{pmatrix}\text{Power of}\\ \text{combination,}\end{pmatrix} = \begin{pmatrix}\text{Power of}\\ \text{first lens}\end{pmatrix} + \begin{pmatrix}\text{Power of}\\ \text{second lens}\end{pmatrix}$$

$$P_{\text{combination}} = \frac{1}{\begin{matrix}\text{focal length, } f_1\\ \text{of first lens}\end{matrix}} + \frac{1}{\begin{matrix}\text{focal lenth, } f_2\\ \text{of second lens}\end{matrix}}$$

$$P_{\text{combination}} = \frac{1}{f_1} + \frac{1}{f_2}$$

Examples:

1. Two converging lenses of focal lengths 15cm and 20cm are placed in contact, find the power of combination.

Solution

Given, $f_1 = 15 \text{ cm} = 0.15 \text{ m}; \; f_2 = 20 \text{ cm} = 0.20 \text{ m}$

$$P_{combination} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$P_{combination} = \frac{1}{0.15} + \frac{1}{0.20}$$

$$P_{combination} = 11.67 \text{ D}$$

2. A convex lens of focal length 20cm is placed in contact with concave lens of focal length 10cm. Find the power of the combination (Ans: -5D).

Solution

Given, $f_1 = 20 \text{ cm} = 0.20 \text{ m}; \; f_2 = 10 \text{ cm} = 0.10 \text{ m}$

$$P_{combination} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$P_{combination} = \frac{1}{0.20} + \frac{1}{-0.10}$$

$$P_{combination} = -5 \text{ D}$$

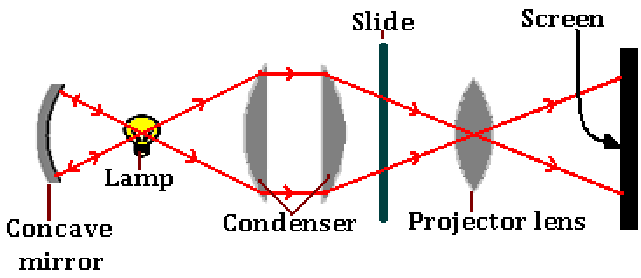
Uses of lenses

- The eye uses it to focus images on the retina
- In spectacles to correct eye defects.
- In lens cameras to focus images on the screen or film.
- In slide projectors to magnify/focus images on the screen.
- In compound microscopes to magnify/ focus images of tiny near objects.
- As simple magnifying glasses, to magnify images of smaller objects without inverting them.

Simple Optical Instruments:

(i) Projector (or Projection Lantern)

A projector is used for projecting the image of a transparent slide onto the screen. Thus the image formed is real.



Mode of Operation

The powerful **source of light (lamp):** is placed at the principal focus of a concave mirror so as to illuminate the slide if the image is to be bright.

Concave mirror: reflects back light which would otherwise be wasted by being reflected away from the film.

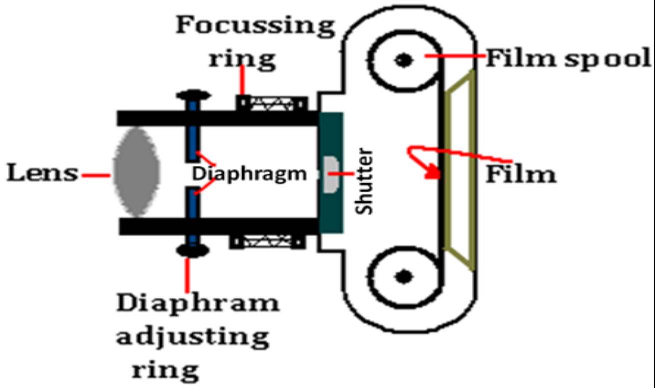
Condenser; this is the combination of two Plano convex lenses. The main function is to collect the rays from the light source and concentrate them onto the slide.

Slide: It contains the object whose image is to be projected on the screen.

Projector lens: is mounted on a sliding tube so that it may be moved to and fro to focus a sharp real image on the screen.

(ii) Lens Camera

A camera is alight tight box in which a convex lens forms a real image on a film.



The film contains chemicals that change on exposure to light. It is developed to give a negative. From the negative the photograph is printed.

The inner surface of the camera is **painted black** in order to prevent reflection of stray rays of light.

A camera is fitted with the provision for adjusting the distance between the film and then lens so that the object can be focused on the film by the convex lens.

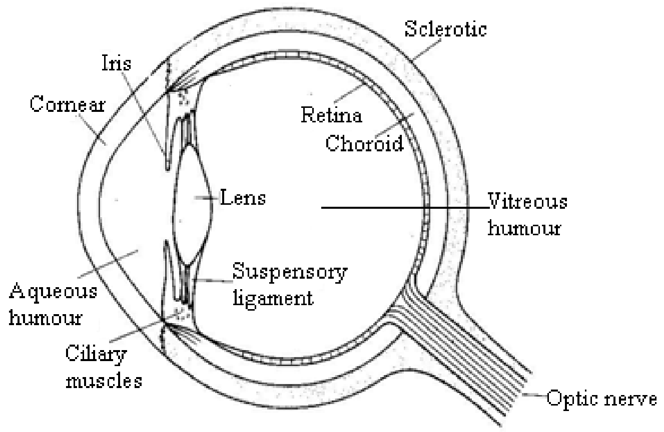
- ❖ **Converging lens**; is to focus the object on the film.
- ❖ **Shutter;** It controls the amount of light entering the camera by the length of times the shutter is open. Fast moving objects require short exposure.
  The brightness of the image on the film depends on the amount of light passing through the lens. The shutter opening is controlled by the size of the hole in the diaphragm.
- ❖ **Diaphragm**; this changes the size of the aperture. The stop is made of a sense of metal plates which can be moved to increase the aperture size.
  Thus it controls the amount of light entering the camera by its size.

***Note:** The correct setting of the lens for an object at any given distance from the camera is obtained from a scale engraved on the lens mount.

- ❖ **Film:** It is a light sensitive part where the image is formed.

THE HUMAN EYE

Light enters the eyes through the cornea, the lens and then is focused on the retina. The retina is sensitive to light and sends messages to the brain through optic nerves. The iris changes in size to vary the amount of light entering through the pupil. The size of the pupil decreases in bright light and increases in dim light.



Functions of the parts of the eye.

1. **Lens:** The lens inside the eye is convex. It's sharp; it changes in order to focus light.

2. **Ciliary muscle:** These alter the focal length of lens by changing its shape so that the eye can focus on image on the retina.

3. **The iris**: This is the coloured position of the eye. It controls the amount of light entering the eye by regulating the size of the pupil.

4. **The retina**: This is a light sensitive layer at the back of the eye where the image is formed.

5. **The optic nerve**: It is the nerve that transmits the image on the retina to the brain for interpretation.

6. **The cornea:** It is the protective layer and it also partly focuses light entering the eye .

Accommodation

This is the process by which the human eye changes its size so as to focus the image on the retina. This process makes the eye to see both near and far objects.

Note: Accommodation is the process by which objects at different distances are focused by the ciliary muscles changing shape, so that the focal length of the lens changes.

Accommodation can also be the ability of the eye to focus objects at various distances.
Near point: this is the closest point at which the eye can accommodate a most clear vision. Its 25m for a normal eye.

Far point: this is the most distant point at which the eye can accommodate a clear vision. It's at infinity since rays travel in a straight line.

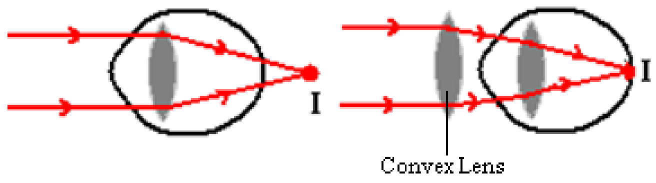
Defects of vision and their corrections

a) Long Sightedness. (Hypermetropia)

This is an eye defect where a person can see distant objects clearly but near objects are blurred.
It is due to either;

(i) Too long focal length, or
(ii) Too short eye ball.

Because of these effects, the ciliary muscles have weakened and cannot make the eye lens fatter (i.e. decrease its focal length) to focus near object on the retina.
Thus, the image is formed behind the retina.



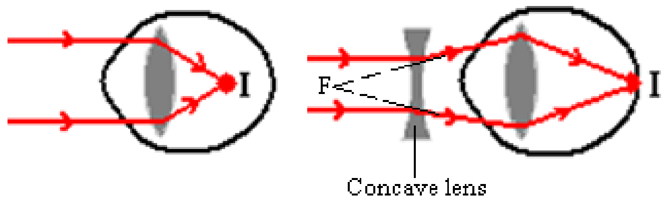
This defect is corrected by using spectacles containing converging lens which increase the convergence of the rays and brings it to focus on the retina.

b) Short Sightedness: (Myopia)

This is an eye defect where person can see near objects clearly but distant ones are blurred.
It is due to either;

(i) Too short focal length, or
(ii) Too long eye ball.

Because of these effects, the ciliary muscles do not relax sufficiently and consequently, distant objects are focused in front of the retina.



This defect is corrected by using spectacles containing diverging lens which increase the divergence of the light rays before they enter the eye and brings them to focus on the retina.

Similarities between the camera and the eye

- Both the eye and camera have light sensitive parts i.e. the retina for an eyes and film for camera.
- Both the eyes and camera have lenses.
- Both have a system which regulates the amount of light entering them i.e. iris for the eye and the diaphragm for the camera.
- The camera has black light proof inside the camera while the eye has a black pigment inside.

Differences between the human eye and camera:

Human eye	Camera
Lens: - ls biological. - Is flexible	-Lens is artificial - Is a rigid glass or plastic
Focal length: f of lens for the eye is variable.	-focal length of lens the for camera is fixed.
Distance: The distance between the lens and retina is fixed.	-The distance between the lens and film is variable.
Focusing: By changing the shape of the lens.	-By moving the lens relative to the film.
Aperture: Controlled by the iris.	-Controlled by the diaphragm.
Exposure: Is continuous.	- Controlled by shutter.
Light sensitive surface: film	-Retina

Exercise:

1. **See UNEB Paper I**

1993Q.7	2000Q.21	2001Q.30	2004Q.14	2007Q.10

2. **Section B**

1993 Qn.7 PII	1994 Qn. 2	1998 Qn.6	2000 Qn.8

COLOURS AND DISPERSION OF LIGHT

Colours of objects we see depend on the colours of the light which reach our eyes from them.

Its by experiments conducted that we can prove that white light is made up of a mixture of seven colours called a **spectrum.**

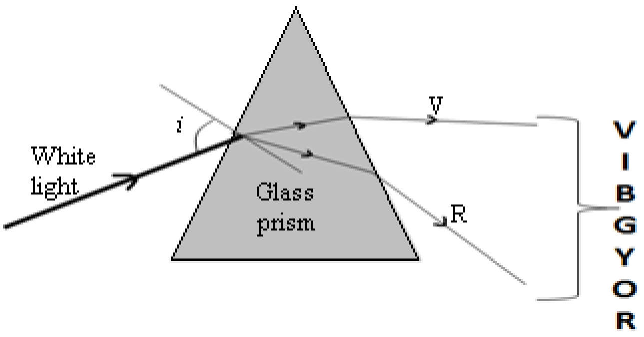
A spectrum is a range of seven colours that form white light. (Day light).

(a) DISPERSION OF LIGHT

Definition:

Dispersion of light is the separation of white light into its component colours.

When white light is passed through a prism, it is deviated and separated into seven colours.



This is because of the refractive index of glass being different for each colour which makes the different colours to move at different speeds.

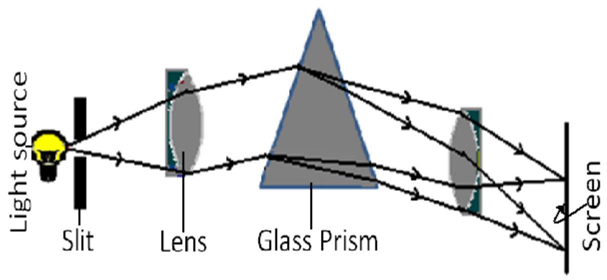
An object colour depends on:

- Colour of light falling on it.
- Colour it transmits or reflects i.e. green light appears green because it absorbs all other colours of white light and reflects green

Impure spectrum: this is the type of spectrum in which the boundaries between the different component colours are not clearly defined. i.e when there is overlapping of colours of white light.

Pure spectrum: this is a spectrum in which light of one colour only forms on the screen without over lapping.

Production of a Pure Spectrum



An illuminated slit is placed at the principle forces of a converging lens so that a parallel beam of white light emerges and falls on the prism.

Refraction through the prism splits up the light into separate parallel beams of different colours each of which is brought to its own focus.

Note: the combination of the slit and first lens is called the **collimator** (To collimate means to make parallel).

Note: The slit should be made narrow to reduce the overlapping of colours to a minimum so as to produce a fairly pure spectrum.

(b) COLOURS

Colour is the appearance of an object that results from their ability or capacity to reflect light.

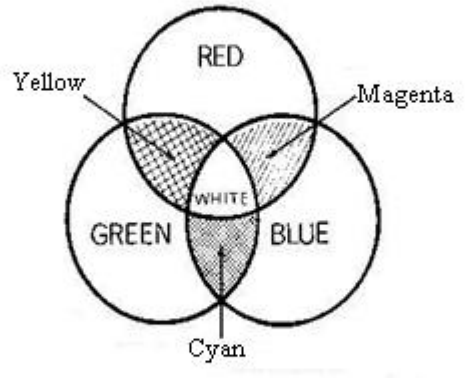
Types of Colour

(i) Primary Colours:

Colours that can't be obtained by mixing any other colours. Examples: Red, Green, Blue

(ii) Secondary Colours:

Colours obtained by mixing any two primary colours. Examples: Yellow, Magenta, Cyan (Peacock Blue)



Colour Addition:

When two colours of light are projected on a screen, they overlap to give a different colour. The new colour is said to be formed by colour addition.

(iii) Complementary Colours:

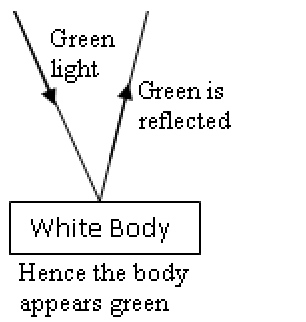
This is a pair of one primary colour and one secondary colour which when mixed gives white light. Examples:

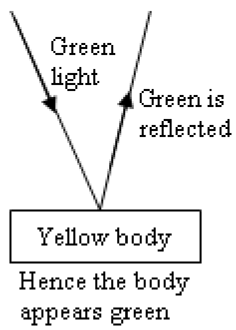
Red + Cyan = White
Blue + Yellow = White
Green + Magenta = White

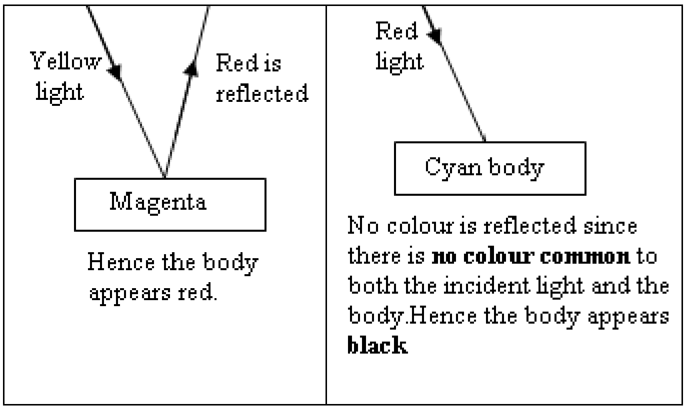
Coloured objects in white light

An object coloured because it reflects and transmits its own colour and absorbs all other colours incident on it.

Examples:







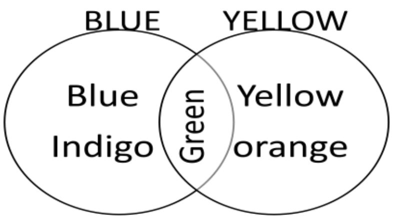
Question
Describe and explain the appearance of a red tie with blue spots when observed in.
a) Red light
b) Green light – the whole tie appears black because both colours are primary colours and none is reflected back.
c) Red light – in the red light the tie appears red and blue spots blacks.
This is because the red reflects the red colour and observes blue colour.

Question2
A plant with green leaves and red flowers is placed in
a) green b) blue c) Yellow
d) what colour will the leaves and flowers appear in each case . Assume all colours are pure

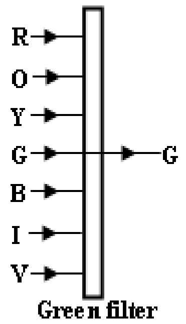
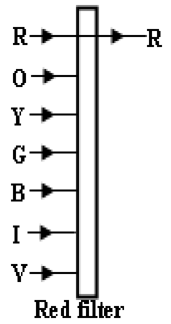
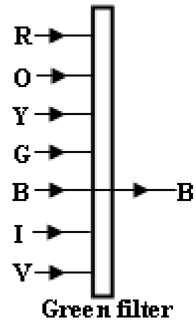
a) green -: the leaves remain green but the flower black
b) blue -: the leaves will appear black and flowers black
c) Yellow -: the leaves appear green and flowers appear red.

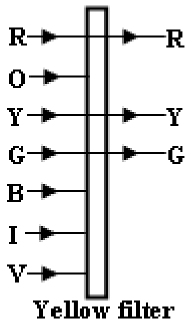
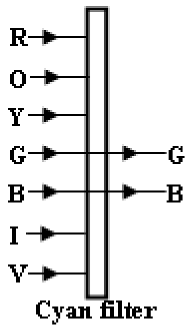
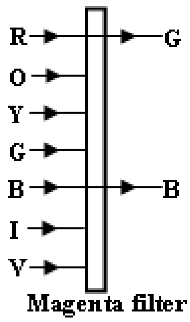
Colour subtraction.
When light falls on a surface of an object, three things may happen to it in varying proportions. Some light may be;
(i) Reflected,
(ii) Transmitted,
(iii) Absorbed.
The light which is absorbed disappears. The absorption of light is known as **subtraction of coloured light.**

Mixing pigments;
Is a phenomenon when a impure colour reflects more than one colour light. Mixing coloured pigment is called mixing by subtraction and mixing coloured light is called mixing by addition.
When two pigments are mixed, they reflect the colour which is common to both and absorb all the other e.g. yellow paint reflects orange, yellow and green. While blue paint reflects green, blue and indigo.
Yellow and blue reflect green but absorb orange, yellow, blue and indigo.



(c) COLOUR FILTERS
Definition:
A filter is a coloured sheet of plastic or glass material which allows light of its own type to pass through it and absorbs the rest of the coloured lights i.e. a green filter transmits only green, a blue transmits only blue, a yellow filter transmits red, green and yellow lights.

Effect of filters of primary colours on white light		
A green filter absorbs all other colours of white light and transmits only green. 	A red filter absorbs all other colours of white light and transmits only red. 	A blue filter absorbs all other colours of white light and transmits only blue. 

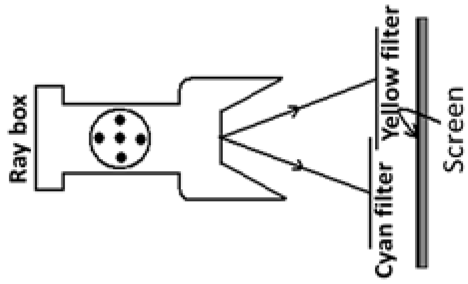
Effect of filters of secondary colours on white light		
A yellow (R+G) filter absorbs all other colours of white light and transmits only Red green and yellow. 	A Cyan (G + B) filter absorbs all other colours of white light and transmits only Green and Blue. 	A magenta (R + B) filter absorbs all other colours of white light and transmits only Red and blue. 

Infrared and Ultra-violet light
The spectrum from the sun has both the visible and invisible spectrum. The invisible spectrum consists of ultra-violet at the extreme end of the violet light and the Infra red found just beyond the red light.

Ultra-violet	**VIBGYOR**	**Infra-red**
Invisible spectrum	Visible spectrum	Invisible spectrum

The invisible spectrum can be detected by;
(i) A thermopile connected to a galvanometer which shows a deflection on its detection.
(ii) A photographic paper which darkens when the invisible spectrum falls on it.

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.

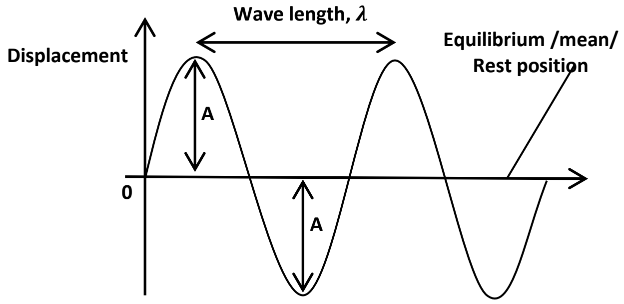
Electromagnetic waves: These are waves produced by a disturbance in form of a varying electric or magnetic fields. These are waves that don't require a material medium for their propagation. Electromagnetic waves travel in a vacuum.
They include radio, infra red, light, Ultraviolet, X-rays, Gamma rays.

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

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

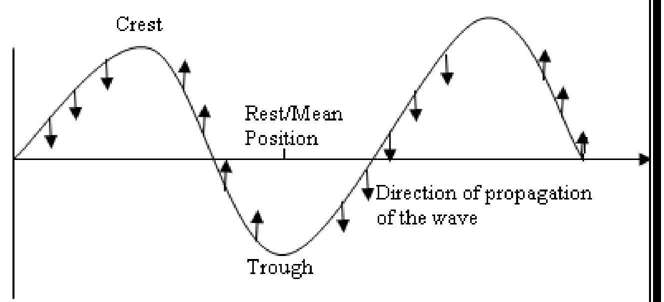
Alternatively,
If a wave covers a distance, λ, the wavelength, then the time taken is T, the period. Hence speed,
$$Speed, v = \frac{\lambda}{T} = \left(\frac{1}{T}\right)\lambda\,, \qquad But, \frac{1}{T} = f$$
$$\Leftrightarrow \qquad \boldsymbol{v = f\lambda}$$

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

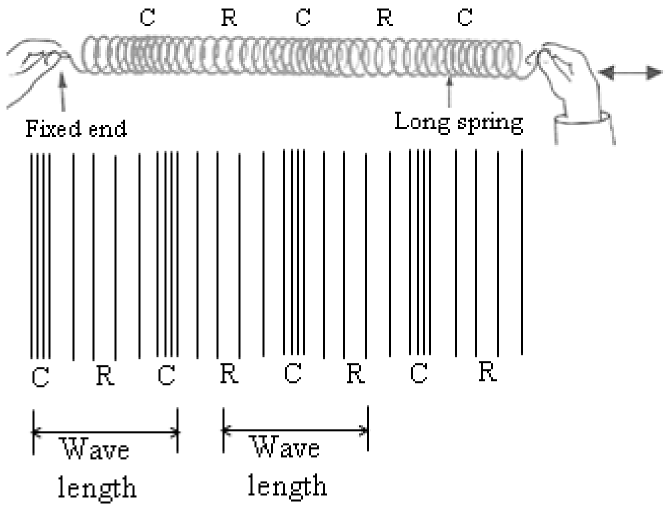
i) Transverse waves
These are waves in which particles vibrate perpendicularly to the direction of propagation of the wave.
Examples
- ✓ water waves,
- ✓ Electromagnetic waves
- ✓ waves formed when a rope is moved up and down.



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:

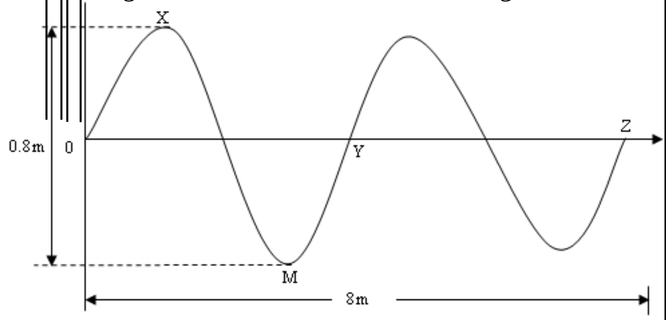
(i) Frequency of radio wave ; λ = 10m, v=3×10^8 m/s	(ii) Period ,T	(ii) Number of cycles
$v = f\lambda$ $3\times10^8 = f\times10$ $f = \frac{3\times10^8}{10}$ $f = 3\times10^7\text{Hz}$	$\text{Period}, T = \frac{1}{f}$ $T = \frac{1}{3\times10^7}$ $T = 3.3\times10^{-7}\text{s}$	$\text{Frequency}, f =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

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;	$v = f\lambda$
$\mathbf{d = (n-1)\lambda}$	$v = 12\times0.04$
$\lambda = \frac{d}{n-1}$ $\lambda = \frac{36}{10-1} = \frac{36}{9} = 0.04\text{m}$ $\lambda = 0.04$ m	$v = 0.48\ \text{ms}^{-1}$

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

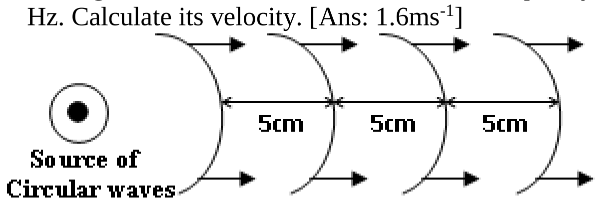
(b) (i) Determine the amplitude of the wave.
   (ii) If the speed of the wave is 8000cm/s. Determine the frequency of the wave.

<u>Questions</u>

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	(ii) wave frequency
$d = 35\text{m}, t = 2s$ $v = \frac{d}{t} = \frac{35}{2} = 17.5\text{ms}^{-1}$ $v = 17.5\text{ms}^{-1}$	$v = f\lambda$ $f = \frac{v}{\lambda} = \frac{17.5}{5} = 3.5\text{Hz}$ $f = 3.5\text{Hz}$

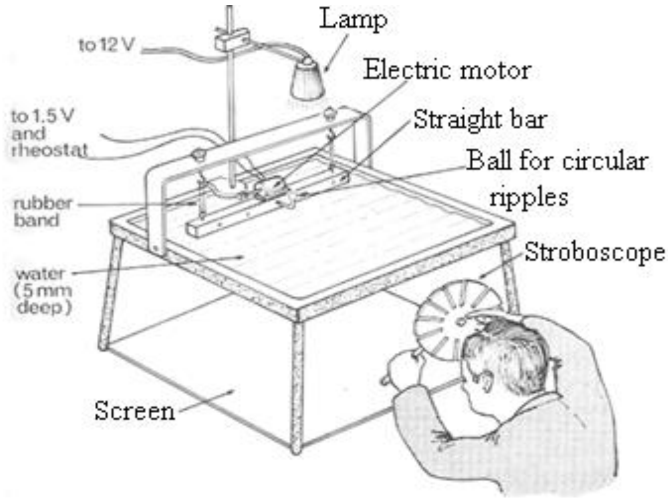
2. The figure below shows circular waves of frequency 32 Hz. Calculate its velocity. [Ans: 1.6ms^{-1}]



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

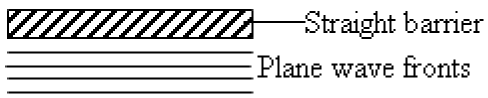
THE RIPPLE TANK



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.

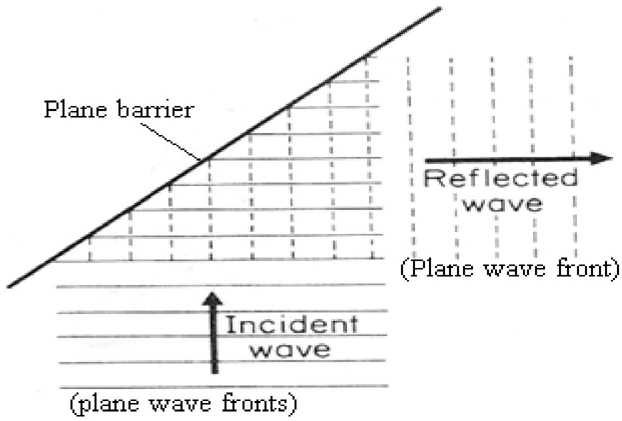
N.B Therefore the speed of the wave in a ripple tank can be reduced by reducing the depth of water in the tank. The effect of reducing the speed of waves is that the wave length of water reduces but frequency does not. The frequency can only be changed by the source of the wave.
Qn: A vibrator in a ripple 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.

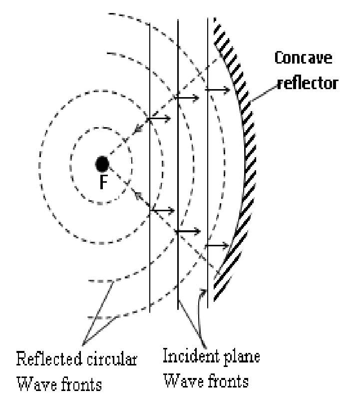
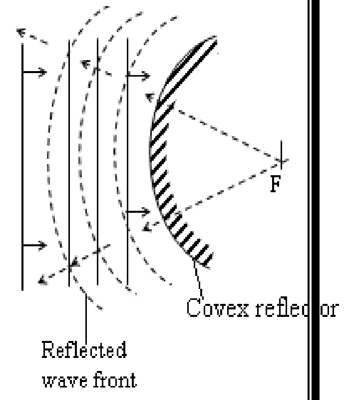
(a) Reflection	(b) Refraction	(c) Diffraction
(d) Interference	(e) Polarization	

(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.

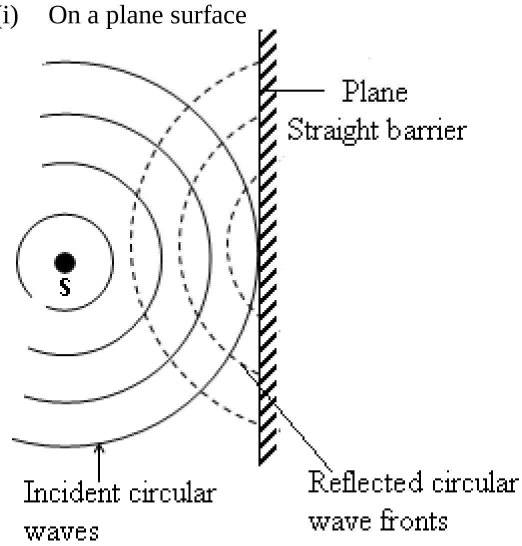
❖ **Reflection of plane wave**
(i) On a plane surface.



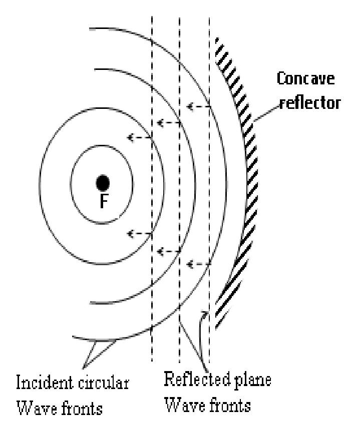
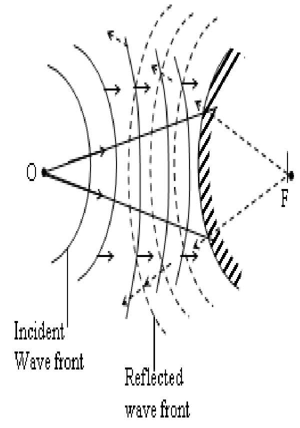
(ii) On a curved surface

• Concave reflector	• Convex reflector
	

❖ **Reflection of circular waves**
(i) On a plane surface



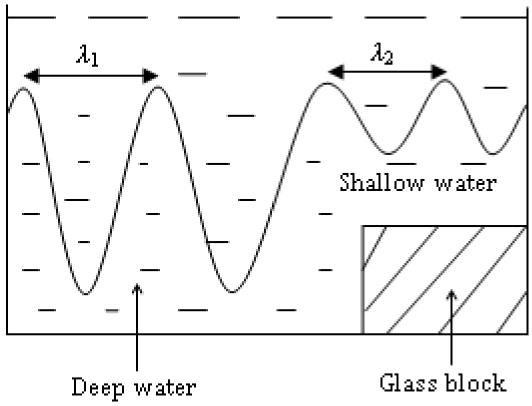
(ii) On a curved surface

• Concave reflector	• Convex reflector
	

Note: During reflection of water waves, the frequency and velocity of the wave do not change.

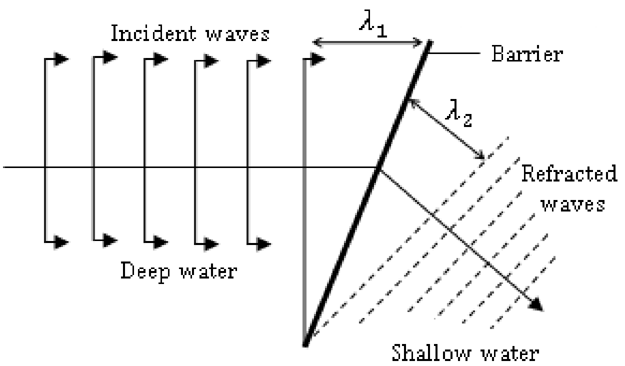
(b) REFRACTION

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:

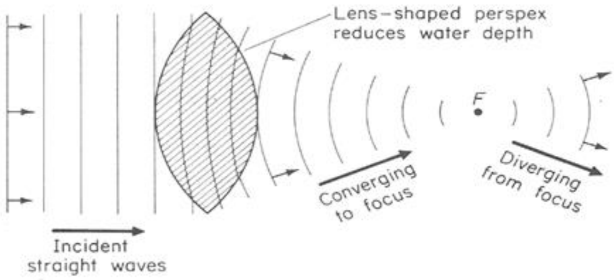
(i) $\lambda_1 > \lambda_2$
(ii) $v_1 = f\lambda_1$ and $v_2 = f\lambda_2$
(iii) $v_1 > v_2$; When f – is constant.

Refractive index n $= \frac{\text{velocity in deepwater}}{\text{velocity in shallowwater}}$

Refractive index $n = \frac{v_1}{v_2} = \frac{f\lambda_1}{f\lambda_2}$

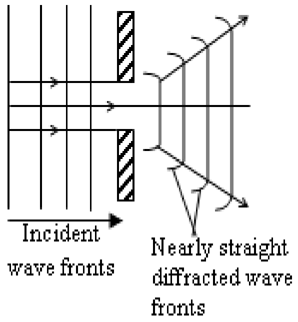
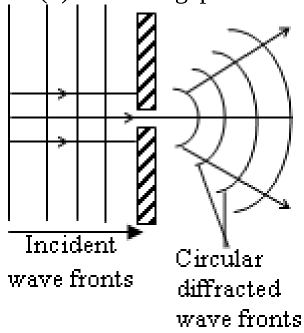
Refractive index $n = \frac{\lambda_1}{\lambda_2} = \frac{\text{Wave length in deep water}}{\text{Wave length in shallow water}}$

Refraction of plane waves by a convex lens

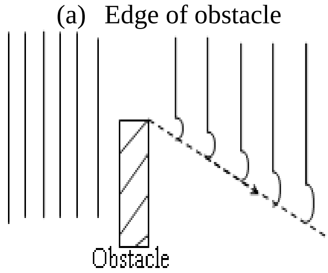


(c) DIFFRACTION

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	(b) Narrow gap
	
The ripples emerge straight and curve at the ends.	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	
	

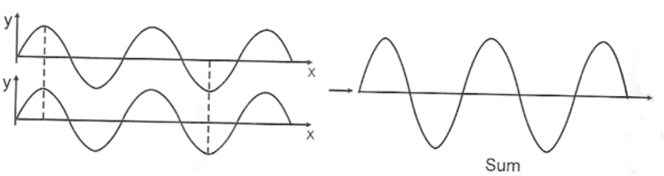
Sound waves are more diffracted than light waves because the wave length of sound is greater than that of light. Therefore sound can be heard in hidden corners.
N.B - When waves undergo diffraction, wave length and velocity remain constant.

(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).

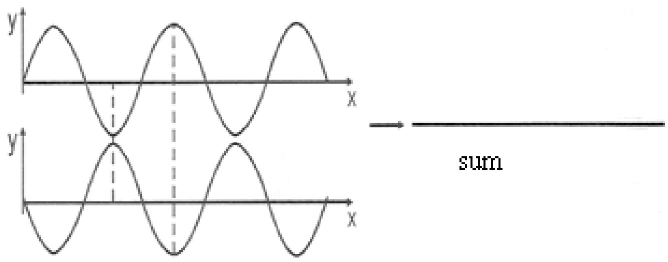
Conditions necessary for producing interference:
1. The two waves must have coherent sources.
2. The two waves must have the same amplitude and the same frequency.
3. The distance between the sources must be very small.

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.
⋂+⋂=⋂ OR ⋃+⋃=⋃



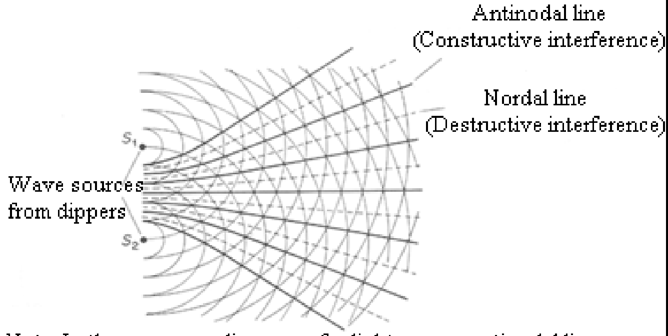
- **For Light,** constructive Interference would give **increased brightness.**
- **For sound,** constructive Interference would give **increased loudness.**

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.
⋂+⋃=……………………………………………

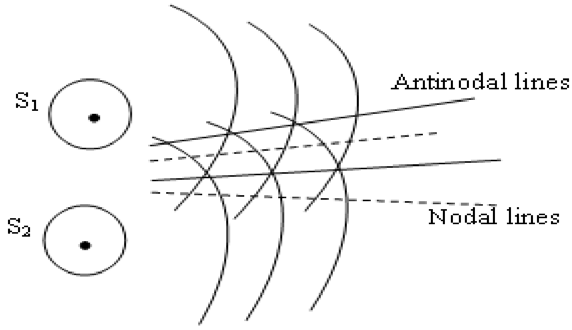


For Light, constructive Interference would give **reduced brightness or darkness.**
For sound, constructive Interference would give **reduced loudness or no sound at all.**

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.

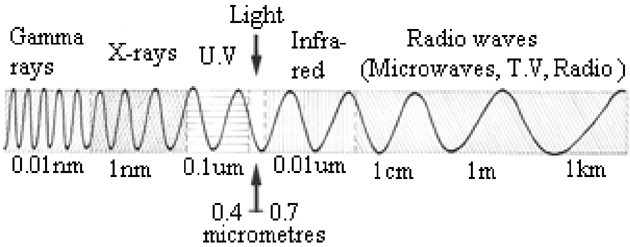
State three differences between sound and light waves.

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.]

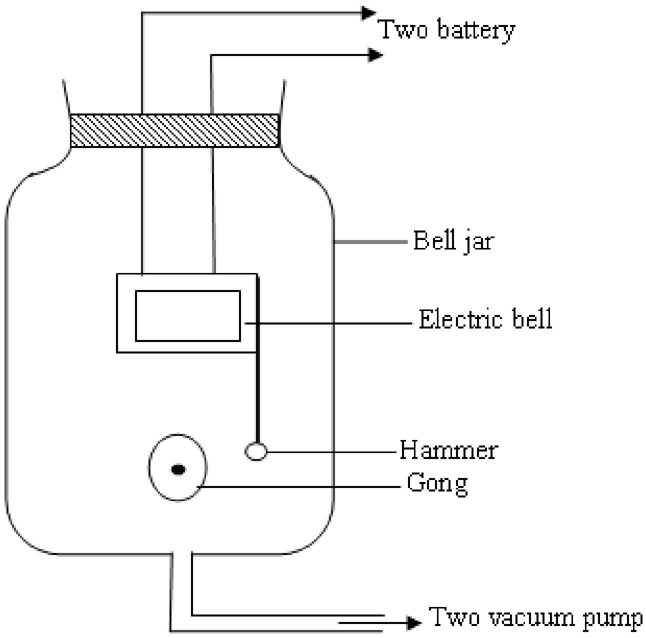
Example: 2

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:

$t_1 - t_2 = 0.5$

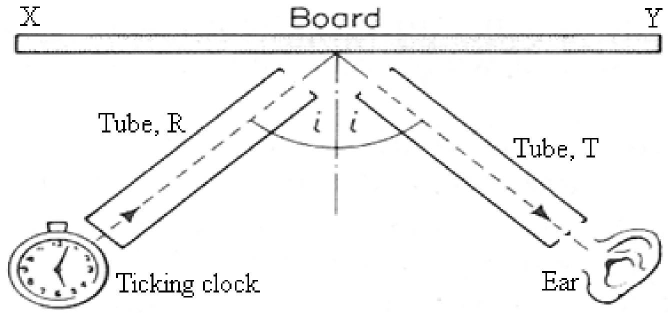
$\frac{x}{330} - \frac{x}{5280} = 0.5$

$x = 176$ 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.

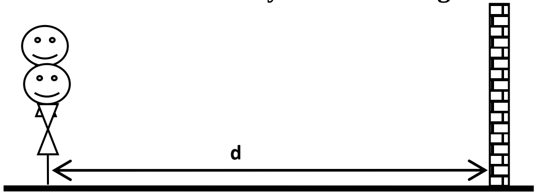
Note: Hard surfaces reflect sound waves while soft surface absorb sound wave.

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;

$$\mathbf{Speed} = \frac{\mathbf{2(distance)}}{\mathbf{time}} = \frac{\mathbf{2nd}}{\mathbf{t}}$$

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.

$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$

$V = \frac{2d}{t}$

$V = \frac{2 \times 34}{0.2}$

$V = 340\ ms^{-1}$

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.

$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$

$V = \frac{2d}{t} = \frac{2 \times 99}{0.6} = 330\ ms^{-1}$

$V = 330\ ms^{-1}$

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?

$\text{Speed} = \frac{2(\text{distance})}{\text{time}}$

$V = \frac{2d}{t}$

$340 = \frac{2d}{8}$

$2d = 340 \times 8$

$2d = 2720$

$d = 1360$ 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.

$V = \frac{2d_1}{t_1}$ $330 = \frac{2d_1}{2} \Rightarrow 2d_1 = 660$ $d_1 = 330$ m	$V = \frac{2d_2}{t_2}$ $330 = \frac{2d_2}{5} \Rightarrow 2d_2 = 1650$ $d_2 = 825$ m
$d = d_1 + d_2$ $d = 330 + 825$ $d = 1155$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)

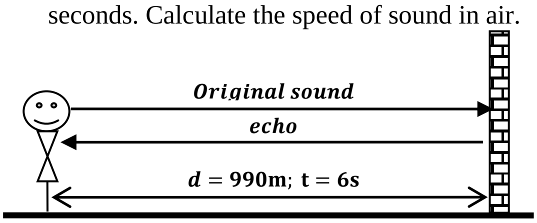
$V = \frac{2d_1}{t_1}$ $330 = \frac{2d_1}{3} \Rightarrow 2d_1 = 990$ $d_1 = 495$ m	Since the man is mid way between the cliffs, $d_2 = d_1 = 495$m $d = d_1 + d_2$ $d = 495 + 495$ $d = 990$m

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.



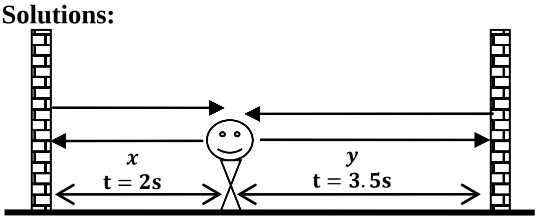
$$V = \frac{2d}{t} = \frac{2 \times 990}{6} = 330ms^{-1}$$

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	

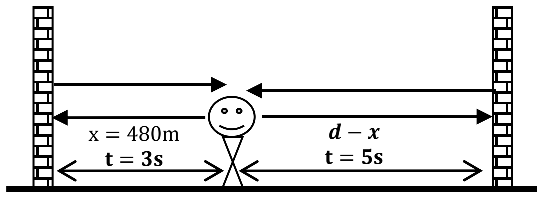
4. A student, standing between two vertical cliffs and 480m from the nearest cliff shouted. She heard the 1st echo after 3 seconds and the second echo 2 seconds later. Calculate;

(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.

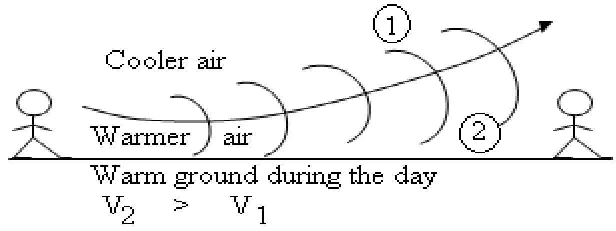
Why echoes are not heard in small rooms?
This is because the distance between the source and reflected sound is so small such that the incident sound mixes up with the reflected sound making it harder for the ear to differentiate between the two.

Questions:
(a) Outline four properties of electromagnetic waves.
(b) Distinguish between:
(i) Sound waves and light waves.
(ii) Sound waves and water waves.

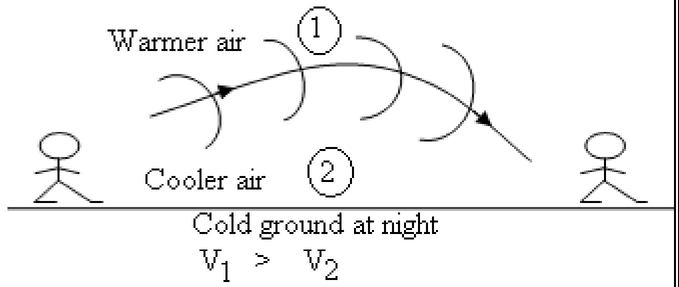
1. A man standing midway between two cliffs makes a sound. He hears the first echo after 3s. Calculate the distance between the two cliffs (Velocity of sound in air = 330m/s)

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.

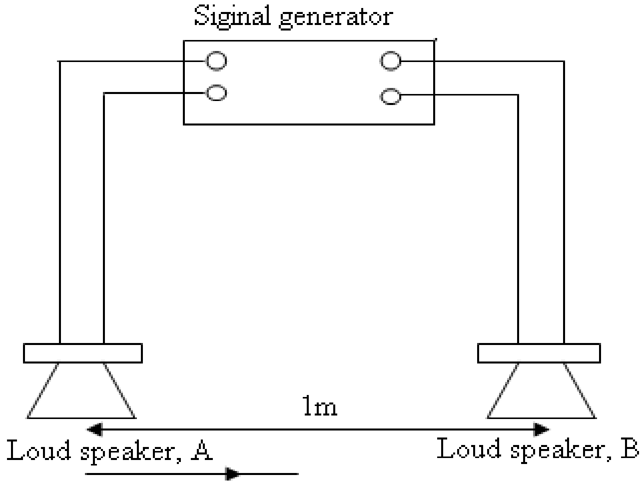
A person in one room can be heard by another person in the next room because of diffraction of sound waves.
The mouth acts as a gap and the waves from mouth spread and the person is able to hear the sound.
If you are sitting in a room and the door is open, you can hear music from a radio in the next 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.

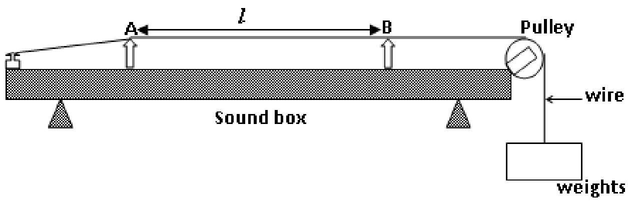
Beats

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, $\mu = mass\ per\ unit\ length = \frac{mass}{length}$

<u>The three factors can be combined into a single formula to give the expression for frequency of a stretched string (wire) as:</u>

$$\boldsymbol{f = \frac{1}{l}\sqrt{\frac{T}{\mu}}}$$

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, $\quad l_2 = \frac{1}{2} l_1$

$420 \times l_1 = f_2\left(\frac{1}{2} l_1\right)$

$f_2 = 840$ 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.

<u>**Fundamental note:**</u>

- Is a note with the lowest audible frequency.
- It is the note produced at the first position of resonance.

<u>**Overtones:**</u>

- Is a note whose frequency is higher than the fundamental frequency.
-

<u>Uses of overtones:</u>

-Determining the overall quality of sound

-Describing sound systems in pipes or plucked strings.

<u>**Harmonics:**</u>

- 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

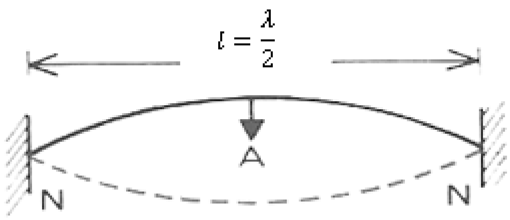
Find the frequency of a note of four octaves below a note of frequency 512Hz.

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 .

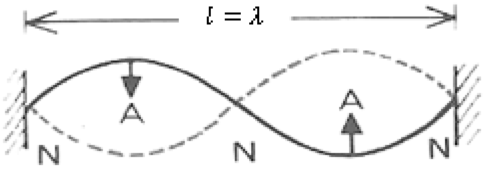
The frequency at which it vibrates is called the fundamental frequency.

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.

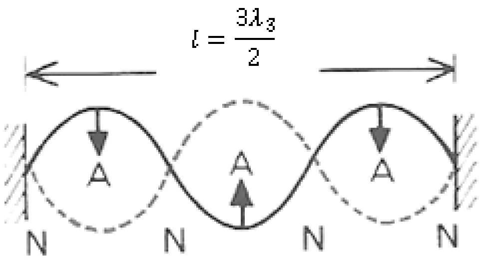


If f_2 is the frequency of the wave, then;

$$f_2 = \frac{v}{\lambda_2} = \frac{v}{l} = \frac{2}{2} \times \frac{v}{l} = 2 \times \left(\frac{v}{2l}\right) = 2f_1$$

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.

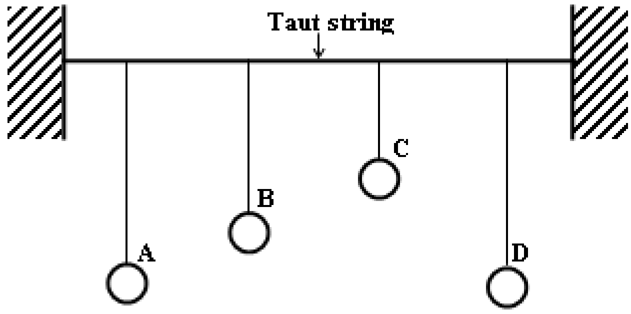
RESONANCE

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.

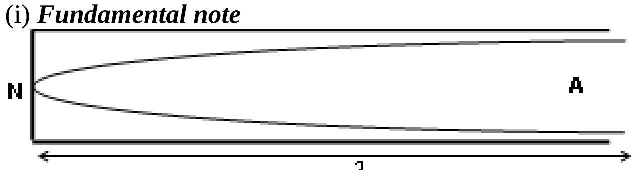
(a) Closed pipes.

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***

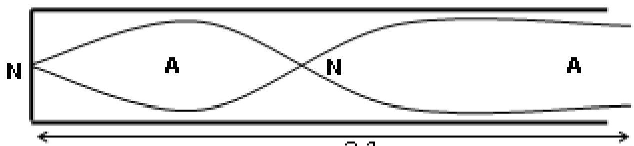


$$l = \frac{\lambda_1}{4}$$

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*** (3rdharmonic)

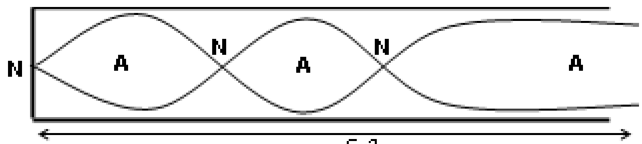


$$l = \frac{3\lambda_1}{4}$$

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*** (5thharmonic)



$$l = \frac{5\lambda_3}{4}$$

$$f_3 = \frac{v}{\lambda_3} = \frac{v}{\left(\frac{4l}{5}\right)} = \frac{5v}{4l} = 5f_1$$

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.

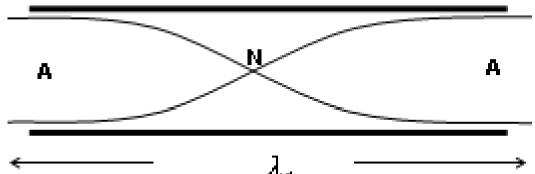
(b) Open pipes

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:-

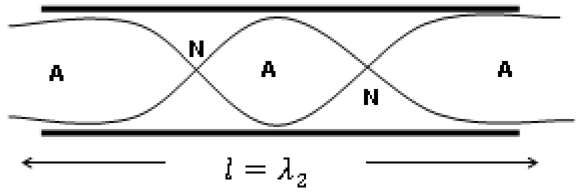
(i) ***Fundamental note.(* 1st harmonic)**



$$l = \frac{\lambda_1}{2}$$

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:** $\boldsymbol{f_n = n\left(\frac{v}{4l}\right) = nf_1}$**,** Where**, n** = 1, 3, 5, 7………
- For an **open pipe: ;**$\boldsymbol{f_n = n\left(\frac{v}{2l}\right) = nf_1}$, Where, **n** = 1, 2, 3, 4………

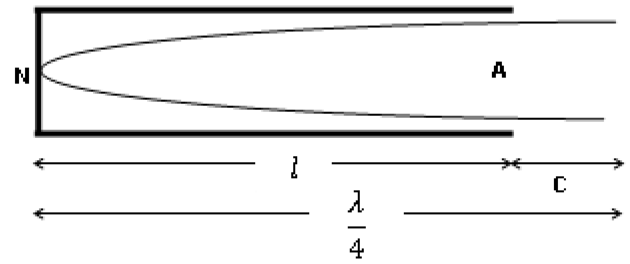
End correction

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



$$\frac{\lambda_1}{4} = l + c \Leftrightarrow \lambda_1 = 4(l + c)$$

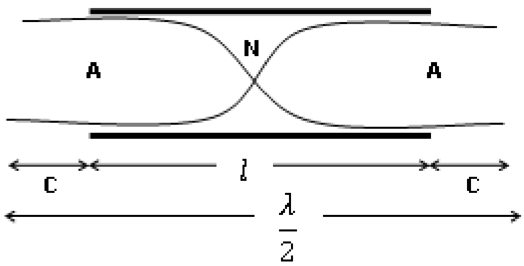
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{4(l + c)}$$

Fundamental frequency,

$$\boldsymbol{f_1 = \frac{v}{4(l + c)}}$$

For open pipe;-

Fundamental mode,



$$\frac{\lambda_1}{2} = l + 2c \Leftrightarrow \lambda_1 = 4(l + 2c)$$

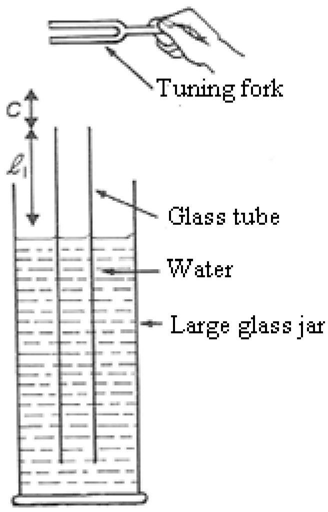
$$f_1 = \frac{v}{\lambda_1} = \frac{v}{2(l + 2c)}$$

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

$(l_2 - l_1) + (c - c) = \frac{3}{4}\lambda - \frac{1}{4}\lambda$

$l_2 - l_1 = \frac{1}{2}\lambda$

$2(l_2 - l_1) = \lambda$

- 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.

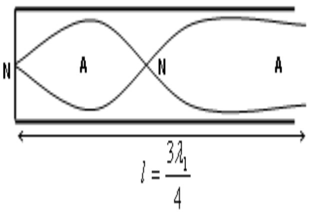
A glass tube open at the top is held vertically and filled with water. A tuning fork vibrating at 264 Hz is held above the table and water is allowed to flow out slowly .The first resonance occurs when the water level is 31.5cm from the top while the 2nd resonance occurs when the water level is 96.3cm 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})



$$\lambda = \frac{4l}{3}$$

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;

$3f_1 = 280$

$f_1 = 93.33\ Hz$

$$f_1 = \frac{v}{4l}$$

$$93.33 = \frac{330}{4l}$$

$$4l \times 93.33 = 330$$

$$l = 0.884\text{ m}$$

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 = $5f_1$ = 900Hz.

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

5. ELECTROSTATICS

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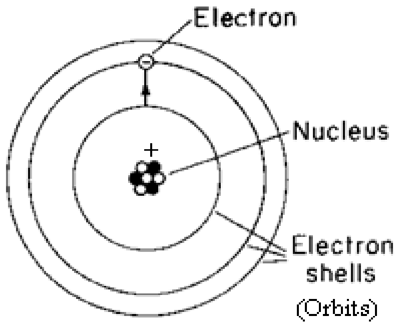
This refers to the study of charges at rest.
To understand the nature of charge, it is necessary to know the structure of an atom.

Structure of an atom
The atom consists of three particles, namely

Particle	Charge	Location
(i) Neutron	No charge	In the nucleus of the atom
(ii) Proton	Positive (+)	In the nucleus of the atom
(iii) Electron	Negative (+)	Outside the nucleus of the atom



The electrons are negatively charged while protons are positively charged. The two types of charges however are of the same magnitude in a neutral atom.
In a neutral atom, the number of negative charges is equal to the number of positive charges and the atom is said to be electrically neutral. Therefore, electrostatics is the study of static electricity because the charges which constitute it are stationary.

Conductors and insulators
A conductor is a material which allows charge to flow through it.
It has loosely bound electrons known as conduction electrons. The flow of these electrons constitutes current flow.
Conduction occurs when electrons transfer charges as they move from one part to another.
Examples: all metals, graphite, acids, bases and salt solutions are conductors.

An insulator is a material which does not allow flow of charge through it.
It has no conduction electrons because its electrons are strongly bound by the nuclear attractive forces.
Examples: rubber, dry wood, glass, plastic, ebonite, fur, polythene, sugar solutions etc.

Note: A body (Conductor or Insulator) can lose or gain electrons.
- Loss of electrons leaves the body with a positive charge.
- Gain of electrons leaves the body with a negative charge.

Differences between conductors and insulators

Conductors	Insulators
- Electrons easily move - Electrons loosely held - The charge acquires is not fixed.	- Electrons hardly move - Electrons tightly held - Charge acquires is fixed

Electrification
This is the process of producing electric charges which are either positive or negative.

Methods of producing Electric charges.
(i) By friction or rubbing or electron transfer (good for insulators and non conductors).
(ii) By conduction/contact (good for conductors).
(iii) By induction (conductors).

(i) Electrification by friction
- Two uncharged bodies (insulators) are rubbed together. Electrons are transferred from the body to the other.
- The body which looses electrons becomes positively charged and that which gains electrons becomes negatively charged.

Acquire positive charge	Acquire negative charge
-Glass, Fur, Cellulose	-silk, Ebonite (hard rubber), Polythene

Explanation of charging by friction
All insulators do not have electrons arranged in the same way i.e. some insulators have electrons held to them fairly loosely e.g. in glass electrons are held fairly loose compared to silk.

When glass is rubbed with silk, glass tends to lose electrons faster than silk. This results in electrons being lost from atoms of glass at the same time being carried by silk.
The lost electrons from glass are carried by atoms of silk, so glass becomes positively charged and silk becomes negatively charged.

NOTE: The production of charge by rubbing is due to electrons being transferred (lost) from materials where they are less held by the nucleus to the other materials where they are tightly held by the nucleus.

Law of Electrostatics
- Like charges repel each other.
- Unlike charges attract each other.

NOTE: However, attraction between a charged body and any other body DOES NOT necessarily mean that the other body is of opposite charge.
Thus the only SURE/ TRUE test for presence of charge on a body is **repulsion.**

Explanation of attraction between a charged body and an uncharged body

When a negatively charged body is brought near a conductor, induced charges are produced on the conductor.

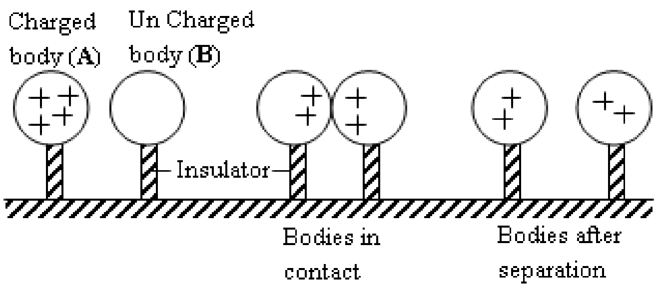
The negative charges on the conductor are repelled by the negative charge on the rod.

Consequently, the part of the conductor near the rod becomes positively charged and the far end becomes negatively charged.

Because the positive charge on the conductor is nearer the negatively charged rod than the negative charge on the conductor, the attraction between the positive charge and negatively charged rod is greater than the repulsion between the negative charge and the negatively charged rod.

The net force between the rod and the conductor is therefore an attraction. Therefore because of this fact, the only SURE/ TRUE test for presence of charge on a body is **repulsion.**

Electrification by conduction i.e Contact method
(By sharing excess electrons)



- Support the uncharged conductor on an insulated stand.
- Put a positively charged rod in contact with the conductor.
- Because of mutual repulsion between the positive charges in the rod, some of them are converted or transferred to the conductor.
- When the conductor is removed from the rod, it is found to be positively charged.

NOTE:

❖ The negative charges (electrons) migrate from the un charged body to the charged body until the positive charge on both of them is the same.

❖ Sphere B acquires a positive charge because it has lost electrons while sphere A is still positive but it is left with less positive charges.

❖ The insulated stand prevents flow of charge away from the conductor.

❖ To charge the conductor negatively, a negative rod is used.

Electrification by induction (By Electrostatic induction)

Electrostatic Induction is the acquisition of charges in an un charged conductor from a charged body placed near it but not in contact with it.

Facts about charging a conductor by induction.

❖ Bringing a charging rod near the conductor to be charged.

A charged body is brought near one end of the conductor to be charged without touching it.

It induces charges on the conductor. That is electrons are either repelled or attracted to one end.

❖ Earthing the side of the conductor remote to the charging rod in presence of the charging rod.

The other side of the conductor is earthed to allow inflow or out flow of electrons from or to the earth.

❖ Breaking the earth connection in presence of the charging rod.

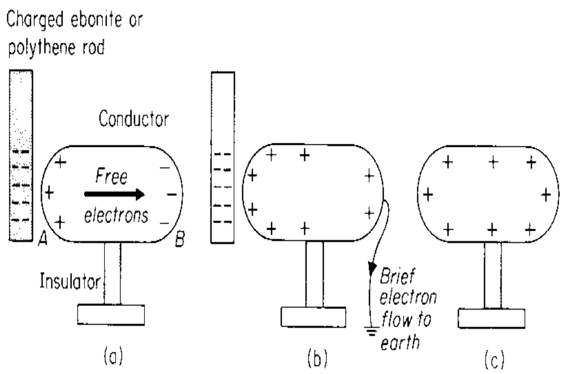
While the charged body is still in position, the earth line disconnected.

❖ Removing the charging rod

The charged body is the removed and the net charge distributes its self all over the conductor.

Note: The charge obtained is always opposite to that of the charging body.

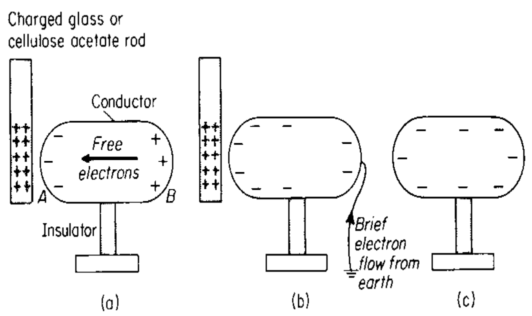
(a) Charging the body positively.



Procedure:

- Bring a negatively charged rod near the conductor placed on an insulated stand. The positive and negative charges separate as shown in (a)
- In presence of the charged rod, earth the conductor by momentarily touching it at the side furthest from the charging rod with a finger. Electrons flow from it to the earth as shown in (b).
- In presence of the charged rod, disconnect the earth line and then remove the charged rod.
- The conductor is found to be positively charged.

(b) Charging the body by induction negatively,

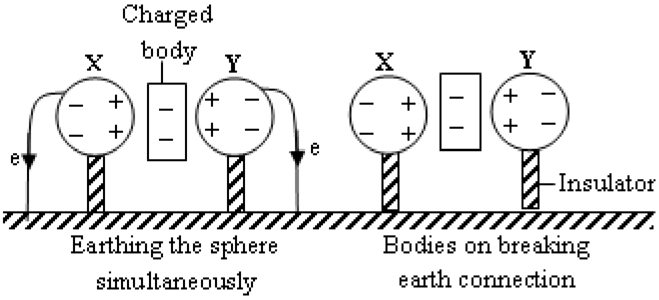


Procedure:

- Bring a positively charged rod near the conductor placed on an insulated stand. The positive and negative charges separate as shown in (a)
- In presence of the charged rod, earth the conductor by momentarily touching it at the side furthest from the charging rod with a finger. Electrons flow to it from the earth as shown in (b).
- In presence of the charged rod, disconnect the earth line and then remove the charged rod.

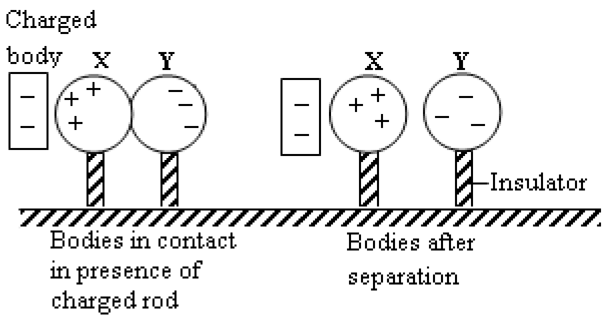
- The conductor is found to be negatively charged.

Charging two bodies simultaneously:
(i) Such that they acquire an opposite charge.



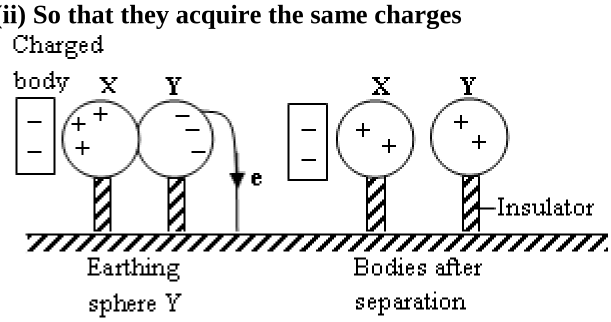
- Two identical metal X and Y are supported by insulating stands.
- A negatively charged rod is placed between the two metal spheres.
- Positive charges in each sphere are attracted towards the negatively charged rod and negative charges (electrons) are repelled to the side remote to the charging rod.
- In presence of the charging rod, both conductors are earthed at the same time by touching the sides remote to the charging rod.
- On earthling the sphere, electrons flow to the ground. When the earth is disconnected, the radial spheres are left with positive charge.
- When the charging rod is withdrawn, the positive charge on the spheres distributes themselves over the entire surface of the sphere.

Alternatively;



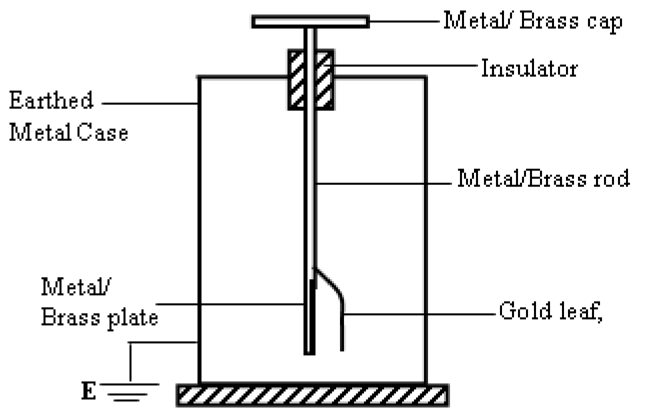
- Support two uncharged bodies, X and Y on an insulated stand and then place them in contact as shown in (a)
- Bring a positively charged rod near the two bodies, positive and negative charges separate as in (b).
- Separate, X from Y in presence of the inducing charge.
- Remove the inducing charge, X will be negatively charged and Y will be positively charged.

(ii) So that they acquire the same charges



To charge the two spheres simultaneously such that they acquire the same charge, Sphere Y (one remote to the charging rod) is earthed by touching it in presence of the charging rod.

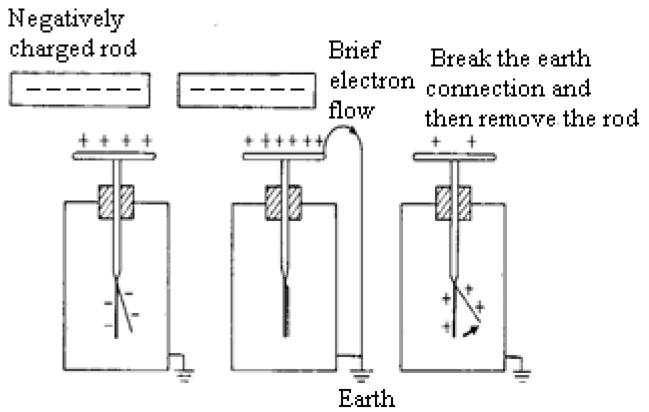
The gold leaf electroscope



- It consists of a brass cap and brass plate connected by a brass rod.
- A gold leaf is fixed together with a brass plate with a brass.
- The brass plate, gold leaf and part of brass rod are put inside a metallic box which is enclosed with glass windows.

Mode of action
- When a charged body is brought near or in contact with the cap of the electroscope, the cap will acquire an opposite charge to that on the body by induction.
- The charge on the body will repel all charges similar to it down to the metal rod, to the plate and the leaf.
- Due to presence of like charges on the plate and gold leaf, the leaf diverges as it is repelled by the plate.
- Leaf divergence implies that the body brought near or in contact with the cap carries a charge.

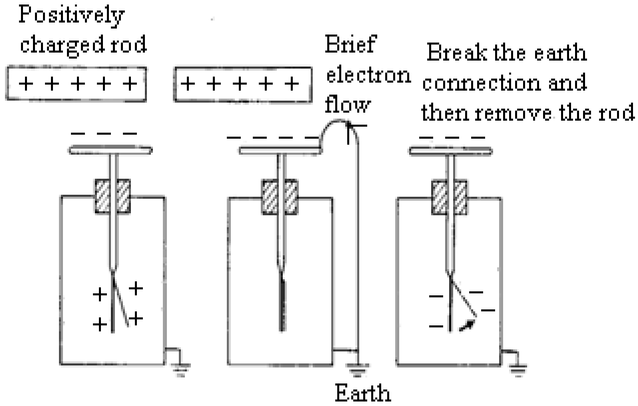
Charging a gold leaf electroscope by induction.
(i) Charging it positively



- Bring a negatively charged rod near the cap of the gold leaf electroscope.
- Positive charges are attracted to the cap and negative charges are repelled to the plate and gold leaf.
- The leaf diverges due to repulsion of the same number of charges on the plates.
- Earth the gold leaf electroscope in presence of a negatively charged rod.
- Electrons on the plate and leaf flow to the earth.
- The leaf collapses.

- Remove the negatively charged rod, positive charges on the ca spread out to the rod and leaf therefore the leaf diverges hence the gold leaf is positively charged.

(ii) Charging it negatively.



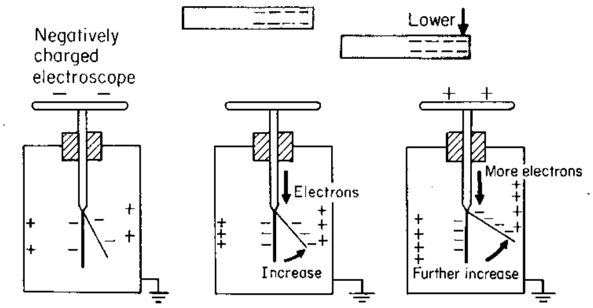
- Get an uncharged gold leaf of electroscope.
- Bring the positively charged rod near the gold leaf cap.
- Negative charges are attracted to the cap and positive charges are repelled to leaf and glass plate.
- Earth the gold leaf electroscope in presence of a positively charged rod.
- Negative charges flow from the earth to neutralize positive charges on plate and leaf.
- The leaf collapses.
- Remove the positively charged rod, negative charges on the cap spread out on the leaf plate, therefore, the leaf diverges and a gold leaf therefore becomes negatively charged.

Uses of a Gold leaf Electroscope

1. <u>To detect the presence of charge on a body.</u>

Bring the body under test near the cap of a **neutral G.L.E**.
If the leaf deflects, then the body has got a charge.
However, if the leaf remains un deflected, then the body is neutral (has no net charge).

2. <u>To test the nature or sign of charge on a body.</u>



Bring the body under test near the cap of a **charged G.L.E.**
If the leaf diverges further, then the body has a charge similar to that on the G.L.E.

However, if the leaf collapses, then the body is either neutral or it carries a charge opposite to that on the G.L.E. In this case, we cannot conclude. But the G.L.E is discharged by touching its cap with a finger and then given a charge opposite to the one it had previously and the experiment is repeated.
If still the leaf collapses, then the body is neutral.

NOTE: An increase in leaf divergence is the only sure test for the sign of charge on a body.

Increase in leaf divergence occurs when the test charge and the charge on the gold leaf electroscope are the same.

3. <u>To compare and measure potentials.</u>

Two bodies which are similarly charged are brought in contact with the cap of a G.L.E one after the other.
The divergences in the two cases are noted and compared.
The body which causes more divergence is at a higher potential.

4. <u>To classify conductors and insulators.</u>

Bring the body under test in contact with the cap of **a charged G.L.E.**
If the leaf collapses suddenly, then the body is a good conductor.
If the leaf collapses gradually, then the body is a poor conductor. The leaf collapses due to charge leakage.
If the leaf **does not collapse**, then it is an **insulator**.

Distribution of charge on a conductor.

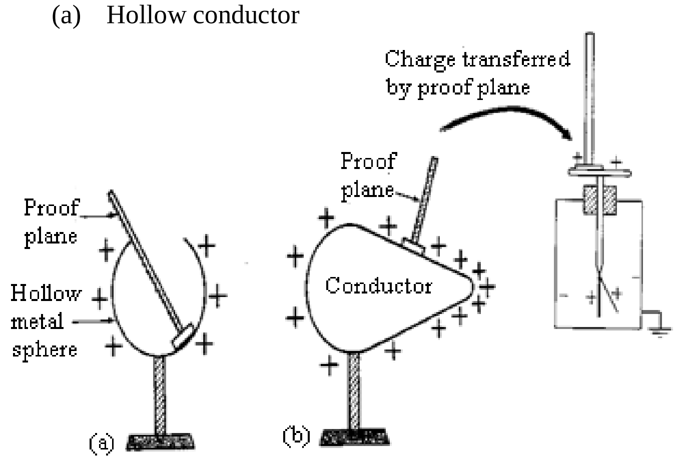
Surface density is the quantity of charge per unit area of the surface of a conductor.

- ❖ The distribution of surface density depends on the shape of the conductor.
- ❖ It is investigated using a gold leaf electroscope and a proof plane (a small metal disc with a handle made of insulator).
- ❖ The surface conductor is touched using a proof plane. The proof plane is then transferred to an electroscope by allowing it to touch the cap of the G.L.E.
- ❖ The angle of leaf divergence is noted and it gives a rough measure of the charge transferred and hence the magnitude of surface density at that point.

Experimental results show that:

(i) Charge density is greatest at the most curved point.
(ii) Charge always resides on the outside of a hollow conductor.

(a) Hollow conductor

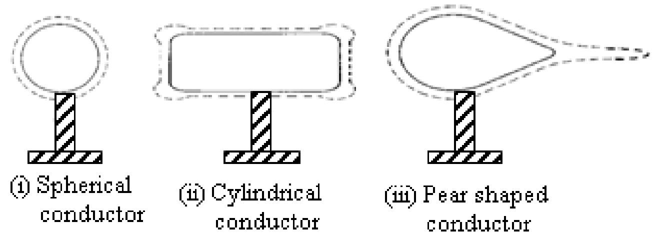


When the proof plane is placed on the outside surface of a charged hollow conductor, charge is transferred to the uncharged G.L.E, the leaf diverges as shown in (a). This proves that charge was present on the outside of the surface.
When the proof plane is placed on the inside of a charged conductor is transferred to the uncharged G.L.E, the leaf does not diverge as in (b) therefore, charge resides on the outside surface of the hollow charged conductor.

(b) Curved bodies

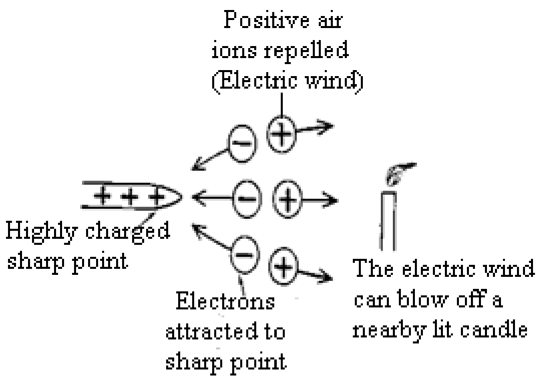
A curve with a big curvature has a small radius and a curve with small curvature has big radius therefore, curvature is inversely proportional to radius. A straight line has no curvature.

Surface charged density is directly proportional to the curvature. Therefore a small curvature has small charge density. Surface charge density is the ratio of charge to the surface area.



ACTION OF POINTS

Charge concentrates at sharp points. This creates a very strong electrostatic field at charged points which ionizes the surrounding air molecules producing positive and negative ions. Ions which are of the same charge as that on the sharp points are repelled away forming **an electric wind** which may blow a candle flame as shown in the diagram below and ions of opposite charge are collected to the points.



Therefore, a charged sharp point acts as;

(i) Spray off' of its own charge in form of electric wind.

(ii) Collector of unlike charges.

The spraying off and collecting of charges by the sharp points is known as **corona discharge** (action of points.)

Application of action of points (corona discharge)

- Used in a lightening conductor.
- Used in electrostatics generators.
- Electrostatic photocopying machines.
- Air crafts are discharged after landing before passengers are allowed. Air crafts get electrified but charge remains on the outer surface.

Lightening

A lightening is a gigantic (very large) discharge between clouds and the earth, or between the charges in the atmosphere and the earth.

A lightening conductor:

Lightening conductor is a single component in a lightening protection system used to safe guard tall building from being destroyed by lightening.

It provides a safe and easy passage of charge to the earth hence safe guarding the building.

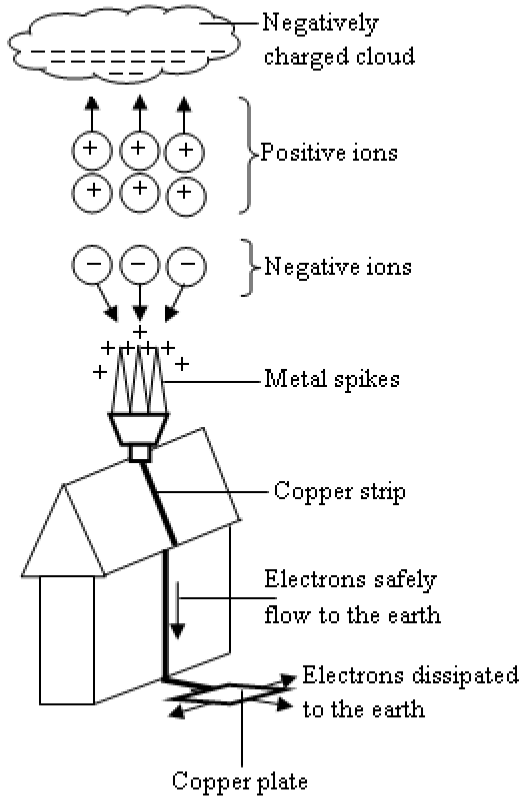
A lightening conductor is made up of:

(i) **Spikes** placed high up on a tall building**.**

(ii) **copper strip** which is fixed to the ground and on the walls of the tall building ending with several

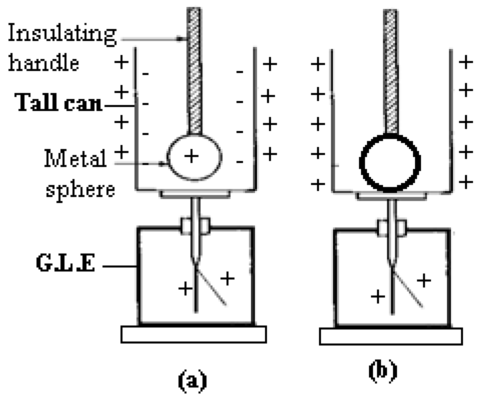
(iii) **Copper plate** buried under the grounded

How it works



- Charging the clouds negatively by friction: A moving cloud becomes negatively charged by friction.
- Induction: Once it approaches the lightening conductor, it induces opposite charge on the conductor.
- Ionization and neutralization: A high charge density on the conductor ionizes the air molecules and sends a stream of positively charged ions which neutralize some of the negative charges of the cloud.
- Conduction: The excess negatively charged ions are safely conducted to the earth through a copper strip.

Faraday's Ice pail experiment



PART I
Procedures:
- Place an un charged metal can on an uncharged G.L.E.
- Suspend a positively charged metal sphere and lower it into the pail, without touching the pail as shown in diagram (a).
- Move the charged metal sphere about inside the can and then remove the metal sphere completely.

Observation:

Action	Observation
On lowering the metal sphere	G,L,E diverges
On moving the metal sphere about	No observable change
On complete removal of the metal sphere	Leaf returns to its original shape.

PART II
Procedures continued:
- Lower the metal sphere again into the metal can, this time allow the sphere to touch the bottom of the can as shown in diagram (b).
- Test the charge on the sphere using another G.L.E.

Observation:

Action	Observation
On touching the metal can	G,L,E remains diverged
On testing the metal sphere with another G.L.E	The sphere is found to have lost all the charge

Conclusions from Faradays' experiment.
- ✓ A charged metal object suspended inside a neutral metal container induces an **equal but opposite charge** on the inside of the container.
- ✓ When the charged sphere touches the inside of the container, the induced charge exactly neutralizes the excess charge on the sphere.
- ✓ When a charged body is suspended within a metal container, an equal charge of the same sign is forced to the outside of the container.

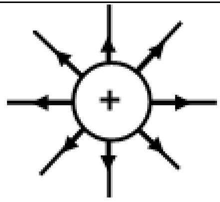
Electric fields
This is a region a round the charged body where electric forces are experienced. Electric fields may be represented by field lines.
Field lines are lines drawn in an electric field such that their directions at any point give a direction of electric field at that point. The direction of any field at any given point is the direction of the forces on a small positive charge placed at that point.

Properties of electric field lines
- They begin and end on equal quantities of charge.
- They are in a state of tension which causes them to shorten.
- They repel one another side ways.

Electric Field patterns

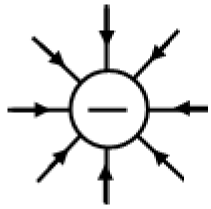
(a) Isolated charges

(i) Isolated positive charge



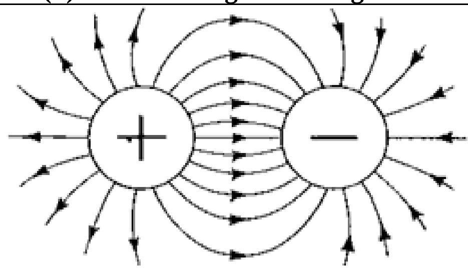
Field lines point away from the charge.

(ii)Isolated negative charge



Field lines point towards the negative charge.

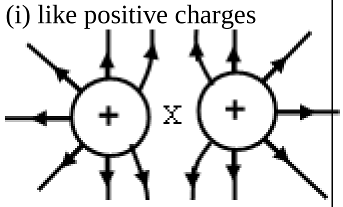
(b) Unlike charges close together



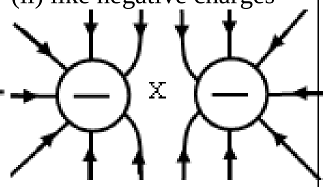
The lines of force connect from positive charge to negative charge.

(c) Like charges close together
The field lines repel side ways.

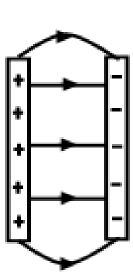
(i) like positive charges

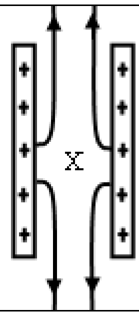


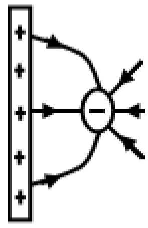
(ii) like negative charges



(d) Two charged plates/ a charged plate and a point charge







Exercise:

1991 Qn.2	2005 Qn.34	2002 Qn.30
1997 Qn.28	2008 Qn.6	2005 Qn.5
1998 Qn.28	**Lightening & Electric fields**	2006 Qn.33
1999 Qn.31	1992 Qn.21	2007 Qn.32
2000 Qn.35	1994 Qn.14	1988 Qn.17
2001Qn.22	1995 Qn.26	
2004 Qn.10	1998 Qn.40	
2005 Qn.28	2000 Qn.17	

SECTION B
1989 Qn. 60
(a) Sketch the electric field patterns for the following;
(i) Two negative charges close to each other
(ii) A positively charged conducting sphere
(iii) Two oppositely charged parallel plates

(b) Explain the following observations;

(i) The leaves of a positively charged gold leaf electroscope fall when the cap is touched.

(ii) When a positively charged conductor is lowered in an ice pail placed on the cap of an uncharged electroscope, the leaves diverge. When the conductor touches the inside of the pail, the divergence of the leaves is not altered.

(c) Explain how a lightening conductor safe guards a house against lightening.

1990 Qn.8

(a) Draw a well labeled diagram of a gold leaf electroscope.

(b) Describe an experiment to test the charge on a charged body using a gold leaf electroscope.

(c) Draw electric field patterns for;

(i) Two positively charged bodies at a small distance apart.

(ii) An isolated negative charge.

1991 Qn.7

(a) State the law of electrostatics.

(b) Describe how two identical metal balls may be charged positively and simultaneously by induction.

(c) (i) Explain what happens when a negatively charged rod is brought near the cap of an uncharged electroscope and slowly taken away.

(ii) Briefly explain how an electroscope can be used to test whether a material is a conductor or an insulator.

(d) What precautions should be taken when carrying out experiments in electrostatics?

1994 Qn.7

(a) Explain why a pen rubbed with a piece of cloth attracts pieces of paper.

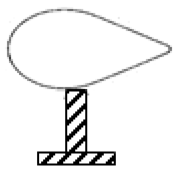
(b) A positively charged metallic ball is held above a hollow conductor resting on the cap of a gold leaf electroscope.

Explain what happens to the leaf of the electroscope as the ball is lowered into the hollow conductor.

1998 Qn.10

(a) Explain what happens to an insulator when it is rubbed with another insulator of different material?

(b) The figure below shows a conductor supported on an electrical insulator. The conductor is given some positive charge.



Show how the charge is distributed on the conductor.

(c) Sketch the electrical field pattern due to two unlike charges **P** and **Q** below.

2005 Qn.4

(a) Describe how you would use a gold leaf electroscope to determine the sign of a charge on a given charged body.

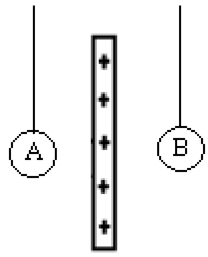
(b) Explain how an insulator gets charged by rubbing.

(c) Sketch the electric field pattern between a charged point and a metal plate.

(d) Four non- metallic rods W, X, Y and Z are tested for charges. X attracts W and Y and repels Z. Z repels W and Y. W and Y repel each other. Which of the following statements is true about W, X, Y and Z?

A. X is charged, Y is uncharged.
B. X is un charged, W and Y are charged.
C. W, Y and Z carry the same charge.
D. X, Y and Z carry the same charge.

(e) Two pith balls are suspended by a nylon thread. When a positively charged rod is placed between them, A is attracted while B is repelled.



What charge does A and B have?

	A	B
A	Positive	Positive
B	Neutral	Positive
C	Positive	Negative
D	Neutral	Neutral

6. ELECTRICITY

6.1. ELECTRIC CELLS OR BATTERIES

A cell is a device which directly changes chemical energy to electrical energy.

Types of electric cells

a) Primary cells, these are cells which cannot be recharged and their chemical reaction which produces electrical energy cannot be reversed e.g the simple cells, dry cells
b) Secondary cells, these are cells that can be recharged and the chemical reaction that produces electricity can be reversed by passing the current thru the opposite direction.

(a) Primary cells

These are cells which produce electricity from an irreversible chemical reaction.
They cannot be recharged by passing a current through them from another source and their chemical reaction which produces electrical energy cannot be reversed

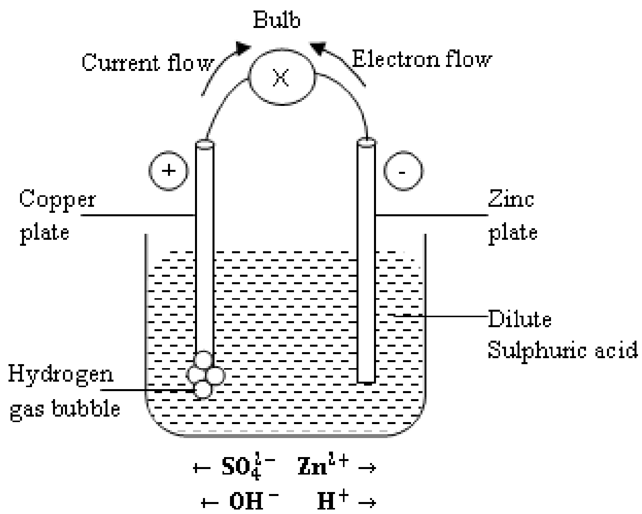
Examples of primary cells;

(i) Simple cells (Voltaic cells)
(ii) Leclanche' cell (Dry cell and Wet cell)

(i) Simple cells (Voltaic cells)

A simple cell is made up of two electrodes and an electrolyte. A more reactive metal becomes the cathode while the less reactive metal becomes the anode.
It commonly consists of a copper rod (Positive electrode) and the zinc rod (Negative electrode) dipped into dilute sulphuric acid (Electrolyte). The electrodes are connected by pieces of conducting wires.

In a simple cell, the cathode is Zn, the Anode is copper and the electrolyte is dilute H_2SO_4.



Mechanism of the simple cells

A simple cell gets its energy from the chemical reaction between Zn and H_2SO_4 (aq) i.e.

$$\mathbf{Zn\,(s) + H_2SO_4\,(aq) \longrightarrow ZnSO_4\,(aq) + H_2}$$

Electrons flow the negative plate zinc to the positive plate copper while current flows from the positive to negative plate.

At the cathode

When the circuit is complete, the zinc rod slowly dissolves and goes into electrolyte as zinc ions Zn^{2+}, according to the equation;

$$\mathbf{Zn\,(s) \rightarrow Zn^{2+}(aq) + 2\bar{e}}$$

At the anode

The electrons travel through the external circuit and arrive at the copper electrode, where they are picked up by the hydrogen ions from the acid to form hydrogen gas according to the equation:

$$\mathbf{2H^+(aq) + 2\bar{e} \rightarrow H_2(g)}$$

- Thus bubbles of a colourless gas are seen at the copper plate.
- The reaction generates an electric current.

DEFECTS OF A SIMPLE CELL

Defect	**How to minimize**
1. Polarization: This is the formation of hydrogen bubbles on the copper plate. The hydrogen given off insulates the anode from the electrolyte. This reduces the voltage of the cell.	-Use of a depolarizing agent like potassium dichromate,(K_2,Cr_2O_7) or manganese dioxide (MnO_4), which oxides hydrogen to form water. -Brushing the copper plate occasionally.
2. Local action: This is due to some reaction between the impurities in Zinc and the acid resulting into the formation of hydrogen bubbles on the zinc plate. The hydrogen bubbles insulate zinc from the electrolyte.	-Rubbing clean Zinc with mercury (amalgamating zinc).This prevents contact of the impurities with the electrolyte) -Cleaning Zinc with conc. H_2SO_4.

NOTE: A simple cell stops working after a short time because of polarization and local action.

(ii) Leclanche' cells

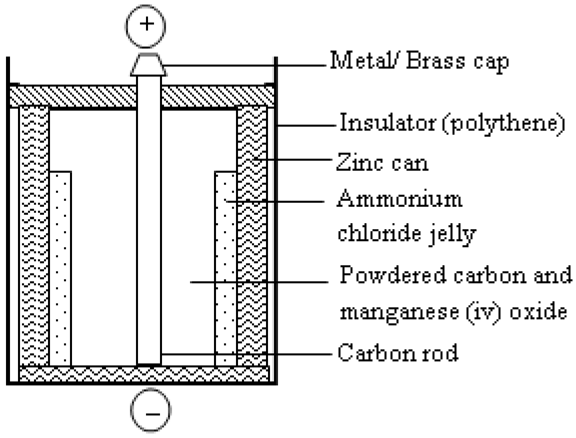
- Dry Leclanche' cell (Portable, electrolyte cant pour out, faster depolarizing action & can maintain high steady current for some period of time)

- Wet Leclanche' cell (Bulky and electrolyte can easily pour out, slow depolarizing action & cannot maintain high steady current which lights).

Here polarization and local action are avoided

- Manganese (iv) oxide is in place to act as a depolarizing agent to oxidize hydrogen to water. Thus preventing polarization.
- The carbon powder reduces the internal resistance of the cell and increases the conducting surface area.

❖ **Dry Leclanche' cell**



Carbon is the anode and Zinc is the cathode. The electrolyte is ammonium chloride jelly. The chemical reaction between zinc and ammonium chloride is the source of electrical energy is a dry cell and therefore e.m.f is up.

$Zn\ (s) + 2NH_4Cl\ (aq) \longrightarrow ZnCl_2 + 2NH_3 + H_2\ (g)$

The e.m.f produced goes on to fall due to polarization and local action. These are the defects of a dry cell.

Polarization

The formation of Hydrogen bubbles at the carbon rod.

Its prevention

The manganese IV oxide around the carbon rod acts as a depolarizing agent which oxides hydrogen to water.

Note: Even if the cell is not working (giving out e.m.f) e.m.f reduces because of local action.

(b) Secondary cells (Accumulators) (or storage cells)

Secondary cells are cells that can't be recharged by passing a current through them from another source once they stop working or reduce on the amount of current being supplied.

Current is produced as a result of a reversible chemical change taking place within the cell.

Use of accumulators

-To start (ignition) of a cars and other locomotives and to provide light to motor cars.

-Used in factories to run machines

Examples of secondary cells (Accumulators)

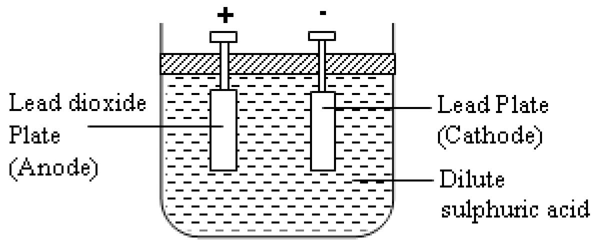
There are two types of accumulators.

(i) Lead acid accumulator
(ii) Alkaline accumulator (e.g Nickel – cadmium cell; **NiCd** cell, Nickel – iron cell **; NiFe** cell)

(i) Lead acid accumulators

A Lead acid storage battery consists of cells connected in series. Each cell consists of a **lead plate** (negative electrode), **lead dioxide** (or lead (iv) oxide) (positive electrode), and **dilute sulphuric acid** as the electrolyte.

When the accumulator is fully charged, the **relative density of the acid** is about **1.25** and the e.m.f of each pair is **2.2V.**



The cathode is lead, the anode is lead dioxide and the electrolyte is dilute sulphuric acid.

When it is working both electrodes gradually change to lead sulphate while the acid becomes more dilute and its relative density decreases.

Mechanism of an accumulator.

When in use, the negative lead electrode dissociates into free electrons and positive lead (ii) ions.

$$\mathbf{Pb}\ (\boldsymbol{s}) \rightarrow \mathbf{Pb^{2+}(aq) + 2\bar{e}}$$

The electrons travel through the external circuit while the lead (ii) ions combine with the sulphate ions in the electrolyte to form lead (ii) sulphate.

$$\mathbf{Pb^{2+}(aq) + SO_4{}^{2+}(aq) \rightarrow PbSO_4(aq)}$$

When the electrons re-enter the cell at the positive lead dioxide electrode, a chemical reaction occurs. The lead dioxide combines with the hydrogen ions in the electrolyte and the electrons to form water, releasing lead (ii) ions into the electrolyte to form additional lead (ii) sulphate.

$$\mathbf{PbO}\ (\boldsymbol{s}) + \mathbf{2\ H^+(aq) + 2\bar{e} \rightarrow H_2O}(\boldsymbol{l}) + \mathbf{Pb^{2+}(aq)}$$

C**are and maintenance of lead –acid accumulator**

Dos	**DONTs**
(i) The battery should be charged regularly. (ii) The liquid level should be maintained using distilled water to ensure that electrodes are nor exposed. (iii) Cells should be charged if the R.D. reduces to 1.18 R.D. can be checked using a hydrometer.	(iv) Cells should not be left uncharged for a long time. (v) When charging, avoid nearby flames because O_2 and H_2 are given off during the process i.e. O_2 is from Anode and H_2 from cathode. (vi) Avoid shortening the terminal i.e. you should not connect the terminals with a low resistance wire or metal because when shortened too much current is taken away from the cell. (vii) Avoid overcharging and over discharging.

(ii) Alkaline cells

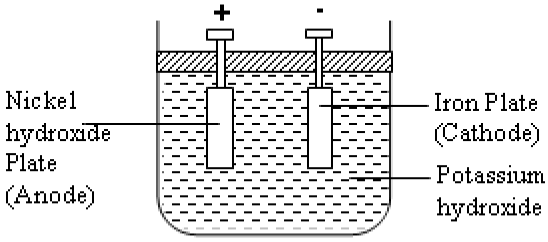
❖ **Nickel – cadmium (NiCd cells)**

Anode is the Nickel –hydroxide and cathode is cadmium

❖ **Nickel – Iron (NiFe Cells)**

Anode is Nickel hydroxide and cathode is iron.

In both cases, the electrolyte is potassium hydroxide dissolved in water (caustic potassium solution)



Uses
- Used in battery driven vehicles
- Used for emergency lighting

Advantages of alkaline cells over Lead-acid cells or accumulators

Alkaline Accumulators	Lead-acid accumulators
(i) Require no special maintenance.	Require special maintenance
(ii) May be left uncharged for a long time without being damaged. They can be out of use for a long time	They get damaged if left un charged for a long time.
(iii) Are less heavy.	Are heavy.
(iv) Are long lasting.	Are not long lasting.
(v) They provide large currents without being damaged.	They provide low currents.
(vi) Are suitable for supplying steady current for a long time.	
(vii) Can with stand over charging.	Can be damaged by over charging.

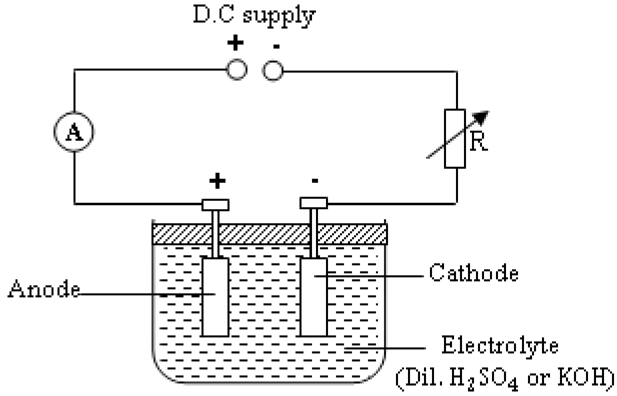
Disadvantages of the alkaline cells over the lead acid cells.
- ❖ Alkaline cells are expensive compared to lead acid cells.
- ❖ Alkaline cells have a low e.m.f and a higher internal resistance.
- ❖ Cadmium compounds are poisonous
- ❖ They do not properly store charge.

Capacity of an accumulator
This is the amount of electricity which an accumulator can store. It's measured in ampere hours (Ah)
$\textbf{Capacity} = \textbf{current (A) x time (h)}$
$\textbf{Capacity} = \textbf{It}$

Example:
How long wills a cell marked 80Ah supply a current of 4.5A before it is exhausted.

Solution:
Capacity = current (A) x time (h)
Capacity = It
$80 = 4.5 \times t$
$t = 17.8$ Hours

Charging an accumulator (battery charging)



An accumulator is recharged by passing a current through it from a D.C supply in the opposite direction to the current it supplies.
Positive of the D.C. supply is connected to the positive of the accumulator while negative terminal of the D.C. supply is connected to the negative of the accumulator.
The acid becomes more concentrated during charging and R.D. of the acid increases.

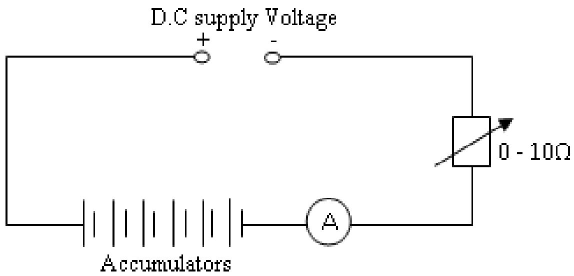
The Rheostat varies resistance to make the current adjustable.

The ammeter measures the charging current which becomes low as the accumulator is charged and restored to usable condition. This is due to the rise in the e.m.f of the accumulators.

When chemicals have been restored to their original condition, hydrogen gas is given off (gassing process) and the cell is said to be fully charged.

Note;
- ❖ When an accumulator (battery) is being charged, electrical energy charges to chemical energy.
- ❖ When a battery (an accumulator) is being used (supplying current), chemical energy changes to electrical energy.
- ❖ Direct current is used during the charging process because alternating current would charge the accumulator in the first half cycle and then discharge it in the next half cycle.

Question:
Six accumulators each of e.m.f 2V and each of internal as shown below;



(i) Explain why its necessary to include a rheostat in the circuit.
(ii) Explain why direct current is used in the charging process.
(iii) What will the ammeter read if the Rheostat is set at 5.4Ω. (I = 2A)

(iv) Find the rate at which electrical energy is converted to chemical energy in (ii) above. (P = 2 4W).

Differences between primary cells and secondary cells.

Primary Cell	Secondary Cell
-Cannot be recharged once it stops working -Current is produced as a result of irreversible chemical change. -Provide a lower e.m.f -Works for a shorter time -Higher internal resistance	-Can be recharged when they stop working. -Current is produced as a result of reversible chemical change. -Provide a hiigher e.m.f -Works for a longer time. -Lowe internal resistance

Exercise:

1.

1995 Q.28	1998 Q.33	1998 Q.39	2002 Q.15

2. Which of the following statement(s) is or are true?
(i) Regular charging
(ii) Maintaining the level of acid by topping it up with distilled water.
(iii) Avoid over discharging
(iv) Avoid shorting the terminals.

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

3. 1993 Qn.6
(a) (i) Draw a diagram to show the structure of a simple cell.
(ii) Give one defect of a simple cell and state how it is minimized.
(b) Explain how a lead acid accumulator can be recharged when it has run down.

4. 1994 Qn.4
(a) List four different sources of e.m.f
(b) State two advantages of a secondary cell over a primary cell.

5. 1995 Qn.6
(a) Explain why a current does not flow between the electrodes in dilute sulphuric acid until a certain value of p.d is exceeded.

6. 1996 Qn.10
(a) State two advantages of nickel iron accumulator over a lead acid accumulator.
(b) Name the gases evolved during the charging of the lead acid accumulator.
(c) Why a dry cell is called a primary cell?

6.2.	CURRENT ELECTRICITY

Electricity is the flow of charged particles such as electrons and ions.
Electricity has various forms which include static electricity and current electricity. Static electricity is discussed in Electrostatics and current electricity will be discussed majorly now.

Electric current is the rate of flow of charge. OR It is the rate of flow of electrically charged particles.

Steady current is the constant rate of flow of charge.
It's measured in **amperes** represented by A. 1 A = 1 CS^{-1}.
An ampere is a current when the rate of flow of charge is one coulomb per second.
Qn. What type of quantity is current?

Source of electric energy
It has various sources which include among others;-

(i) Chemical energy. It is also known as potential or stored energy and releasing it always requires combustion of burning of coal, natural gas etc.

(ii) Thermal energy. Heat means thermo/ it can produce electrical energy when /after combustion of fossil fuels and biomass.

(iii) Kinetic energy. This is energy in motion e.g. moving water, moving wind etc as they turn the turbines.

(iv) Nuclear energy. Its energy in the bonds inside atoms and molecules during its release it can emit radioactive and thermal energy as well. It is normally produced in nuclear reactors

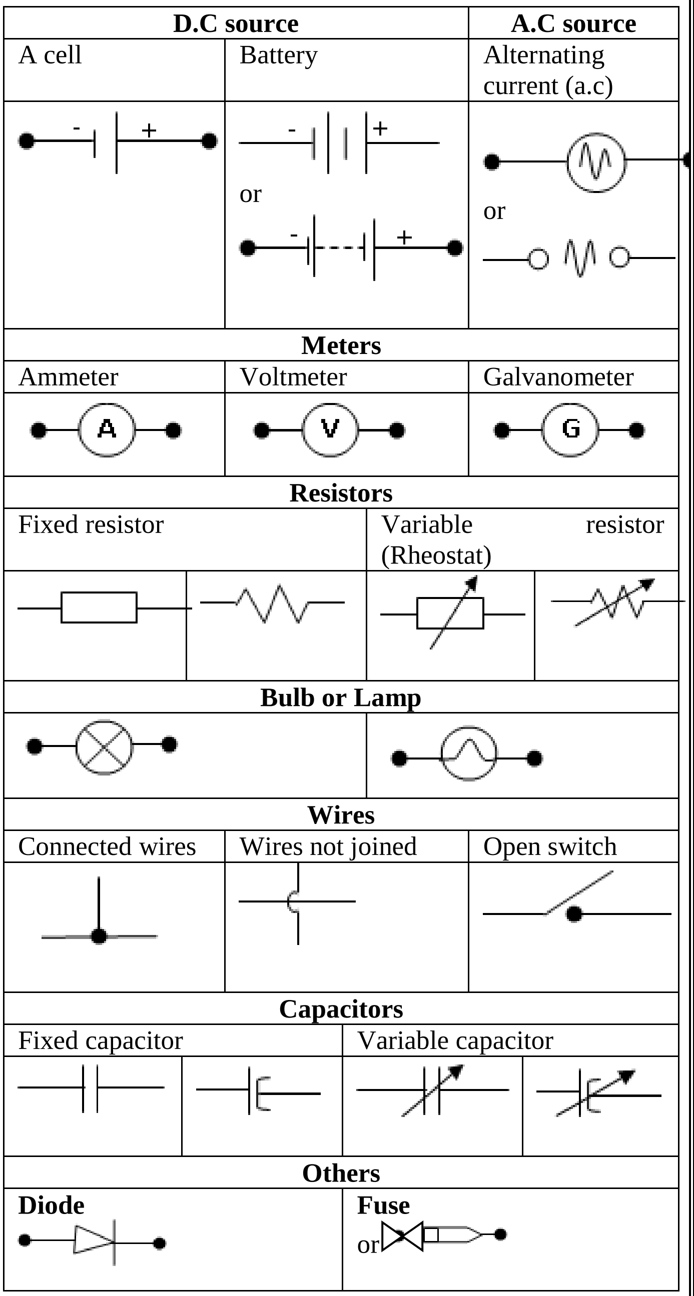
(v) Solar energy. This is energy from the sun which can be captured by photovoltaic cells and then a source of electrical energy.

There could be other sources of energy but generally, the above are the major sources.

Common electrical /appliances we use in Uganda include.
- Electrical lamps - Electric kettles
- Electric plates (cookers) - Electric flat irons

N.B. Electrical appliances can be defined as devices used to simplify worker but use electricity as a form of energy.

Electric circuits and symbols
Symbols
Electric symbols are symbols used in electricity during the circuits to draw them schematically and represent electrical and electronic components.
They include;



There are very many symbols but these are the mostly used electrical symbols.

Terms used;
(i) Charge, Q; Is the quantity of electricity that passes a given point in a conductor at a given time.
The S.I unit of charge is a coulomb. **A coulomb** is the quantity of electric charge that passes a given point in a conductor when a steady current of 1A flows in one second.

(ii) Current, (I); Is the rate of flow of charge. i.e. $I = \frac{Q}{t}$.
The S.I unit of current is an **ampere**. An ampere is a current flowing in a circuit when a charge of one coulomb passes any point in the circuit in one second.
$\mathbf{1A = 1Cs^{-1}}$

Example 1: UNEB 2008 Qn.32
A current of 6A amperes flows for two hours in a circuit. Calculate the quantity of electricity that flows in this time.

Solution:

Given: $I = 6A, t = 2hrs$ $= 2 \times 60 \times 60 = 7200s.$ $Q = ?$	$\mathbf{Q = It}$ $Q = 6 \times 7200$ $Q = 43200\ C$

Example 2: UNEB 2007 Qn.48 (b)
A charge of 180C flows through a lamp for two minutes. Find the electric current flowing through the lamp.

Solution:

Given: $Q = 180\ C, t = 2minutes$ $= 2 \times 60 = 120s.$ $Q = ?$	$\mathbf{Q = It}$ $180 = I \times 120$ $I = 1.5\ C$

(iii) Potential difference (P.d); Is the work done in transferring one coulomb of charge from one point to another in a circuit.
Whenever current flows, it does so because the electric potential at two points are different. If the two points are at the same potential, no current flows between them. $P.d = \frac{W}{Q}$
The S.I unit is a volt. A **volt** is the potential difference between two points in circuit in which, 1J of work is done in transferring 1C of charge from one point to another.
$\mathbf{1V = 1JC^{-1}}$

(iv) Electromotive force, (e.m.f): Is the work done in transferring one coulomb of charge around a complete circuit in which a battery is connected.
It is the p.d across a cell in an open circuit.

Sources of electrical e.m.f.
(i). Electric cell: This converts chemical energy to electrical energy.
(ii). Generators: These convert mechanical energy to electrical energy.
(iii). Thermo couple: This converts thermal energy (or heat energy) to electrical energy.
(iv). Piezo-electric effect (Crystal pick ups)
(v). Photo electric effect (solar cells)

(v) Electrical Resistance, (R): Is the opposition to the flow of current in a conductor. $R = \frac{V}{I}$.
The S.I unit of resistance is an ohm (Ω). **An ohm** is the resistance of a conductor through which a current of one ampere flows when a p.d across it is one volt.

(vi) Internal resistance of a cell, r:
Internal resistance of a cell is the opposition to the flow of current within the cell.

(vii) Open circuit: where current is not being supplied to an external circuit.
(viii) Closed circuit: Where the cell is supplying current to an external circuit.
1. E.m.f:- Is the work done to move a charge of IC through a circuit including a source (cell) i.e. the p.d. when the cell is not supplying current to an external circuit.

2. Terminal p.d. The work done to move a charge of IC through a circuit across the terminals of a battery i.e. it's the p.d when current is being delivered to an external circuit.

NB. The value of the terminal p.d. is always less than e.m.f because of the opposition to the flow of current inside the cell.
Internal resistance: Is the opposition to the flow of current within the cell.

$$E.m.f = \text{Terminal pd.} + \begin{pmatrix}\text{p.d across the internal} \\ \text{resistance, r}\end{pmatrix}.$$
$$E = VR + Vr$$
$$\mathbf{E = IR + Ir}$$

Factors affecting resistance of a conductor.
The resistance of a conductor is independent of the P.d, V and the current I through the conductor but it depends on physical factors like; length, cross sectional area and temperature.

Factor	**Effect on resistance**
(i) Length, l $R \propto l$	Increasing the length increases the resistance of the conductor. This is because increase in length increases the number of collisions electrons have to make with atoms as they travel through the conductor. This reduces the drift velocity of the free electrons and hence increases the resistance of the conductor.
(ii) Cross sectional area, A $R \propto \frac{1}{A}$	When there is an increase in the cross sectional area of the conductor, the number of free electrons that drift along the conductor also increases. This means that there is an increase in the number of electrons passing a given point along the conductor per second, thus an increase in current Consequently, this reduces the resistance of the conductor.
(iii)Temperature, T $R \propto \frac{1}{T}$	When there is an increase in the temperature of the conductor, the atoms vibrate with greater amplitude and frequency about their mean positions. The velocity of the free electrons increases which increases their kinetic energy. Consequently, the number of collisions between the free electrons and the atoms increases. This leads to a decrease in the drift velocity of the electrons. This means that there is a decrease in the number of electrons passing a given point along the conductor per second, thus a decrease in current Consequently, this increases the resistance of the conductor.
(iv) Nature of the substance.	Good conductors like metals have low resistance while poor conductors (insulators) have very high resistance.

Note: **Supper conductors** are materials whose resistance vanishes when they are cooled to a temperature near -273^0C.

Combining the first two factors at constant temperature, we get:

$$R \propto \frac{l}{A} \Leftrightarrow \boldsymbol{R = \rho\frac{l}{A}}$$

Where, ρ is a constant which depends on the nature of the conductor. It is called the Resistivity of the conductor.
Thus thick and short conductors have lower resistances compared to thin and long conductors.

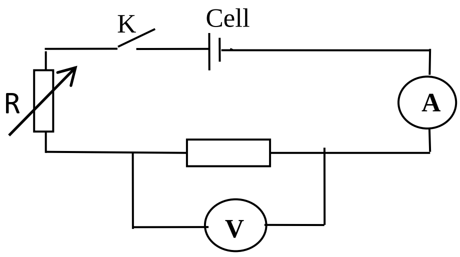
Resistivity, ρ:
Is the electrical resistance across the opposite faces of a cube of 1m length.
The S.I unit of resistivity is an ohm metre,(Ωm).

Conductivity, σ:
Is the reciprocal of electrical resistivity.

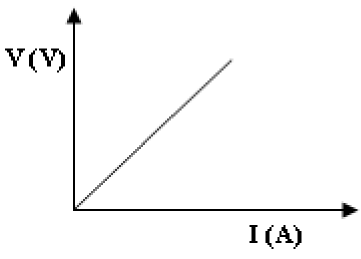
$$\boldsymbol{\sigma = \frac{1}{\rho}}$$

Ohms law:
It states that the current through an ohmic conductor is directly proportional to the P.d across it provided the physical conditions remain constant.

Experiment to verify Ohms law;



-The circuit is connected as shown above.
-Switch, K is closed, and a current, I flows through the circuit.
-Read and record the ammeter reading and the corresponding voltmeter reading.
-The rheostat is adjusted to obtain several values of V and I.
-Plot a graph of V against I



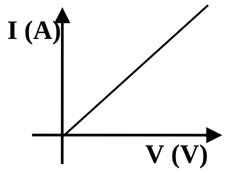
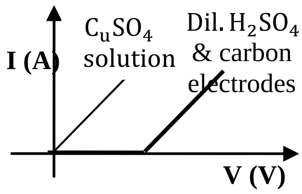
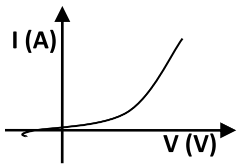
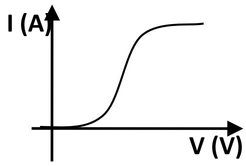
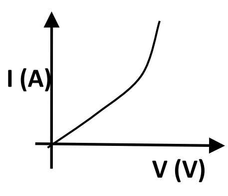
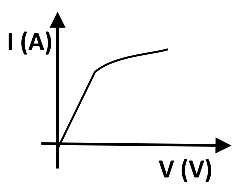
-It is a straight line graph through the origin, implying that V is directly proportional to I which verifies Ohm's law.

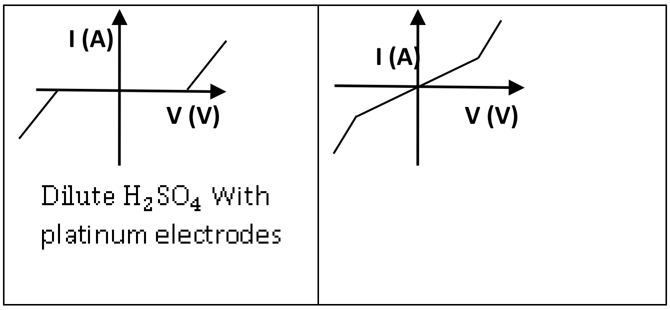
Note: In case the experiment requires resistance, then the slope of the graph is the resistance.
From the graph; **Slope**, $\mathbf{R = \frac{V}{I} = \tan\theta}$.
Where θ is the angle between the line and the horizontal.

Limitations of ohm's law
- ✓ It only applies when the physical conditions of a conductor are constant e.g. temperature, length of a conductor, cross section area e.t.c.
- ✓ It doesn't apply to semi conductors e.g. diodes and electrolytes

Ohmic and non- ohmic conductors
- Ohmic conductors are conductors which obey ohm's law. E.g. Metals.
- Non Ohmic conductors are conductors which do not obey ohm's law e.g. filament lamps, in diodes, neon gas tubes.

The graphs of current against voltage for different conductors.

(i) **Ohmic conductor** (Pure metal)	**(ii) Electrolytes**
 The straight line passes through the origin. The conductor closely obeys Ohm's law.	 Conductions in electrodes and electrolytes are both ohmic. For some electrodes conduction begins after the voltage has reached a certain value,
(iii) Semi Conductor diode	**(iv) Thermionic diode (diode valve)**
 There is a slow rise in the current and it is nearly Ohmic.	 The graph is fairly Ohmic. At saturation, the current becomes constant.
(v) Thermister And carbon resistor	**(vi) Filament bulb**
 The resistance of a thermister decreases as temperature increases. A fall in resistance causes current to increase more rapidly.	 At low currents, the graph is a straight line. As current increases, more heat is produced and temperature increases which increases the resistance of the filament wire.
(v) Acid water	**(vi) Neon gas**



ELECTRIC CIRCUITS
An electric circuit can be defined as a combination of electric appliances represented by electric symbols for a particular purpose.
A circuit can be open (incomplete) or closed (completed).
An open circuit is circuit in which electrons are not continuously flowing.
A closed circuit is a circuit which is complete and having electrons continuously flowing.

Parallel and series electric circuits' connection
In connections, we must either connect in series or in parallel.
Some examples
1. A current of 4A flows through an electric kettle when the p.d. across it is 8V. Find the resistance.
2. What voltage is needed to make a current of 0.4A flow through when the appliance has resistance of 20Ω?

Questions
1. Give the unit and its symbol for
   (a) Current
   (b) Charge
2. What instrument is used to measure current.
3. A charge of 4C flows through an ammeter in 1s. What reading will the ammeter show? If the same charge flowed through the ammeter in 2s. What would the current be?
4. (a) Draw a circuit diagram to show two cells connected in series with a switch and two bulbs.

(b) Draw a 2nd circuit diagram with the same components, but with a switch and two bulbs in Parallel with each other.

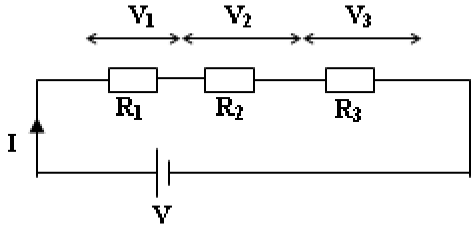
Qn. Determine resistance from the information given.

p. d (V)	1.05	1.40	1.80	2.20	2.40
I (A)	0.15	0.20	0.25	0.30	0.34

RESISTANCE
It can be defined as the opposition to the flow of current thru a conductor. A resistor is a conductor which opposes the flow of current thru it.

The unit of resistance is an ohm (Ω)
An **ohm** is the resistance of the conductor when a current of 1 A is flowing and a p.d. of 1 V is across its ends.

Resistor Net works
(i) Series arrangement of resistors
Resistors are said to be in series when they are connected end to end so that the same amount of current is the same.
The positive of one load is connected to the negative of another load.



In series
(i) Same current flows through each resistor.
(ii) P.d across each resistor is different
(iii) Total p.d V = sum of p.d across each resistor.

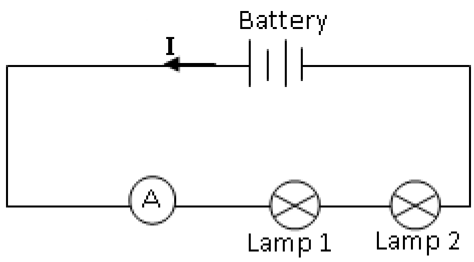
Thus: $V = V_1 + V_2 + V_3$

Using Ohm's law, $V_1 = IR_1$, $V_2 = IR_2$ and $V_3 = IR_3$
$V = IR_1 + IR_2 + IR_3$
$V = I(R_1 + R_2 + R_3)$

If **R** is the resistance of a single resistor representing the three resistors, then V=IR.
$IR = I(R_1 + R_2 + R_3)$

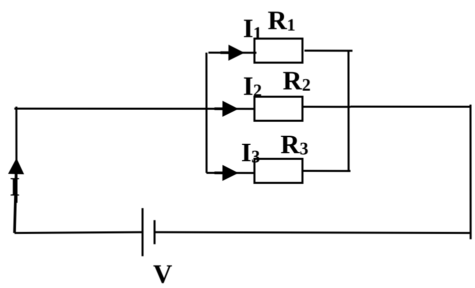
$\mathbf{R = R_1 + R_2 + R_3}$

Series circuits
The current is the same at all points around a series circuit connections i.e. from the source (battery/cell) up to all points when its fully connected.



Which is a series connection and current being measured in series.

(ii) **Parallel arrangement of resistors**
Resistors are said to be in parallel if they are connected such that they branch from a single point (known as a **node**) and join up again.
The positive of one load is connected to the positive of another load.



For parallel

(i) P.d across each resistor is the same.

(ii) The main current flowing splits and therefore, the current through each resistor is different

(iii) Total current, I is equal to sum of the current through each resistor.

Thus: $I = I_1 + I_2 + I_3$

Using Ohm's law, $V_1 = \frac{V}{R_1}$; $V_2 = \frac{V}{R_2}$ and $V_3 = \frac{V}{R_3}$

$$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$I = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

If **R** is the resistance of a single resistor representing the three resistors, then: $\mathbf{I = \frac{V}{R}}$.

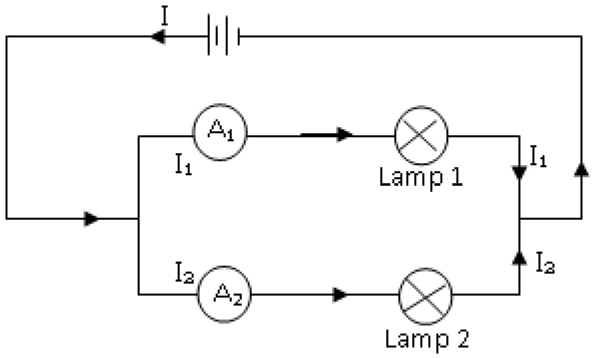
$$\frac{V}{R}. = V\left(\frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}\right)$$

$$\mathbf{\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}}$$

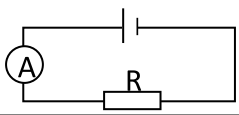
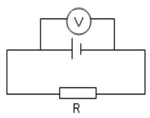
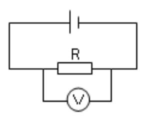
Note: For only two resistors in parallel, the effective resistance can be obtained as follows:

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} \Leftrightarrow \frac{1}{R} = \frac{R_2 + R_1}{R_1R_2} \Leftrightarrow \mathbf{R = \frac{R_1R_2}{R_2 + R_1}}$$

Parallel circuits



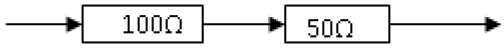
Ammeters are for measuring the current in a parallel circuit. It's characteristic in parallel connections to derive current whenever it reaches the parallel arms of the circuit. But current later recombines to form the original current again before it returns to the cell.

Ammeter	**Voltmeter**	
-A device used to measure current -It has a very low resistance -Always placed in the path of current, i.e in series 	-A device used to measure potential different -It has a very high resistance -Connects across the path of the conductor whose p.d. is to be determined, i.e in parallel. 	

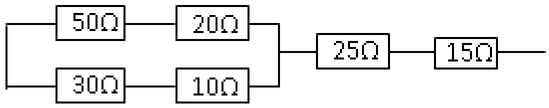
Examples:

1. Show that for two resistors in parallel, the effective resistance $R = \frac{R_1R_2}{R_1 + R_2}$

2. What is the total resistance of the resistors below;

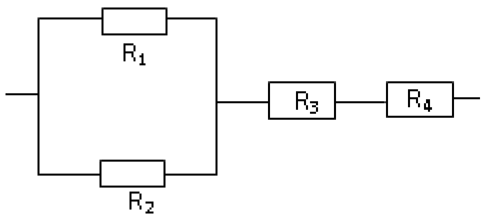


3. What is the effective resistance of the circuit below?



More combinations:

It's very possible to have series and parallel connections combined and in this case, we apply both principles within a given circuit.



If the effective is R

Let the effective of R_1 and R_2 be R_p

$$\frac{1}{R_p}. = \frac{1}{R_1} + \frac{1}{R_2} = \frac{R_1 + R_2}{R_1R_2} \Leftrightarrow R_p = \frac{R_1R_2}{R_1 + R_2}$$

Let the effective of R_3 and R_4 be R_s

$R_s = R_3 + R_4$

Thus the effective resistance R is given by:

$R = R_p + R_s$

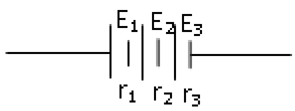
$$R = \frac{R_1R_2}{R_1 + R_2} + R_3 + R_4$$

Voltage and connections

Voltages or e.m.f's can also be connected in series or parallel.

Cells in series

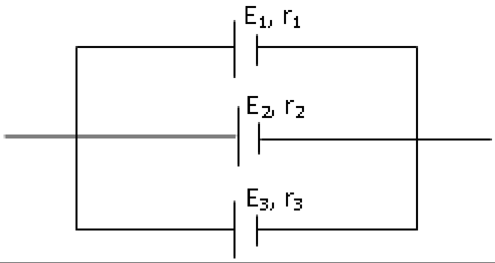
In this case, we sum all the individual e.m.f's to obtain the total e.m.f's:



Effective e.m.f, E	Effective resistance, r
$\mathbf{E = E_1 + E_2 + E_3}$	$\mathbf{r = r_1 + r_2 + r_3}$

Cells in parallel

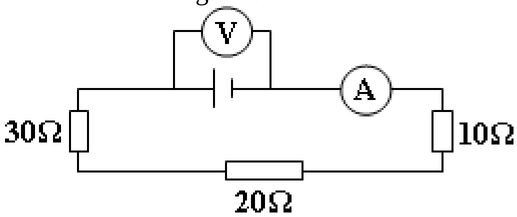
For the case of parallel connection of e.m.f. they have the same e.m.f.



Effective e.m.f, E	Effective resistance, r
$E = E_1 = E_2 = E_3$	$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3}$

EXAMPLES

1. (1991 Qn. 35). In the circuit diagram below, the ammeter reading is 0.2 A. Find the voltmeter reading.

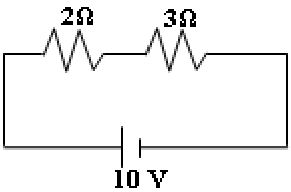


Let R_1=10Ω, R_2=20Ω, R_3=30Ω, I=0.2A, V=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$R = R_1 + R_2 + R_3$ $R = 10 + 20 + 30$ $R = 60\Omega$	$V = IR$ $V = 0.2 \times 60$ $V = 12$ V.

2. **(1997 Qn. 35).** Two coils of wire of resistance 2Ω and 3Ω are connected in series with a 10 V battery of negligible internal resistance. Find the current through the 2Ω resistor. [**Ans: 2A**]

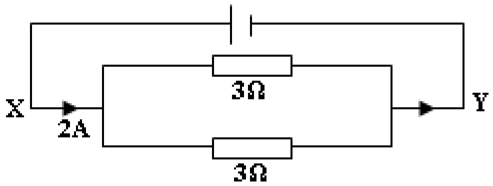
Solution:

Let R_1=10Ω, R_2=20Ω, R_3=30Ω, I=0.2A, V=?



First determine the effective resistance, R	Now that we know V and R, let us use Ohms law; **V=IR**
$R = R_1 + R_2$ $R = 2 + 3$ $R = 5\Omega$	$V = IR$ $10 = I \times 5$ $5I = 10$ $I = 2$ A

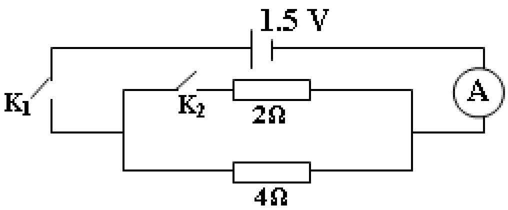
3. **(1993 Qn. 15).** A current of 2A in flows in a circuit in which two resistors each of resistance 3Ω are connected as shown in the figure below. Calculate the P.d across XY.



Solution:

Let R_1= 3Ω, R_2= 3Ω, I= 2A, V=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R} = \frac{1}{3} + \frac{1}{3} = \frac{2}{3}$ $R = \frac{3}{2}\Omega = 1.5\Omega$	$V = IR$ $V = 2 \times 1.5$ $V = 3$ V.

4. **(2007 Qn. 3).** What will be the reading of the ammeter in the figure below if switch **K_2** is**;**

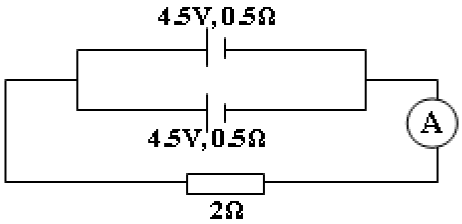


(i) Open and **K_1** is closed
(ii) Closed and **K_1** is closed**.**

Solution:

(i) When K_2 is open and K_1 closed, current flows through the 4Ω only. Let R = 4Ω, V=1.5 V, I=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$R = 4\Omega$	$V = IR$ $1.5 = I \times 4$ $I = 0.375$ A
(ii) When K_2 is closed and K_1 closed, current divides into the 2Ω and 4Ω. Let R_1= 2Ω, R_2= 4Ω, V=1.5 V, I=?	
First determine the effective resistance, R	Now that we know I and R, let us use Ohms law; **V=IR**
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$ $\frac{1}{R} = \frac{1}{2} + \frac{1}{4} = \frac{3}{4}$ $R = \frac{4}{3}\Omega = 1.33\Omega$	$V = IR$ $1.5 = I \times \frac{4}{3}$ $I = 1.125$ A

5. **(2008 Qn. 28).** The figure below shows two cells each of e.m.f 4.5 V and internal resistance 0.5Ω, connected to a 2Ω resistor.



What is the ammeter reading?

Solution:

Let $r_1 = 0.5\Omega$, $r_2 = 0.5\Omega$, $R_3 = 2\Omega$ V= 4.5V (Voltages in parallel; $E_1 = E_2 = V$), I=?

First determine the effective resistance, Rp of the resistors in parallel.

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2}$$

$$\frac{1}{R} = \frac{1}{0.5} + \frac{1}{0.5} = \frac{4}{1}$$

$$R = \frac{1}{4}\Omega = 0.25\Omega$$

This resistance Rp is now in series with the 2Ω resistor.

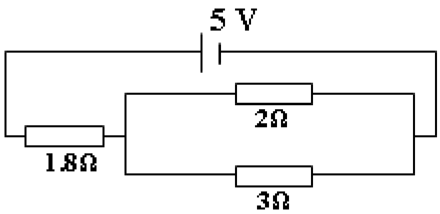
Thus the effective resistance, R is;

$$R = R_P + R_3$$
$$R = 0.25 + 2$$
$$R = 2.25\Omega$$

Now that we know I and R, let us use Ohms law;

$$V = IR$$
$$4.5 = I \times 2.25$$
$$I = 2 \text{ A.}$$

6. **(1994 Qn. 4).** The diagram below shows three resistors, 1.8Ω, and 2.0 Ω and 3Ω resistor.



Calculate the; (i) Effective resistance of the circuit
(ii) Current through the circuit.
(iii) P.d across the 2Ω resistor
(iv) Current through the 3Ω resistor.

Solution:

(i) Effective resistance of the circuit

The 2Ω and 3Ω are in parallel. Their effective resistance is in series with the 1.8Ω resistor.

Thus the effective resistance R is given by:

$$R = R_p + R_s$$

$$R = \frac{R_1 R_2}{R_1 + R_2} + R_3$$

$$R = \frac{2 \times 3}{2 + 3} + 1.8 \Leftrightarrow R = \frac{6}{5} + 1.8 \Leftrightarrow R = 1.2 + 1.8$$
$$R = 3\Omega$$

(ii) Current through the circuit.

From Ohms law; **V=IR.**

$$V = IR$$
$$5 = I \times 3$$

$$I = \frac{5}{3} = 1.67 \text{ A}$$

(iii) P.d across the 2Ω resistor

P.d across the 2Ω resistor is equal to the P.d across the 3Ω which is equal to the P.d across the parallel combination.

Thus from Ohms law; **V=IR.**

$$V_P = IR_P$$
$$V_P = \frac{5}{3} \times 1.2$$
$$V_P = 2 \text{ V}$$

Thus the P.d across the 2Ω resistor is 2V.

(iv) Current through the 3Ω resistor.

Let the 3Ω resistor = R_1; Then;

$V_1 = I_1 R_1$; In this case, $V_1 = V_P = 1.2$ V

$$1.2 = I_1 \times 3$$
$$I_1 = 0.4 \text{ A}$$

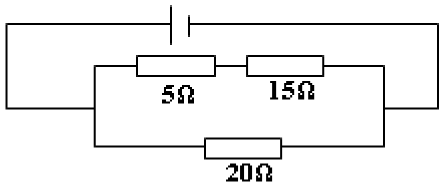
Thus the current through the 3Ω resistor is 0.4A.

7. **(2001 Qn. 31**). Find the effective resistance when two resistors of 5Ω and 15Ω joined in series are placed in parallel with a 20Ω resistor.

Solution:

Let $R_1 = 5\Omega$, $R_2 = 15\Omega$, $R_3 = 20\Omega$,

A sketch diagram showing the network of resistors.



First determine the effective resistance, **R_s** for the resistors in series.

$$R_s = R_1 + R_2$$
$$R_s = 5 + 15$$
$$R_s = 20\Omega$$

Now **R_s** is in parallel with the **$R_3 = 20\Omega$.**

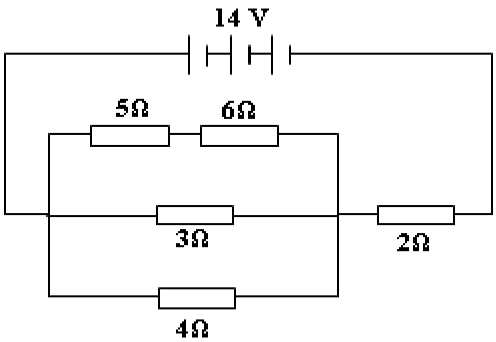
Thus the effective resistance in the circuit is;

$$R = \frac{R_s R_3}{R_s + R_3}$$

$$R = \frac{20 \times 20}{20 + 20} = \frac{400}{40}$$

$$R = 10\Omega$$

8. In the figure below, find the ;



(i) Effective resistance in the circuit.
(ii) Current through the circuit.
(iii) P.d across the 2Ω resistor.
(iv) P.d across the 6Ω resistor.

Solution:

<table>
<tr><td colspan="2">Let $R_1 = 5\Omega$, $R_2 = 6\Omega$, $R_3 = 3\Omega$, $R_4 = 4\Omega$, $R_5 = 2\Omega$,
(i) Effective resistance in the circuit.</td></tr>
<tr><td rowspan="3">First determine the effective resistance, R_s for the 5Ω and 6Ω resistors in series.
$R_s = R_1 + R_2$
$R_s = 5 + 6$
$R_s = 11\Omega$

Now R_s is in parallel with the 3Ω. and 4Ω resistors.
Thus the effective resistance in parallel is;
$\frac{1}{R_p} = \frac{1}{R_s} + \frac{1}{R_3} + \frac{1}{R_4}$

$\frac{1}{R_p} = \frac{1}{11} + \frac{1}{3} + \frac{1}{4}$

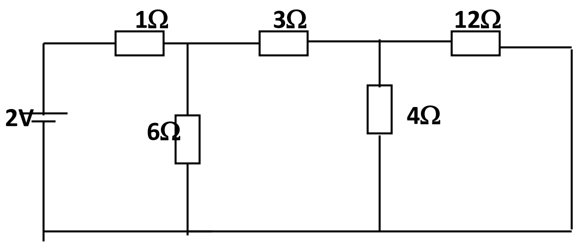
$\frac{1}{R_p} = \frac{12 + 44 + 33}{132} = \frac{89}{132}$

$\frac{1}{R_p} = \frac{12 + 44 + 33}{132} = \frac{89}{132}$

$R_p = \frac{132}{89}\Omega = 0.674\Omega$</td>
<td>Now R_P is in series with the 2Ω resistor.
Thus the effective resistance in the circuit is;
$R = R_P + R_5$
$R = 0.674 + 2$
$R = 2.674\Omega$</td></tr>
<tr><td>(ii) Current through the circuit.
From Ohms law; V=IR.
$V = IR$
$14 = I \times 2.674$
$2.674I = 14$
$I = 5.236$ A</td></tr>
<tr><td>(iii) P.d across the 2Ω resistor.
From Ohms law; V=IR.
$V = IR$
$V = 5.236 \times 2$
$V = 10.472$ V</td></tr>
<tr><td colspan="2">(iv) P.d across the 6Ω resistor.
The P.d across $R_s(5\Omega \text{ and } 6\Omega)$ is equal to the p.d across the 3Ω and is also equal to the p.d across the 4Ω resistor.
This is because, R_s, 3Ω and $4\Omega$are in parallel.</td></tr>
<tr><td>P.d across the parallel combination:
From Ohms law; V=IR.
$V_P = I_P R_P$
$V_P = 5.236 \times 0.674$
$V_P = 3.529$

Current through $R_s(5\Omega \text{ and } 6\Omega)$ resistors.
From Ohms law; V=IR.
$V_P = I_s R_s$
$3.529 = I_s \times 11$
$11I_s = 3.529$
$I_s = 0.321$ A</td>
<td>Then the P.d across the 6Ω resistor is obtained as follows;
From Ohms law; V=IR.
$V = I_s R$
$V = 0.321 \times 6$
$V = 1.925$ V</td></tr>
</table>

Example: 8



4 Ωand 12Ω resistors are parallel, their effective resistance is $R_1 = \frac{4 \times 12}{4+12} = 3\Omega$

R_1 and 3Ω resistors are in series, their effective resistance is $R_2 = R_1 + 3 = 3 + 3 = 6\Omega$

R_2 and 6Ω resistors are in parallel, their effective resistance is $R_3 = \frac{6 \times 6}{6+6} = 3\Omega$

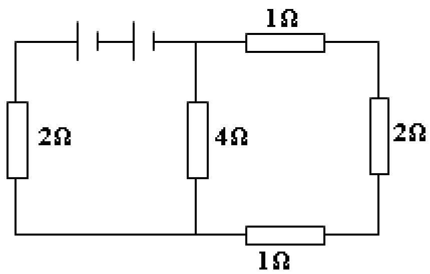
R_3 and 1Ω resistors are in series, their effective resistance is $R = R_3 + 1 = 3 + 1 = 4\Omega$

Hence effective resistance of the whole circuit is R = 4Ω

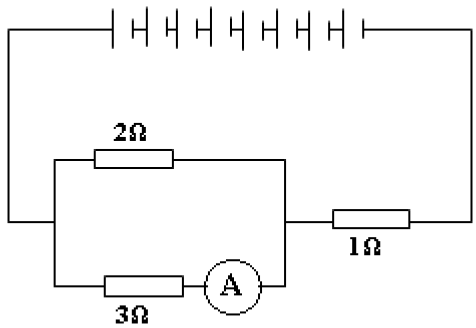
Current flowing $I = \frac{V}{R} = \frac{2}{4} = 0.5A$

Exercise:

1. Calculate the effective resistance of the circuit below. [**Ans: 4Ω**]



2. Eight identical cells each of e.m.f 1.5 and internal resistance 0.1Ω are connected in a circuit as shown bellow.

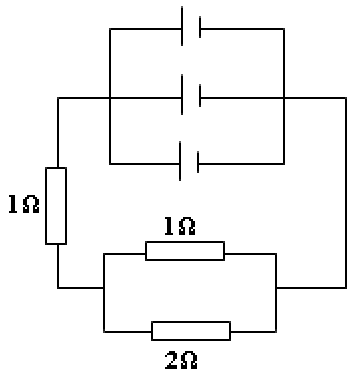


Calculate the;

(i). Current in the circuit.[Ans: 4A]

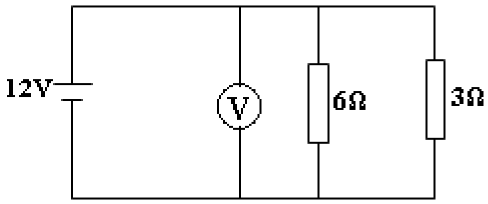
(ii). Ammeter reading, A. [Ans: 1.6 A]

3. Three identical cells each of e.m.f 1.5V and internal resistance 0.1Ω are connected as shown bellow.



Calculate the current in the circuit. [Ans: 0.88A]

4. (1997 Qn. 30). A battery of e.m.f 12V is connected across two resistors of 6Ω and 3Ω as shown below.



Calculate the current through the resistors.

5. A number of 8 ohm resistors are available. How would you connect a suitable number of these to obtain an effective resistance of :

(i) 2 ohms.
(ii) 24 ohms

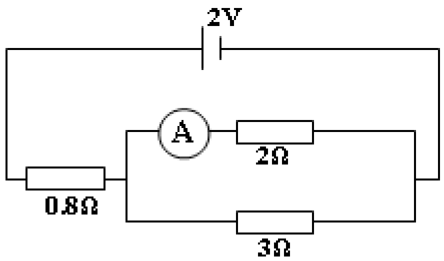
6. See UNEB Paper1
Section A:

1987 Qn.29	1989 Qn.32	1992 Qn.8	1994 Qn.4
1998 Qn.35	2000 Qn.37	2006 Qn.38	2008 Qn.36
1992 Qn.15	1989 Qn.11	1991 Qn.28	1994 Qn.24
1995 Qn.29	1998 Qn.37	2004 Qn.6	2007 Qn.12
1994 Qn.32			

Section B:

2002 Qn.50	1994 Qn.5	1997 Qn.8	1998 Qn.8
2000 Qn.9	2002 Qn.7		

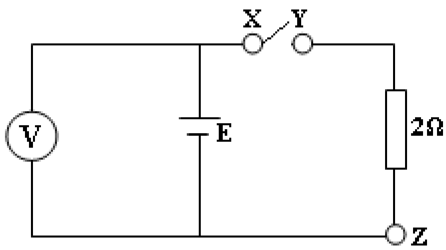
(1989 Qn. 7). (b) A battery of e.m.f 2.0 V and of negligible internal resistance is connected as shown below.



Find the reading of the ammeter, A.

(c) A battery of e.m.f 12 V and internal resistance1Ω is connected for three minutes and two seconds across a heating coil of resistance 11Ω immersed in a liquid of mass 0.2 kg and specific heat capacity of $2.0 \times 10^3 \text{Jkg}^{-1}\text{K}^{-1}$. Find the rise in temperature of the liquid. Clearly state any assumptions made.

(1989 Qn. 7). (b) A cell of e.m.f, E and internal resistance 1.0 Ω is connected in series with a 2Ω resistor as shown bellow.

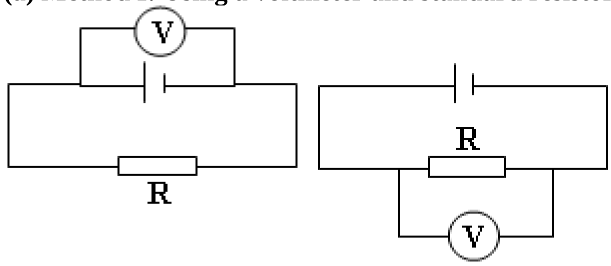


The voltmeter reads 1.5V when the switch is open.

(i). Find the value of E.
(ii). What will be the voltmeter's reading when the switch is closed?
(iii). What will be the voltmeter's reading when X is connected to Z? Give a reason for your answer.

An experiment to obtain internal resistance of a cell.

(a) Method I: Using a voltmeter and standard resistors.

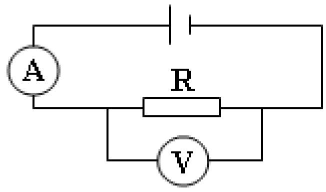


-A high resistance voltmeter is connected across the terminals of the cell, we take the reading which is the E.m.f., **E** of the cell.
-A standard resistor is connected to the cell terminals and the voltmeter reading is taken again which is **V**.
-Calculate the internal resistance of the cell, **r** from;

$$\mathbf{r} = \frac{\mathbf{R(E-V)}}{\mathbf{V}}$$

-Repeat the procedure using other resistors of different resistances.
-Finally take the mean value of internal resistance.

(b) Method II: Using a voltmeter, Ammeter and standard resistors.



-A high resistance voltmeter is connected across the terminals of the cell, we take the reading which is the E.m.f., **E** of the cell.
-A standard resistor is connected in series with the cell terminals and the voltmeter connected across it as shown above.
-Read and record the voltmeter reading, **V** and the corresponding ammeter reading, **I**.
-Calculate the internal resistance of the cell, **r** from;

$$\mathbf{r} = \frac{\mathbf{E-V}}{\mathbf{I}}$$

-Repeat the procedure using other resistors of different resistances.
-Finally take the mean value of internal resistance

<table>
<tr><td>Derivation:
Find the total resistance using R and r and them apply ohm's law
Total resistance $= \text{R} + \text{r}$
$\text{E} = \text{I} \times \text{Total restance}$
$\text{E} = \text{I}(\text{R}+\text{r})$
$\text{E} = \text{IR} + \text{Ir} \ldots\ldots\ldots\ldots (\text{i})$</td><td>For the resistor alone;
$\text{V} = \text{IR} \ldots\ldots\ldots\ldots\ldots\ldots (\text{ii})$

Subtracting equation (ii) from equation (i) , we get;
$\text{E} - \text{V} = \text{Ir}$
Making r the subject of the formula gives;
$\mathbf{r} = \frac{\mathbf{E-V}}{\mathbf{I}}$</td></tr>
<tr><td colspan="2">Note: The expression $\mathbf{E-V}$ is called lost volt and it is defined as the voltage wasted in overcoming the internal resistance of a cell.</td></tr>
</table>

Alternatively: From; $V = IR$, $I = \frac{V}{R}$ Substituting for current, I in the equation for r above, gives;	$r = \frac{E - V}{\left(\frac{V}{R}\right)}$ $\mathbf{r = \frac{R(E - V)}{V}}$

6.3 ELECTRICAL ENERGY AND POWER

The advantage of electric energy is the ease with which it may be transferred to light, heat and other forms of energy. Because of this, it can be used in many types of equipment like refrigerators, cookers, lamps, e.t.c.

When electricity passes thru an appliance, it develops and produces some heat which may depend on any of the following;

- Resistance of the conductor
- The amount of current flowing
- The time for which the current has been flowing

Work done by an electric current.

When a charge moves through a resistance wire, the work done becomes the electrical energy which changes to heat energy.

$$\textbf{Work done} = \textbf{Voltage} \times \textbf{Charge}$$
$$\mathbf{W = V \times Q}$$

From the definition of current, $Q = It$: Thus;

$$W = V \times It$$
$$\mathbf{W = VIt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots. \mathbf{(i)}$$

But from Ohm's law, $V = IR$: Thus;

$$W = IR \times It$$
$$\mathbf{W = I^2Rt} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(ii)}$$

$$\mathbf{W = \frac{V^2t}{R}} \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \mathbf{(iii)}$$

Electrical Power

Power is the rate of doing work or it's the rate of energy transfer.

$$\text{Power} = \frac{\text{Work done}}{\text{Time taken}} = \frac{\text{Energy transfered}}{\text{Time taken}}$$

$$\text{Power}, P = \frac{IVt}{t} = IV$$

$$\mathbf{P = IV = I^2R = \frac{V^2}{R}}$$

Examples

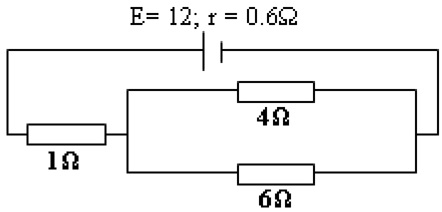
1. An electrical flat iron of rated 240V, 1500W. calculate the;

(i) The current through the flat iron.
(ii) The resistance of the flat iron
(iii) The energy consumed in $1\frac{1}{2}$ hours.

Solution:

P = 1500W; V = 120V, I = ?	
(i) the current through the flat iron. $\mathbf{P = IV}$ $1500 = I \times 240$ $240I = 1500$ $I = 6.25$ A	(ii) The resistance of the flat iron $\mathbf{P = \frac{V^2}{R}}$ $1500 = \frac{(240)^2}{R}$ $1500R = 57600$ $R = 38.4\ \Omega$
(iii) The energy consumed in $1\frac{1}{2}$ hours: $\mathbf{E = Pt}$ $E = 1500 \times (1.5 \times 60 \times 60)$ $E = 8{,}100{,}000J$	**One can use;** $\mathbf{E = IVt}$, **or** $\mathbf{E = \frac{V^2}{R}}$

2. In the diagram, below, a 12V battery of internal resistance 0.6Ω is connected to the 3 resistors. A, B, C.



Find the:
(i) Current in each resistor.
(ii) Power dissipated in the 4Ω resistor.

Solution:

R=0.6Ω; E= 12V, I = ?	
<u>Effective resistance of the circuit</u> The 2Ω and 3Ω are in parallel. Their effective resistance is in series with the 1.8Ω resistor. Thus the effective resistance R is given by: $R = R_p + R_s$ $R = \frac{R_1R_2}{R_1 + R_2} + R_3 + r$ $R = \frac{4 \times 6}{4 + 6} + 1 + 0.6$ $R = \frac{24}{10} + 1 + 0.6$ $R = 2.4 + 1 + 0.6$ $R = 4\Omega$	**(i) Current through the circuit.** From Ohms law; **V=IR.** $V = IR$ $12 = I \times 4$ $I = \frac{12}{4} = 3$ A Thus current through the 1Ω resistor is 3 A. P.d across the parallel combination, 4Ω and 6Ω resistors. From Ohms law; **V=IR.** $V_P = IR_P$ $V_P = 3 \times 2.4$ $V_P = 7.2$ V Thus the P.d across the 4Ω and 6Ω resistors is 7.2V.
Current through the Ω resistor. From Ohms law; **V=IR.** $V_1 = I_1R_1$ $7.2 = I_1 \times 4$ $4\,I_1 = 7.2$ $I_1 = 1.8$ A	**Current through the 6Ω resistor.** From Ohms law; **V=IR.** $V_2 = I_2R_2$ $7.2 = I_2 \times 6$ $6\,I_2 = 7.2$ $I_2 = 1.2$ A Alternatively: $I_2 = I - I_1$ $I_2 = 3 - 1.8$ $I_2 = 1.2$ A
(ii) Power dissipated in the 4Ω resistor. $P = I^2R$ $P = (1.8)^2 \times 4$	**One can use;** $\mathbf{P = IV}$, **or** $\mathbf{P = \frac{V^2}{R}}$

$P = 3{,}24 \times 4$
$P = 12.96$ W

3. **(1992 Qn. 6).** An electrical appliance is rated 240V, 60W. (a) What do you understand by this statement?
(b) Calculate the current flowing through and the resistance of the appliance when operated at the rated values above. [0.25A, 960Ω respectively]

Solution:

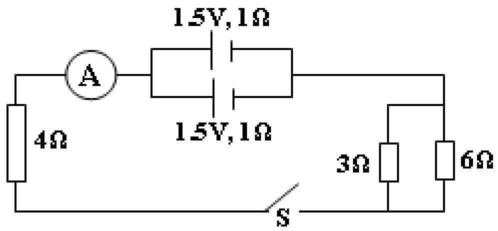
(a) 240V, 60W means that the appliance supplies or consumes 60 joules of electrical energy in one second when connected to a 240V mains supply.

(b) V=240V, P=60W, I=?

(i) From: $P = IV$
$60 = I \times 240$
$240I = 60$
$I = 0.25A$

(ii) From: $P = \frac{V^2}{R}$
$P = \frac{V^2}{R}$
$60 = \frac{(240)^2}{R}$
$60R = 57600$
$R = 960\Omega$

4. **(1990 Qn. 3).** (c) In the diagram below, two batteries of e.m.f 1.5V and internal resistance of 1Ω each are connected to a network of resistors in a circuit which includes a switch, S.



(i). What will be the reading on the ammeter when switch S is closed? [Ans: 0.23A]
(ii). What is the power developed in the 4Ω resistor when S is closed? [Ans: 0.21 W]

Solution:

$R_1 = 4\Omega$; $R_2 = 3\Omega$; $R_3 = 6\Omega$; $V_1 = 1.5V$; $V_2 = 1.5V$;
$r_1 = 1\Omega$; $r_2 = 1\Omega$;

Effective resistance of the circuit
For the two cells in parallel.
$r = \frac{r_1 r_2}{r_1 + r_2} = \frac{1 \times 1}{1+1} = 0.5\Omega$

For the two standard resistors in parallel.
$R_P = \frac{R_1 R_2}{R_1 + R_2} = \frac{3 \times 6}{3+6}$
$= 2\Omega$

Thus effective resistance is;
$R = R_p + R_s + r$
$R = 0.5 + 2 + 4$
$R = 6.5\ \Omega$

(i) Current through the ammeter.
From Ohms law; **V=IR.**
$V = IR$
$1.5 = I \times 6.5$
$6.5I = 1.5$
$I = 0.23$ A

(ii) power developed in the 4Ω resistor when S is closed?
From Ohms law; **V=IR.**
$P = I^2R$
$P = (0.23)^2 \times 4$
$P = 0.0529 \times 4$
$P = 0.21$ W

Exercise:

1. An electric appliance is rated 200V, 0.05kW. Calculate the;
   (i) Current through the appliance.[0.25A]
   (ii) Resistance of the appliance.
   (iii) Time it will take to transfer energy of 10,000J.
[200 seconds]

2. Appliance A allows 3A of current to go through it when connected to a 200 V supply while appliance B has a resistance of 40Ω when connected to the same supply.
Which of the two appliances heats up first and why?

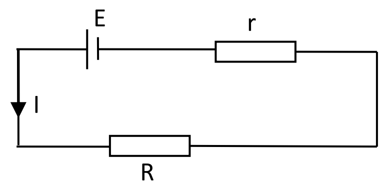
3. see UNEB

Section A			
1997 Qn. 37	1989 Qn. 8	2007 Qn. 4	2003 Qn. 38
1988 Qn. 10	1991 Qn. 15	1998 Qn. 35	1999 Qn. 36
2006 Qn. 36			

Example: 5

A battery of un known e.m.f and internal resistance is connected in series with a load of resistance, R ohms. If a very high resistance voltmeter is connected across the load reads 3.2V and the power is dissipated in the battery is 0.032W and efficiency of the circuit is 80%. Find the:
(i) Current flowing
(ii) Internal resistance of the battery.
(iii) Load resistance, R
(iv) E.m.f of the battery.

Solution:



Total resistance, $= R + r$
From the circuit formula;
$I = \frac{E}{R+r} \ldots\ldots\ldots\ldots\ldots\ldots (i)$
Power dissipated in the battery;
$P = I^2r = 0.032 \ldots\ldots\ldots (ii)$

From Ohm's law; the terminal p.d is;

$V = IR = 3.2 \ldots\ldots\ldots\ldots (iii)$
$\text{Efficiency}, = \frac{\text{P. out}}{\text{P. in}} \times 100$

$\frac{80}{100} = \frac{I^2R}{ER}$
$0.8 = \frac{I^2R}{I^2(R+r)}$
$R = 0.8(R+r)$
$R = 4r$

From equation (iii)
$I(4r) = 3.2 \ldots\ldots\ldots\ldots (iv)$

Equation (ii) ÷ (iv)
$\frac{I^2r}{4Ir} = \frac{0.032}{3.2}$
$\underline{I = 0.04\ A}$

From equation (ii)
$(0.04)^2 r = 0.032$
$\underline{r = 20\Omega}$

$R = 4r$
$\underline{R = 4(20) = 80\Omega}$

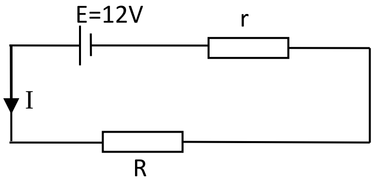
From equation (ii)
$E = I(R + r)$
$E = 0.04(40 + 20)$
$\underline{E = 4\ V}$

Example:6

A battery of e.m.f 12V and un known internal resistance is connected in series with a load resistance, R reads 11.4V and the power dissipated in the battery is 0.653W. Find the:

(i) Current flowing.
(ii) Internal resistance of the battery.
(iii) Load resistance, R.
(v) Efficiency of the circuit.

Solution:



From Ohm's law; the terminal p.d is;
$V = IR$
$= 11.4 \ldots\ldots\ldots\ldots$ (i)

P.d across the internal resistance is lost volts (Ir). From;
$E = I(R + r) \Leftrightarrow Ir = E - IR$
$Ir = 12 - 11.4$
$Ir = 0.6 \ldots\ldots\ldots\ldots\ldots\ldots\ldots$ (ii)

Power dissipated in the battery;
$P = I^2r$
$= 0.653 \ldots\ldots.$ (iii)
Equation (iii) ÷ (ii)
$$\frac{I^2r}{Ir} = \frac{0.653}{0.6}$$
$$\underline{\underline{I = 1.088\ A}}$$

From equation (iii)
$(1.088)^2 r = 0.653$
$$\underline{\underline{r = 0.55\Omega}}$$

From equation (i)
$IR = 11.4$
$(1.088)R = 11.4$
$$\underline{\underline{R = 10.48\Omega}}$$

$$\text{Efficiency}, = \frac{\text{Power output}}{\text{Power input}} \times 100\%$$
$$= \frac{I^2R}{ER} \times 100\%$$
$$= \frac{(1.088)^2(10.48)}{12(1.088)} \times 100\%$$
$$= 95\%$$

Question:
A cell of electromotive force 2.0V and negligible internal resistance is connected in series with a resistance of 3.5Ω and an ammeter of resistance 0.5Ω. Calculate the current in the circuit. [**Ans: 0.5A**]

Commercial Electric Energy
All electric appliances are connected in parallel so that each is at the same voltage.
All electric appliances are marked showing the power rating in watts (W) and the voltage in volts (V).
The power of an appliance indicates the amount of electrical energy it supplies or the amount of work it does per second.

For example: A heater marked 240V, 1000W, means that the heat consumes 1000J of electrical energy every second when connected to 240V.

6.4 COMMERCIAL ELECTRICAL ENERGY

There are always charges for electricity consumed that the electricity board gives for us for payment and they use our meters to estimate the energy consumed.
The energy consumed is measured in **kWh** which is an abbreviation for **kilowatt hour**.
The commercial unit of electrical energy is a kilowatt-hour, (kWh) since a watt second is very small.

A kilowatt hour is the electrical energy used by a rate of working of 1000 watts for 1 hour.
It is the quantity of electrical energy converted into other forms of energy by a device of power 1000watts in one hour.
1 watt = 1 joule per second
1 kWh = 1000x1hr
= 1000 x 60 x 60 x 60 joules.
1 kWh = 3,600,000J = 3.6 MJ

Cost of electric energy calculation

$$\begin{bmatrix}\textbf{Number of units used}\\ \text{(Energy consumed)}\end{bmatrix} = \begin{bmatrix}\textbf{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\textbf{Time}\\ \text{(in hours)}\end{bmatrix}$$

$$\textbf{Total cost} = \begin{bmatrix}\textbf{Number of units used}\\ \text{(Energy consumed in kWh)}\end{bmatrix} \times \begin{bmatrix}\textbf{Rate per}\\ \textbf{unit}\end{bmatrix}$$

The **rate per unit** is the **cost per unit** of electrical energy consumed. Thus the cost of using an appliance is given by;

$$\textbf{Total Cost} = \begin{bmatrix}\textbf{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\textbf{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\textbf{Cost per}\\ \textbf{unit}\end{bmatrix}$$

Examples;
1. **(1995 Qn. 33).** Four bulbs each rated at 75W operate for 120 hours. If the cost of electricity is sh.100 per unit, find the total cost of electricity used.

Solution:

Number of bulbs = 4;
Power rating for each bulb = 75W
Total Power rating for 4 bulb $= 4 \times 75W = 300W$
$$= \frac{300}{1000}\ \text{kW}$$
$$= \mathbf{0.3\ kW}$$

Total Time = 120 Hours

Cost per unit = sh. 100

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

$$\text{Total Cost} = [0.3\ \text{kW}] \times [120\ \text{hrs}] \times [\text{sh}.\,100]$$

$$\text{Total Cost} = \text{sh}.\,3600$$

2. An electric immersion heater is rated at 3000W, 240V. Calculate the;
   (i) Current and resistance of the heating element.
   (ii) Total number of electric units it consumes in $1\frac{1}{2}$ hours.
   (iii) Cost per unit if sh. 9000 is paid after using it for 3hours everyday for ten days.

Solution:

(i) V= 240V, P =3000W, I=?, R = ?

From: $P = IV$ $3000 = I \times 240$ $240I = 3000$ $I = 12.5A$	From: $P = \frac{V^2}{R}$ $P = \frac{V^2}{R}$ $3000 = \frac{(240)^2}{R}$ $3000R = 57600$ $R = 19.2\Omega$

(ii)

Total Power $= 3000W$ $= \frac{3000}{1000}$ kW $= \mathbf{3\ kW}$	Total Time $= 1\frac{1}{2}$ hours $= \frac{3}{2}$ hours $= \mathbf{1.5\ hours}$

$$\begin{bmatrix}\text{Number of units used}\\ \text{(Energy consumed)}\end{bmatrix} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix}$$

$$\begin{matrix}\text{Number of units used}\\ \text{(Energy consumed)}\end{matrix} = 3 \times 1.5$$

$$\begin{matrix}\text{Number of units used}\\ \text{(Energy consumed)}\end{matrix} = 4.5\ \text{kWh} = 4.5\ \text{Units}$$

(iii)

Total Power $= 3000W$ $= \frac{3000}{1000}$ kW $= 3$ kW	Total Time $= 3 \times 10$ hours $= 30$ hours

Let the cost per unit be y

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

$$9000 = 3 \times 30 \times y$$
$$9000 = 90y$$
$$y = \text{sh}.100$$

3. Mr. Bagira uses 3 kettles of 800W each, a flat iron of 1000W, 3 bulbs of 60W each and 4 bulbs of 75W each. If they are used for 3 hours every day for 30 days and that one unit of electricity costs sh. 200, find the total cost of running the appliances.

Solution:

Kettles	**Flat irons**	**60W Bulbs**	**75W Bulbs**
$P = 3 \times 800$ $P = 2400$ W $= \frac{2400}{1000}$ kW $= 2.4$ kW	$P = 1 \times 1000$ $P = 1000$ W $= \frac{1000}{1000}$ kW $= 1$ kW	$P = 3 \times 60$ $P = 180$ W $= \frac{180}{1000}$ kW $= 0.18$ kW	$P = 4 \times 750$ $P = 300$ W $= \frac{300}{1000}$ kW $= 0.3$ kW

Total power $= (2.4 + 1 + 0.18 + 0.3)$ kWh $= 3.88$ kWh

Total time $= (3 \times 30)$ hours $= 90$ hours.

$$\text{Total Cost} = \begin{bmatrix}\text{Power}\\ \text{(in kW)}\end{bmatrix} \times \begin{bmatrix}\text{Time}\\ \text{(in hours)}\end{bmatrix} \times \begin{bmatrix}\text{Cost per}\\ \text{unit}\end{bmatrix}$$

$$\text{Total Cost} = [3.88\ \text{kW}] \times [90\ \text{hrs}] \times [\text{sh}.200]$$

$$\text{Total Cost} = \text{sh}.69840$$

4. Find the cost of running five 60 W lamps and 4 100 W lamps for 8 hours if the electric energy costs shs. 5.0 per unit.**[Shs.28**]

5. A house has one 100 W bulb, two 75 W bulbs and 5 40 W bulbs. Find the cost of having all lamps switched on for 2 hours every day for 30 days at a cost of shs. 30 per unit.

[**Shs. 810**].

6. See UNEB

Section A			
2002 Qn. 36	1999 Qn. 40	2003 Qn. 37	2006 Qn. 28
2007 Qn. 14			
Section B			
1992 Qn. 2	1997 Qn. 8	2008 Qn. 4	

Generation and Transmission of electricity

(a) Generation of electricity

Electricity is generated at power stations by using one of the following;

- ❖ Coal, Nuclear reactions, Falling water, e.t.c.

(b) Transmission of electricity

- ❖ The electricity generated at the power station is then stepped up to higher voltage using step up transformers for transmission.
- ❖ Electricity is transmitted at high voltages to reduce power loss through heating effect in the transmission cables.

Transmission cables are made thick to reduce its resistance hence minimizing power loss through the $\mathbf{I^2R}$ − mechanism.

- ❖ The electricity is then stepped down using step down transformers in phases. That is, it is first stepped down to heavy factories, industries, cities, towns, and finally to homes.
- ❖ The transmission can either be over head or underground. In some developed countries, the grid system is used

The grid system is a system where different power stations are inter connected or networked so that in cases there is power failure in one power station or when one station is stopped for maintenance work, the other stations continue to supply the power.

(c) House wiring.

Domestic electric installation

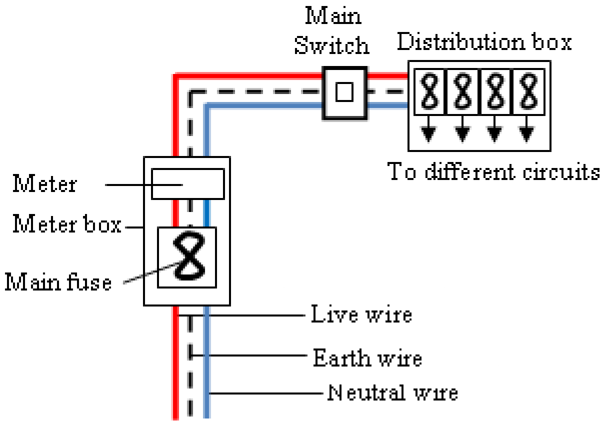
Power is connected in a house by thick cables from the pole called mains to the fuse box {meter box}, then main switch and to the distribution box. Here, power is directed to

electrical equipments. Each circuit has its own fuse which is connected to a live wire.
The main switch board (distribution box) breaks both wires when in OFF position and is therefore called a **double pole switch.**
It completely cuts off the supply in the house.

In supply cable:
Power enters the house thru the supply cable from the electric pole from which two insulated wires, the live and the neutral come from. They are distinguished by colour i.e;

Type of wire	Colour
(i) Live wire	Red or Brown
(ii) Neutral wire	Blue or Black
(iii) Earth wire	Yellow or Green or Yellow with green stripes

The earth wire is usually earthed and is therefore at zero potential while the live wire is at a potential of 240V for the case of Uganda.
The electricity being supplied is alternating and it therefore alternates from positive to negative in a single cycle.

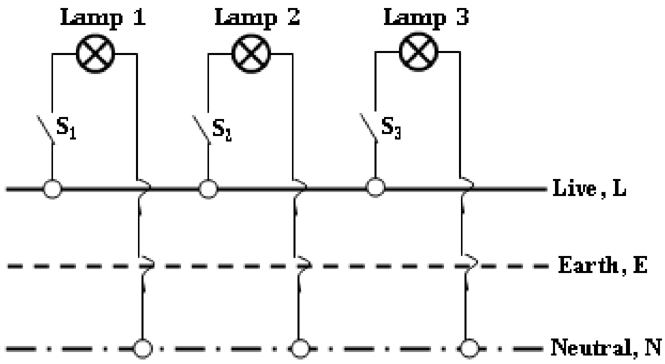


Switches, Sockets and Plugs

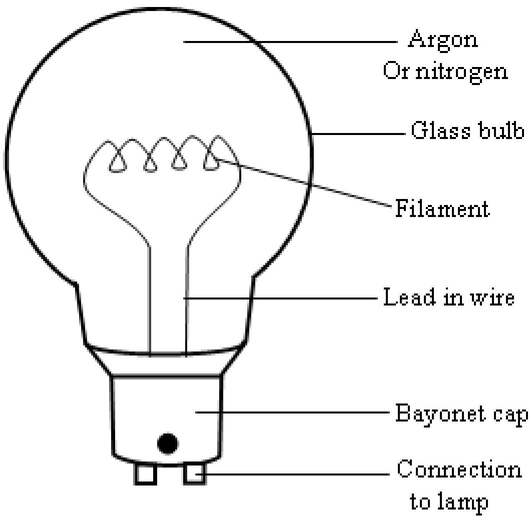
Electric system	Connection
(i) Switches	❖ Control the flow of current ❖ Connected to the live wire to prevent the appliance from being live when switched off. Thus they are called single pole switches.
(ii) Fuses	❖ It is a thin wire of low melting point which melts when the current exceeds a required value so as to break the circuit. ❖ It must be connected to the live wire.
(iii) Sockets	❖ These are power points usually put on the walls. ❖ They have 3 holes leading to the live wire L, neutral wire N and earth wire E.
(iv) Plugs	❖ These are points which connect or tap power from the socket to the appliance. ❖ It has 3 pins that fit into the 3 holes in the socket. The pins are marked with L, N and E for live, neutral and earth wires respectively.

Connection of appliances
Electrical appliances are usually connected in parallel with the mains so that;
(i) They receive full main potential difference.
(ii) When one circuit is faulty or switched off, the other circuits remain working.

(a) Light circuits
All lamps in house wiring are connected in parallel with the switch on the live wire to the lamp.



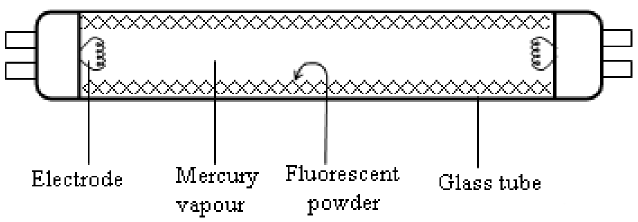
(i) Filament Lamp / Incandescent lamp:



-When switched on, the coiled tungsten filament is heated, it becomes white hot and emits light.
-The higher the temperature of the filament, the greater the electrical energy changed to light.

Note:
- ❖ The filament is made out of tungsten, because tungsten has a higher melting point. Hence it can't easily melt when white hot.
- ❖ The filament is coiled in order to reduce space occupied and hence reduce the rate of heat loss by convection currents in the gas.
- ❖ The glass bulb is filled with an inert gas at low pressure, to prevent evaporation of tungsten and increase the operating temperature. Otherwise it would condense on the bulb and blacken it.

(ii) Fluorescent lamps/ Tubes/ Discharge lamp.



-When switched on, the mercury vapour emits ultra-violet radiations.
-The radiations strike the fluorescent powder (e.g Zinc sulphide, **ZnS**) and the tube glows emitting light.

Differences between a filament lamp and a fluorescent lamp

Filament lamp	Fluorescent lamp
-Not long lasting	-Long lasting
-Cheaper	-Expensive
-Emit light by heating the filament in the bulb.	-Emit light by sending an electrical discharge through an ionized gas.
-Have high operating temperatures.	-Have low operating temperatures.
-Can easily be disposed off since the inert gasses are not poisonous.	-Care should be taken when disposing them off, since mercury vapour is poisonous.
-High energy/ power consumption, hence high energy costs.	-Low energy/ power consumption, hence low energy costs.

Qn. With the aid of diagrams, describe how a filament lamp and a fluorescent/discharge lamp work.

(b) Socket ring mains.
The sockets on the ring main circuit are connected in parallel so that they receive full main potential difference.
The use of a **ring** of wire reduces the thickness of wire which has to be used.
Both ends of the loop are connected to the fuse box.
The current, I flowing is normally 12 amperes. Thus the fuse used should be just above 12 A.

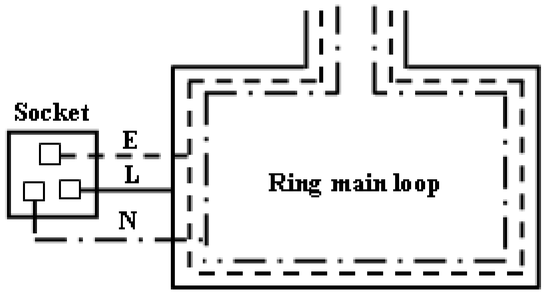
Choosing an ideal fuse for the appliance
The ideal fuse to be used should have a maximum rating which is a little higher than the normal current expected.

Example:
Suggest an appropriate fuse value to be used for a 3kW appliance when used on a 240V main supply.

P = 3kW=3000 W; V = 240 V

$$P = IV$$
$$3000 = I \times 240$$
$$240I = 3000$$
$$I = 12.5A$$

Thus the appropriate fuse should be slightly higher than 12.5A



Safety precautions in a house

- Electric cables must be properly insulated
- Keep hands dry whenever dealing with electric supply
- In case of an electric shock, switch off the main switch immediately
- Before a fuse is replaced check the fault in the circuit which caused the problem and make sure it's rectified.

Sources of e.m.f
They are;
- Cells. These change energy to electric energy
- Batteries/accumulators. Also convert chemical energy to electrical energy
- D.C and A.C. generators
- Photo cells, they convert light energy to electrical
- Thermo couples. They convert heat energy to electrical energy.

Exercise:

1. (1989 Qn. 17). How many lamps marked 75W, 240V could light normally when connected in parallel having a 5A fuse.
A: 1 B: 3 C: 16 D: 26

2. (1990 Qn.39). Very high voltages are used when distributing electric power from the power station because;
A: Some electric equipment require very high voltages
B: Currents are lower, so energy losses are smaller
C: Very high voltages are generated at the power stations
D: There is less likely hood of the transmission lines being struck by lightning.

3. (1991 Qn.7). An electric toaster plate rating is 220-240V, 750W. The fuse is:
A: 1 A B: 3 A C: 5 A D: 13 A

4. (2000 Qn. 31). For safety in a house, a fuse and a switch are connected to:

	Fuse	Switch
A	Live wire	Neutral wire
B	Neutral wire	Earth wire
C	Live wire	Live wire
D	Earth wire	Neutral wire

5. (1999 Qn. 39). Which of the following statements are true about electric wiring?
(i) The fuse is always connected into the live wire leading to the circuit.
(ii) The fuse is always connected into the Neutral wire leading to the circuit.
(iii) When a fault develops in a circuit, it is the neutral which has to be disconnected.

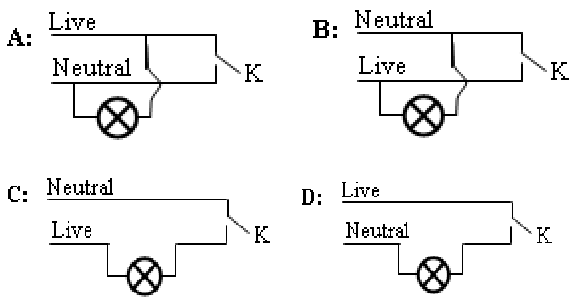
A: (i) only B: (iii) only
C: (i) and (iii) only D: (i), (ii) and (ii).

6. (2002 Qn. 18). The device which disconnects the mains when there is a sudden increase in voltage is;
A: Fuse B: Switch C: Earth wire D: Circuit breaker

7. (1992 Qn. 2). In a house wiring system, all connections to the power points are in parallel so as to:
A: Supply the same current.
B: Operate at the same voltage.
C: Minimize the cost of electricity
B: Consume the same amount of energy.

8. (2008 Qn. 17). The possible energy transfer in an electric bulb is;
A: Light energy to heat energy.
B: Heat energy to electrical energy.
C: Electrical energy to light energy.
D: Light energy to electrical energy.

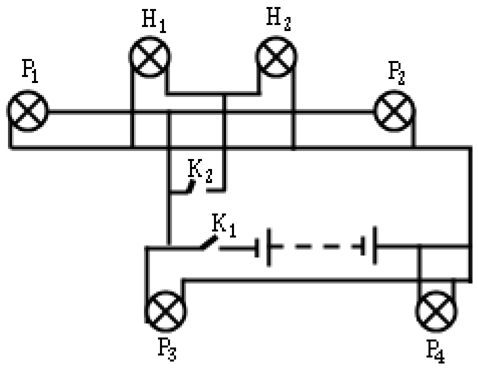
9. (1993 Qn. 33). Which of the following circuit diagrams shows the correct positions for the lamp and the switch K in a lighting circuit?



10. (1991 Qn. 7).

SECTION B

11. (1991 Qn.3). The figure below shows a circuit diagram of a part of a wiring system of a car. H_1 and H_2 are headlamps and P_1, P_2, P_3 and P_4 are parking lamps.



(a) How can;
(i) All the lamps be switched on?
(ii) Both headlamps be switched off without affecting the parking lamps.

(b) State what happens to the lamps if P1 is broken when all the lamps are on. Give a reason for your answer.

12. (2000 Qn.8). (a) Describe the structure and action of a fluorescent tube.
(b) Give **one** advantage of a fluorescent tube over a filament lamp.
(c) Describe the functions of;
(i) A fuse.
(ii) An earth wire
(d) Describe briefly how power is transmitted from a power station to a home.
(e) Find the cost of running two 60W lamps for 20 hours if the cost of each unit is sh.40.

7. MODERN PHYSICS

MODERN PHYSICS

STRUCTURE OF AN ATOM

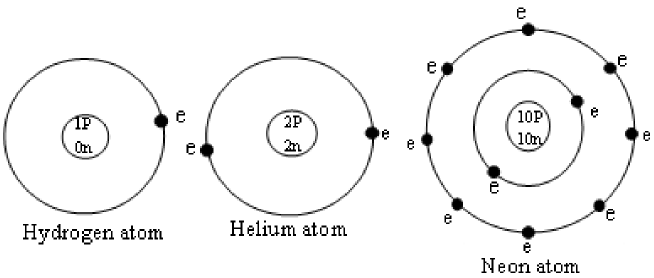
(a) The atom

An atom is defined as the smallest electrically neutral particle of an element that can take part in a chemical reaction.

An atom consists of 3sub atomic particles namely -:

- Proton
- Neutrons
- Electrons

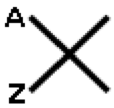
It is made up of the central part called nucleus around which electrodes rotate in orbit or shells or energy levels. The protons and neutrons lie within the nucleus and these particles are sometimes referred to as nuclei particles or **nucleons**.



Name of p'cle	Symbol	change	Location
Protons	1_H	$+1$	In the nucleus
Neutrons	0_n	0	In the nucleus
Electrons	-1_e	-1	Outside nucleus

The nucleus is positively charged

The atom of an element is represented in a chemical equation using a chemical symbol as shown below.



Where, X is the chemical symbol of the element, A is the mass number and Z is the atomic number.

An atom with specified number of protons and neutrons (or specified A and Z) is called a **nuclide**.

(b) Atomic number and mass number

(i) Atomic number (Z)

This is the number of protons in the nucleus of an atom.

(ii) Atomic mass (A)

This is the sum of protons and neutrons in a nucleus of an atom. It is sometimes called **Mass number or nucleon number.**

The atomic number, **Z**, mass number, **A** and the number of neutrons, **n** are related by the expression:

$$\textbf{Atomic mass} = \textbf{Atomic number} + \textbf{No. of nucleons}$$

$$\mathbf{A = Z + n}$$

(c) Isotopes

These are atoms of the same element having the same atomic numbers but different mass numbers.

Thus Isotopes of an element have;

(i) The same number of protons and electrons.

(ii) Different number of neutrons.

Examples of Isotopes:

Element	Isotopes
Carbon	-Carbon-12 ($^{12}_{6}\mathbf{C}$); Carbon-13 ($^{13}_{6}\mathbf{C}$); Carbon-14 ($^{14}_{6}\mathbf{C}$)
Chlorine	-Chlorine-35 ($^{35}_{17}\mathbf{Cl}$); Chlorine-35 ($^{37}_{17}\mathbf{Cl}$);
Uranium	-Uranium-35 ($^{236}_{92}\mathbf{U}$); Uranium-35 ($^{232}_{92}\mathbf{U}$)

Isotropy is the existence of atoms of the same element with the same atomic number, but different mass number.

Question:

Describe the composition of the following nuclides.

(i) $^{228}_{88}\mathbf{Ra}$ **(ii)** $^{210}_{82}\mathbf{Pb}$ **(iii)** $^{335}_{92}\mathbf{U}$

Exercise:

1. (1991 Qn. 18): $^{120}_{80}\mathbf{X}$ is a symbol for a nuclide whose number of neutrons is

   A. 40 B. 80 C. 120 D. 200

2. (1990 Qn. 7): The table below shows the numbers of the respective particles constituting atoms of elements P,Q, R and S.

Element	Neutrons	Protons	Electrons
P	0	1	1
Q	2	1	1
R	2	2	2
S	2	3	3

The isotopes are

A. P and Q C. Q and R

B. C. R and S D. Q and S

3. (1990 Qn. 11): The copper atom $^{63}_{29}\mathbf{Cu}$ has

	electrons	protons	Neutrons
A	29	29	34
B	34	34	29
C	34	29	29
D	34	39	34

4. (1991 Qn. 8): If X is an isotope of Y, then the

   A. Atomic mass of X is equal to that of Y

   B. Atomic mass is equal to the atomic number of Y

   C. Atomic number of X is equal to that of Y

   D. Atomic number of X is equal to the atomic mass of Y

5. (1994 Qn. 9): An atom has mass number 88 neutrons and atomic number 38. Which of the following statements are correct about the atom;

   (i) It has 38 protons and 50 neutrons

   (ii) It has 38 protons and 38 electrons

   (iii) It has 50 protons and 38 neutrons

   A. (i) and (ii) C. (ii) and (iii)

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

6. (1995 Qn. 18): Isotopes are nuclides with the same number of;
   A. Protons but different but different number of electrons
   B. Protons but different number of neutrons
   C. Neutrons but different number of protons
   D. Electrons but the same number of protons

7. (2004 Qn. 22): The table below shows the structure of four atoms P,Q, R and S

Elements	Neutrons	Protons	Electrons
P	6	6	6
Q	8	6	6
R	2	2	2
S	2	3	3

   A. P and Q   C. Q and R
   B. P and S   D. P and R

8. (2004 Qn. 32): An atom contains 3 electrons, 3 protons and 4 neutrons. Its' nucleon number is?
   A. 3 B. 4 C. 6 D. 7

9. (2006 Qn. 21): A Nickel nuclide, $^{60}_{28}\mathbf{Ni}$ contains
   A. 28 protons and 28 neutrons
   B. 32 electrons and 28 neutrons
   C. 28 protons and 32 neutrons
   D. 28 electrons and 32 protons

10. $^{236}_{92}\mathbf{X}$ and $^{232}_{92}\mathbf{X}$ are isotopes of an element. Find the number of neutrons in the nucleus of $^{232}_{Z}\mathbf{X}$.
   A. 144 B. 140 C. 92 D. 4

11. An isotope of nuclide, $^{35}_{17}\mathbf{X}$, has
   A. 18 protons and 17 neutrons
   B. 17 electrons and 18 neutrons
   C. 17 protons and 20 neutrons
   D. 18 protons and 18 neutrons

12. (a) What is the difference between atomic number and mass number?
(b) What is meant by;
   (i) Mass number?
   (ii) Atomic number?

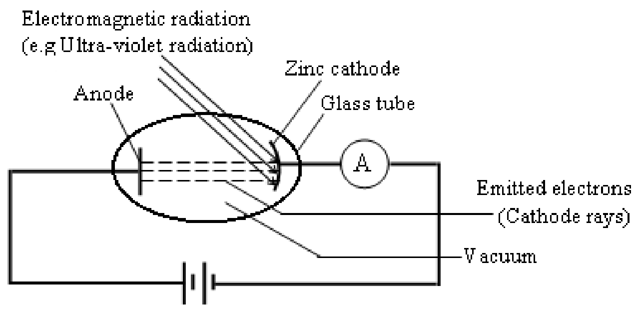
PHOTOELECTRIC AND THERMIONIC EMISSIONS

(a) Photoelectric Emission:

Photo electric emission is the ejection of electrons from a certain metal surface e.g zinc plate, when electromagnetic radiation of sufficient frequency falls on it.
It normally occurs in phototubes or photoelectric cells.

Phototube or Photoelectric cell

- ✓ A photoelectric cell consists of a cathode coated with a photo sensitive material and an anode. These are enclosed in a vacuum glass tube.
- ✓ The glass tube is evacuated in order to avoid collision of the ejected electrons with the air or gas molecules. This would otherwise lead to low currents.



Electromagnetic radiations (eg Ultra violet radiation) are directed onto the cathode and supplies sufficient energy that causes the liberation of electrons.
The electrons are then attracted by the anode. and produce current in the circuit hence the ammeter deflects.
Note: The flow of electrons to the anode completes the circuit and hence an electric current flows which causes the ammeter to deflect.

- ❖ The magnitude of the current produced is proportional to the intensity of the incident radiation.
- ❖ If gas is introduced into the tube, current decreases slowly because gas particles collide with electrons hence reducing the number of electrons reaching the anode.

<u>Conditions for photoelectric effect to take place.</u>

- ❖ Nature of the metal.
- ❖ Frequency of the incident electromagnetic radiation. It should be noted that electrons are not emitted until a certain frequency called Threshold frequency is reached.

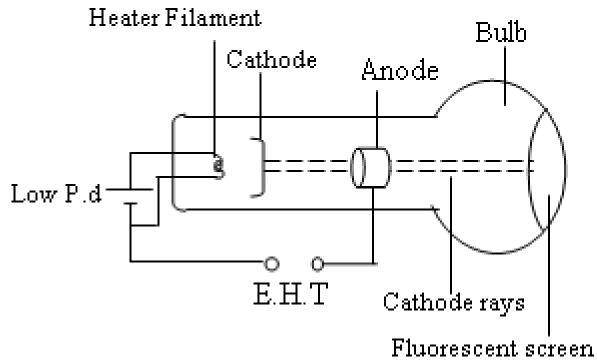
(b) Thermionic Emission:

This is the process by which electrons are emitted from metal surface by heating. The steams of electrons are transmitted or travel in a straight line and these steams are called cathode rays.

CATHODE RAYS:

Cathode rays are steams of fast moving electrons.

Production of Cathode rays:

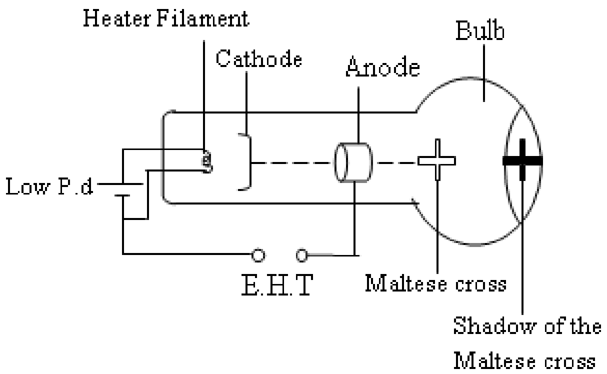


The cathode is heated by a low P.d applied across the filament.
The cathode then emits electrons by thermionic emission. The emitted electrons are then accelerated by a high p.d (E.H.T) applied between the filament and the anode so that they move with a very high speed to constitute the cathode rays.

Other methods by which cathode rays are produced are;
- Photoelectric emission
- Applying a high p.d
- By natural radioactive nucleus which emit beta particles.

Properties of cathode rays
- They travel in a straight line
- They carry a negative charge.
- They are deflected by an electric field. They are deflected towards the positive plate, since they are negatively charged.
- They are deflected by a magnetic field. In an electric field, cathode rays are deflected towards the positive plate and in the magnetic field; the direction of deflection is determined using Fleming's left hand rule. But remember, the direction of flow of current is opposite to that of electrons.
- They ionize air and gas molecules.
- They cause fluorescence to some substance e.g zinc sulphide.
- They darken photographic film.
- They posses kinetic energy and momentum
- They produce X-rays when stopped by matter.

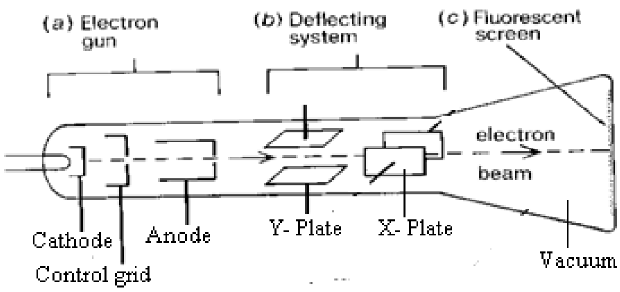
Experiment to show that cathode rays travel in straight line (Thermionic tube).



Cathode rays are incident towards the Maltese cross.
A shadow of the cross is formed on the fluorescent screen.
The formation of the shadow verifies that cathode rays travels in a straight line.

Applications of Cathode rays
The thermionic emission and cathode rays are utilized in cathode ray oscilloscope (C.R.O), X – ray tube, Image tube of a Tv, Electron microscope, etc.

THE CATHODE RAY OSCILLOSCOPE (C.R.O)
The C.R.O consists of three main components.



(a) The electron gun:
This consists of the following parts
(i) The cathode: It is used to emit electrons.
(ii) The control grid: It is connected to low voltage supply and is used to control the number of electrons passing through it towards the anode.
(iii) The anode: the anode is used to accelerate the electrons and also focus the electrons into a fine beam.

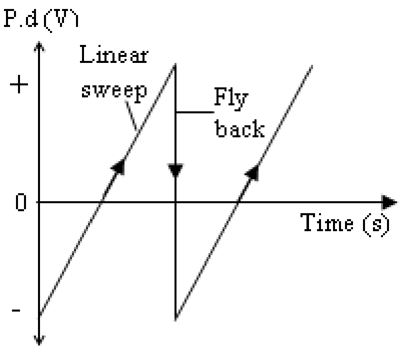
Note: Since the grid controls the number of electrons moving towards the anode. It consequently controls the brightness of the spot on the screen.

(b) Deflecting system:
This consists of the X- and Y- plates. They are used to deflect the electron beam horizontally and vertically respectively.

The X- plates are connected with the C.R.O to a special type of circuit called the time base circuit.

Time base switch: This is connected to the X – plate and is used to move the bright spot on the screen horizontally.

The Time Base or sweep generator
This is a special electrical circuit which generates a "saw tooth" voltage (i.e. a voltage p.d that rises steadily to a certain value and falls rapidly to zero.)
This p.d (time base) is connected to X-plates and causes the spot of electron beam to move across the screen from left to right, This is called a **linear sweep**.
The spot returns to the left before it starts the next sweep. This is called **fly-back.** The time for the fly back is negligible.



Note: During the fly back, the control grid is automatically made more negative thereby suppressing the brightness of the spot.

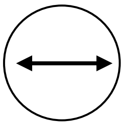
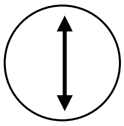
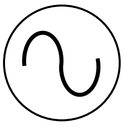
(c) Fluorescent Screen:
This is where the electron beam is focused to form a bright spot.
The coating on the screen converts kinetic energy into light energy and produce a bright spot when the electron beam is focused on it.

The graphite coating on the inner wall of the cathode ray tube traps stray electrons emitted from the screen and makes the potential in that region uniform.

Action of a C.R.O

(a) A.C out put on the screen of a C.R.O

Connecting a signal in form of alternating current (a.c) voltage across the plates has the following traces on the screen of a C.R.O.

(i) Time base off. X-plate a.c signal only.	(ii) Time base off. Y-plate a.c signal only	(iii) Time base on,. X and Y-plate a.c signals combined
		
Horizontal line at the centre	Vertical line at the centre	Sinusoidal wave

(i) When time base (x- plate) is switched on and there is no signal on the y-plate , the spot is deflected horizontally . The horizontal line is observed at the centre of the C.R.O...

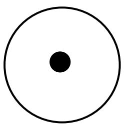
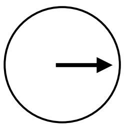
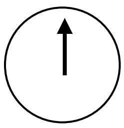
(ii) When alternating current (a.c) is applied to the y- plate and time base (x –plate) is off , the spot is deflected vertically . The vertical line observed at the centre of the C.R.O..

(iii) When a.c is applied on the y-plate and x- plate is on ,a wave form is observed on the screen.

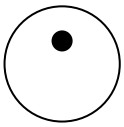
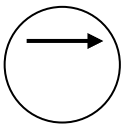
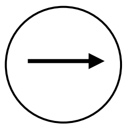
When time base is switched off , and no signal to the y-plate , a spot is only observed.

(b) D.C out put on the screen of a C.R.O

Connecting a signal in form of direct current (d.c) voltage across the plates has the following traces on the screen of a C.R.O.

(i) Time base off. No signal on the plates	(ii) Time base off. X-plate signal only	(iii) Time base off. Y-plate signal only
		
Spot at the centre	One direction horizontal line from the centre	One direction vertical line from the centre

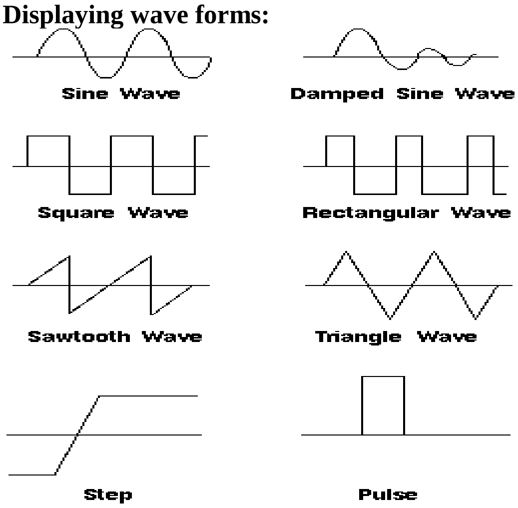
Note:

(i) Time base off. d.c signal on the Y-plates	(ii) Time base on, d.c signal on the Y-plates	(iii) Time base on. d.c signal on the X-plates
		
Spot	One direction horizontal line	One direction vertical line

Uses of a C.R O

(i) Measurement of a.c and d,c voltage
(ii) Measurement of frequency
(iii) Measurement of phase difference
(iv) Displaying pictures in TV sets.
(v) Displaying wave forms

Displaying wave forms:



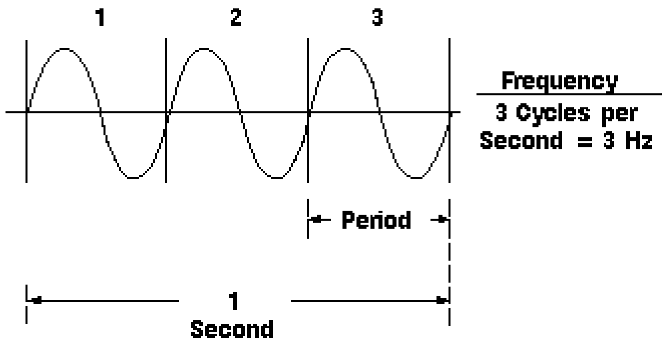
Frequency measurements

This is achieved by comparing a wave form of known frequency with unknown frequency

Method

Adjust the time base of a C.R.O until one complete wave is obtained without altering the control grid of the C.R.O , Apply a signal (input to the Y-plate) of known frequency.
A steady waveform of the input will be displayed on the c.r.o.
Then compare the frequency by counting the number of complete waves

If a signal repeats, it has a **frequency**. The frequency is measured in Hertz (Hz) and equals the number of times the signal repeats itself in one second.



Measurement of p.d

A C.R.O can be used as voltmeter because the spot is deflected depending on the p.d between the plates

Method

- Connect a cell 1.5V to the y-plate and adjust the grid control until the trace indicating the p.d is 1cm above 0 so that every 1cm deflection represents a p.d of 1.5V.

- Get unknown p.d and connect it to y-plate and then compare the deflection by counting the number of of cm deflected. This means that we can measure unknown p.d.

Measuring d.c. Potential Difference

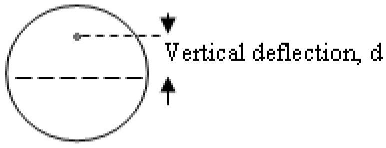
- switch off the time-base.
- a spot will be seen on the c.r.o. screen. Adjust the grid control (Y- gain control) until the trace indicating the p.d is 1cm above 0 so that every 1cm deflection represents a p.d of 1.5V
- d.c. to be measured is applied to the Y-plates.
- spot will either be deflected upwards or downwards.
- Deflection of the spot is proportional to the d.c. voltage applied. Then compare the deflection by counting the number of cm deflected. This means that we can measure unknown p.d.

Measuring d.c. Potential Difference

In this case, the voltage gain or the Y-sensitivity is set at a suitable value. Then the p.d to be measured is connected to the Y-plates and the time base is switched off.

The vertical deflection is measured and the direct voltage is got from:

$$\boldsymbol{V_{dc} = \left[\begin{matrix}Voltage\ gain\\ (\ or\ Y - sensitivity)\end{matrix}\right] \times Vertical\ deflection}$$



If the Y-gain control is set at 2 volts/division And the vertical deflection, y, is 1.5 divisions

Then d.c. voltage

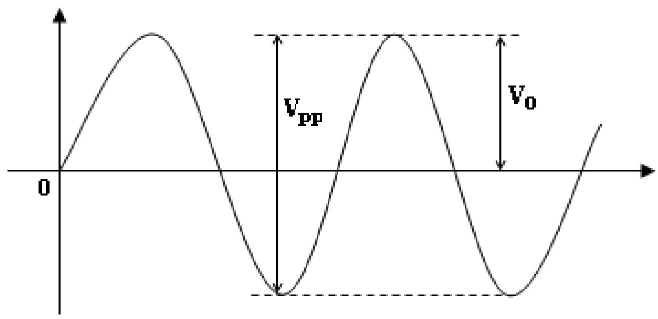
$$= 1.5 \times 2$$
$$= 3.0\,V$$

Measuring a.c. voltage

- switch off the time-base
- a spot will be seen on the c.r.o. screen.
- a.c. to be measured is applied to the Y-plates.
- spot will move up and down along the vertical axis at the same frequency as the alternating voltage.
- The spot moves to the top when the voltage increases to its maximum (positive)
- The spot moves to the bottom when the voltage decreases to its lowest (negative) .

When the frequency is high.

- The spot will move so fast that a vertical line is seen on the screen.
- Length of the vertical line gives the peak-to-peak voltage (Vpp) applied to the Y-plate.
- The peak voltage (Vp) = Vpp/2



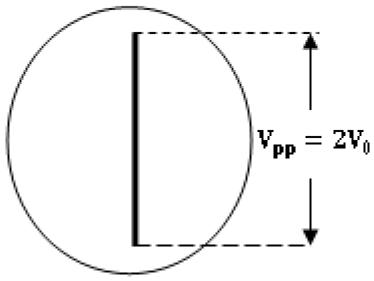
For a.c voltage

The length ***l*** of the vertical trace is measured and

$$V_{pp} = \left[\begin{matrix}\text{Voltage gain}\\ (\text{ or Y} - \text{sensitivity})\end{matrix}\right] \times \text{Vertical deflection}$$

Where$\mathbf{V_{pp}}$ is the peak to peak voltage. The maximum voltage (amplitude, V_0) is given by $\mathbf{V_0 = \frac{V_{pp}}{2}}$ and the actual voltage at root mean square (r.m.s) is given by

$$\mathbf{V_{r.m.s} = \frac{V_0}{\sqrt{2}}}$$



Example: 1

A CRO with Y-sensitivity (voltage gain) of 8Vcm^{-1} has its Y-plates connected (with the time base turned off) to:

(a) A d.c accumulator delivering 16 V,

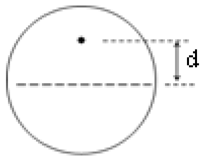
(b) An a.c voltage delivering 16 V at root mean square.

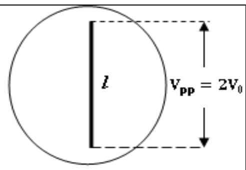
(i) Determine the deflection of the spot in (a) above and the length of a vertical line in (b) above.

(ii) Explain with a diagram what will happen if the plates are connected with time base on to a voltage in (b) above.

Solution

(a)

<table>
<tr><td></td><td>Given:
$V_{dc} = 16\text{ V}$
$\left[\begin{matrix}\text{Voltage gain}\\ (\text{ or Y sensitivity})\end{matrix}\right] = 8\text{V cm}^{-1}$</td></tr>
<tr><td colspan="2">Then from;
$V_{dc} = \left[\begin{matrix}Voltage\ gain\\ (\ or\ Y - sensitivity)\end{matrix}\right] \times Vertical\ deflection$
$16 = 8 \times d$
$d = 2\text{ cm}$
The spot will be deflected by 2 cm from the zero line.</td></tr>
<tr><td>(b)</td><td>$V_{r.m.s} = 16\text{V}$
$\left[\begin{matrix}\text{Voltage gain}\\ (\text{ or Y sensitivity})\end{matrix}\right] = 8\text{V cm}^{-1}$</td></tr>
</table>

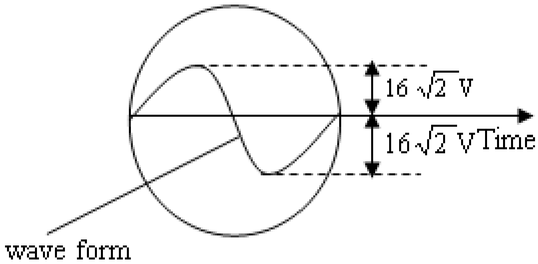


$$V_{r.m.s} = \frac{V_0}{\sqrt{2}} \Rightarrow 16 = \frac{V_0}{\sqrt{2}} \Rightarrow V_0 = 16\sqrt{2}\ \mathrm{V}$$

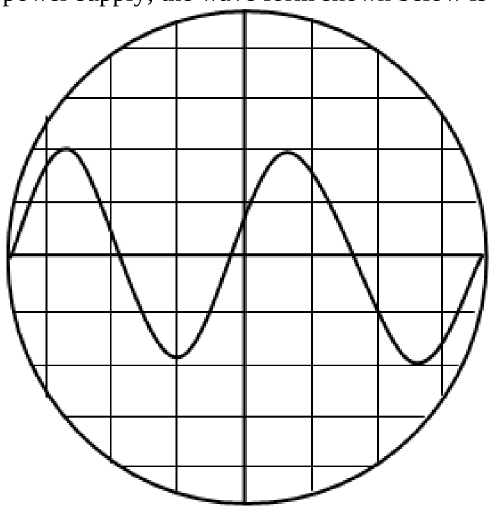
$$V_{pp} = \left[\frac{Voltage\ gain}{(\ or\ Y - sensitivity)}\right] \times Vertical\ deflection$$

$$2 \times 16\sqrt{2} = 8 \times l$$
$$\boldsymbol{l} = 4\sqrt{2}\ \mathrm{cm}$$

(ii) If the time base is on and Y-plates connected then we shall obtain the wave from below with a peak value $V_o = 16\sqrt{2}$ V



Example: 2
A C.R.O with time base switch on is connected across a power supply; the wave form shown below is obtained.



Distance between each line is 1cm

(i) Identify the type of voltage generated from the power source. **Alternating current voltage.**

(ii) Find the amplitude of voltage generated if voltage gain is 5V per cm.

Solution:

$$\left[\frac{\text{Voltage gain}}{(\text{ or Y} - \text{sensitivity})}\right] = 5\text{V cm}^{-1}$$

From the graph, Amplidude = 2 cm

$$V_0 = \left[\frac{\text{Voltage gain}}{(\text{ or Y} - \text{sensitivity})}\right] \times \text{Amplitude}$$
$$V_0 = 5 \times 2$$
$$V_0 = 10\ \text{V}$$

(iii) Calculate the frequency of power source if the time base setting on the C.R.O is 5 X 10^{-3}scm^{-1}.

Solution:

$$\left[\frac{\text{Time sensitivity,}}{(\text{Time base setting})}\right] = 5.0 \times 10^{-3}\ \text{scm}^{-1}$$

From the graph, Length for 2 cycles = 8cm
Time, t for 2 cycles =?

Time, t for 2 cycles

$$\text{Time, t} = \left[\frac{\text{Time sensitivity,}}{(\text{Time base setting})}\right] \times \text{Legnth on time axis}$$
$$\text{Time, t} = (5.0 \times 10^{-3}) \times 8$$
$$\text{Time, t} = 0.04\ \text{s}$$

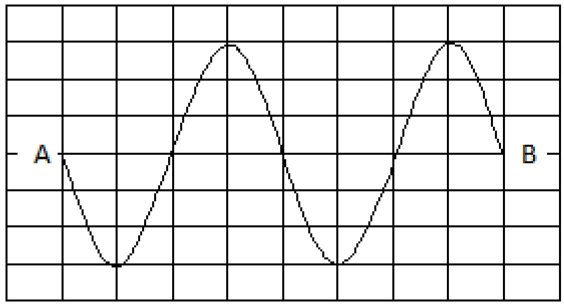
Time, T for 1 cycles (Period time, T)

$$\text{Time, T} = \frac{\text{t}}{\text{No. of cycles}} = \frac{0.04\ \text{s}}{2} = 0.02\ \text{s}$$

Frequency;

$$\text{Frequency, f} = \frac{1}{\text{T}} = \frac{1}{0.02} = 50\ \text{Hz}$$

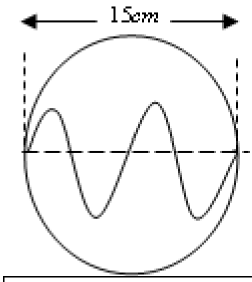
Trial Question:
A cathode oscilloscope CRO with time base switched on is connected across a power supply. The wave form shown in figure below is obtained.



The distance between each line as 1cm.

(i) Identify the type of voltage generated by the power supply.
(ii) Find the amplitude of the voltage generated if the voltage gain is 5Vcm^{-1}.
(iii) Calculate the frequency of the power source, l the time base setting on the C.R.O is 5 X 10^{-3}scm^{-1}.

Example: 3
Determine the frequency of the signal below, if the time base is set at 10 mill-second per cm.



2 cycles occupy	= 15 cm
1 cycle occupies	= 15/2 = 7.5 cm

$$\text{Period time, } T = \begin{pmatrix}\text{Legnth}\\ \text{for 1 cycle}\end{pmatrix} \times (\text{Time base setting})$$
$$\text{Period time, } T = 7.5 \times 10 \text{ ms cm}^{-1}$$
$$\text{Period time, } T = 75 \text{ ms}$$
$$\text{Period time, } T = 75 \times 10^{-3}\text{s}$$

Frequency;

$$\text{Frequency, } f = \frac{1}{T} = \frac{1}{75 \times 10^{-3}} = 13.33 \text{ Hz}$$

Note

If the CRO has no calibrated time base setting, when the unknown frequency f_2 of the signal is determined from the relation

$$\text{Since, } f \propto \frac{1}{d} \Rightarrow \mathbf{f_1 d_1 = f_2 d_2}$$

Where

d_1 – horizontal distance occupied by signal 1 for one cycle

d_2 – horizontal distance occupied by signal 2 for one cycle

f_1 – known frequency of signal at same time base setting.

Advantages of a C.R.O over an ammeter and voltmeter

(i) It has infinite resistance and therefore draws very little current from the circuit.
(ii) It can be used to measure both **a.c** and **d.c** voltages.
(iii) It has instantaneous response.
(iv) It has no coil that can burn out.

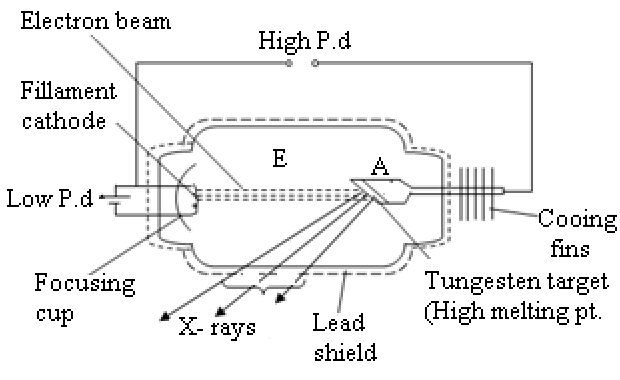
X – RAYS

These are electromagnetic radiations of short wave length. They are produced when fast moving electrons are suddenly stopped by a metal target.

The process involved in the production of X-rays is the inverse of Photoelectric emission.

Production of X-Rays

X-rays are produced in an X-ray tube.



E = Evacuated tube (or Vacuum),
A = Copper anode

The cathode is heated to emit electrons by thermionic emission .using a low voltage supply.

A high p.d is applied across the anode to accelerate the electrons towards the anode.

When the cathode rays strike the metal target, about 99% of their kinetic energy is converted to heat energy and 1% is converted to X- rays.

Energy Changes in the X-ray tube.

$$\begin{matrix}\text{Electrical}\\ \text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Heat enegy in}\\ \text{the filament}\end{matrix} \rightarrow \begin{matrix}\text{K.E of}\\ \text{electrons}\end{matrix} \rightarrow \begin{matrix}\text{E/m}\\ \text{energy}\end{matrix}$$

Note:

(i) The x – ray tube is evacuated to prevent fast moving electrons from being hindered by friction due to air resistance.
(ii) The heat generated is conducted away thru the copper anode to the cooling fins, or by use of a circulating liquid, oil or water through the hollow anode.
(iii) The curvature of the cathode helps to focus the electrons onto the anode.
(iv) The target is made of tungsten because tungsten has a very high melting point (33800).
(v) The lead shied is used to absorb stray X-rays hence preventing exposure of X-rays to un wanted regions.

Intensity of X-rays:

Intensity of X-rays refers to the number of X-rays produced.

- The intensity of X-rays increases when the filament current or heating current (the low P.d) is increased. This is because when the filament current is increased, the number of electrons hitting the target increases.
- The intensity also increases with the applied voltage across the tube since the applied voltage increases the energy with which the electrons hit the target hence increasing energy for X-ray photons.

Penetrating Power (Strength or Quality) of X-rays:

- The penetrating quality of X-Rays increases with the applied voltage across the tube
- X-rays of low frequency or low penetrating power are called **soft X-rays** and are produced when a low voltage is applied across the tube.
- If the applied voltage is high, X-rays (**hard X-rays**) of high frequency are produced.
- The penetrating power of X-rays is independent of the filament current.

Types of x – rays

(i) **Soft x –rays** are X-rays of low penetrating power i.e low frequency and long wave length produced when a low accelerating p.d is applied across the x-ray tube.

(ii) **Hard x –rays** are X-rays of high penetrating power i.e high frequency and short wave length produced when a high accelerating p.d is applied across the x-ray tube.

Properties of x- rays

- They can penetrate matter (the penetration increases with the frequency and its minimum in materials of high density e.g. lead.).
- They travel in straight lines at the speed of light.
- They are not deflected by both electric and magnetic fields since they are not charged.
- They can ionise a gas increasing its conductivity.
- They affect a photographic plate or film.
- They cause some substances to fluoresce e.g. Zinc sulphide.
- They are electromagnetic radiations of short wave length.

- They can produce photo electric emission.
- They undergo refraction, reflection and diffraction.

Health hazards of X-rays

Frequent exposure to X-rays can lead to dangers like;

- They destroy cells especially hard x- rays.
- Cause gene mutation or genetic change.
- Cause damage of eye sight and blood.
- Cause cancer eg Leukemia (cancer of the blood)
- Produce deep seated skin burns.

Safety Precautions

- Avoid unnecessary exposure to x –rays.
- Keep exposure time as short as possible.
- The x- ray beam should only be restricted to parts of the body being investigated.
- Soft X-rays should be used on human tissues.
- Workers dealing with x-rays should wear shielding jackets with a layer of lead.
- Exposure should be avoided for unborn babies and very young children.

Uses of X-rays

a) **Medicine (Hospital Use)**

- Used to investigate bone fractures.
- Detecting lung tuberculosis..
- Used to locate swallowed metal objects.
- Used to detect internal ulcers along a digestive track
- Used to treat cancer especially when it hasn't spread by radiotherapy i.e very hard x-rays are directed to the cancer cells so that the latter are destroyed.

<u>How an x-ray is used to locate broken parts of a bone .</u>

Bones are composed of much denser material than flesh hence if x- rays are passed thru the body , they are absorbed by the bones onto a photographic plate which produces a shadow of the photograph the bone that is studied to locate the broken part.

b) **Industrial use**

- Used to detect cracks in car engines and pipes.
- Used in inspection of car tyres
- Used to locate internal imperfections in welded joints e.g pipes , boilers storage tanks e.t.c.
- Used to detect cracks in building.

c) **X-ray crystallography**

- Used to determine inter – atomic spacing in the crystal. This done by using X-ray diffraction.

d) **Security:**

- X-rays are used to check luggage for potentially dangerous weapons and smuggled items at airports and custom security check point.

Differences between cathode rays and x-rays

Cathode rays	**X-rays**
Negatively charged neutral highly penetrating cannot be deflected	Have no charge
Travel at low speed	Travel at high speed
Low penetrating power	High penetrating power
Deflected by both Magnetic and electric fields	Not deflected since they have no charge.

Exercise:

1. Thermionic emission may occur when
   A. Fast moving electrons hit a metal
   B. A metal is given heat energy
   C. Metal receives light energy.
   D. A substance undergoes radioactive decay

2. Which one of the following will affect the number of electrons emitted in a thermionic tube?
   (i) The p.d between anode and cathode
   (ii) The pressure of the filament
   (iii) The current flowing in the filament circuit
   A. (i) and (ii) only   C. (i) and (iii) only
   B. (ii0 and (iii) only   D. (iii) only

3. What is the process by which electrons are emitted from a hot filament?
   A. Radioactivity
   B. Nuclear reaction
   C. Thermionic emission
   D. Thermo-electric effect

4. Which one of the following are properties of cathode rays?
   (i) They travel in straight lines
   (ii) They can penetrate a thick sheet of paper
   (iii) They darken a photographic plate
   (iv) They are deflected by a magnetic field

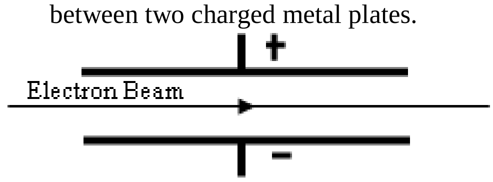
   A. (i), (iii) and (iv) only   C. (i), (ii) and (iv) only
   B. (i), (ii) and (iii) only   D. (iv) only

5. The phenomenon by which electrons are released from a metal surface when radiation falls on it is known as
   A. Radioactivity   C. Photoelectric effect
   B. Thermionic emission   D. Reflection

6. Streams of electrons moving at high speed are called?
   A. X-rays   C. Gamma rays
   B. Cathode rays   D. Alpha particles

7. The process by which electrons are emitted from the surface of a metal by application of heat is known as
   A. Photoelectric emission
   B. Electromagnetic emission
   C. Thermionic emission
   D. Heat emission

8. Fig below shows a beam of electrons incident mid way between two charged metal plates.



Which one of the following is correct? The beam
   A. Is deflected towards the positive plate
   B. Is deflected towards the negative plate
   C. Moves perpendicular to the plates
   D. Passes through the plates undetected.

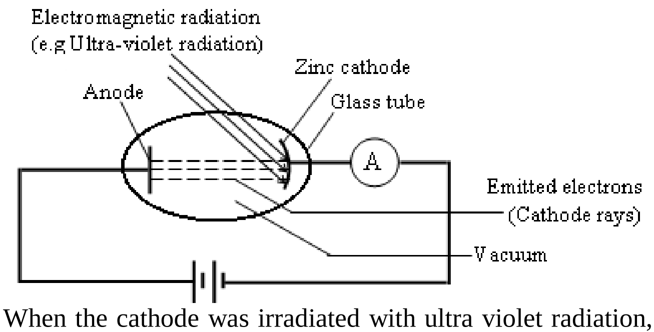
9. The particles that are emitted from a hot metal surface are called

A. Electrons C. Neutrons
B. Protons D. Alpha

10. Cathode rays are;

A. Electromagnetic waves
B. Streams of X-rays
C. Protons emitted by a hot cathode
D. Streams of electrons moving at high speed

11. A Zinc cathode was enclosed in an evacuated glass tube as shown in fig below.



When the cathode was irradiated with ultra violet radiation, the ammeter gave a reading

(i) Explain why the ammeter gave a reading.
(ii) A gas was gradually introduced into the glass tube. Explain what happened.

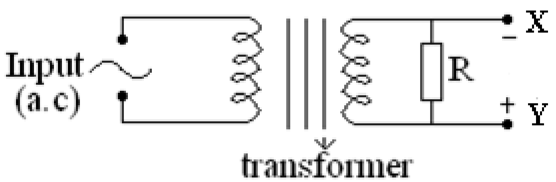
12. (a) What is meant by the following?

(i) Thermionic emission.
(ii) Photoelectric effect

(b) State the conditions necessary for photoelectric effect to occur.

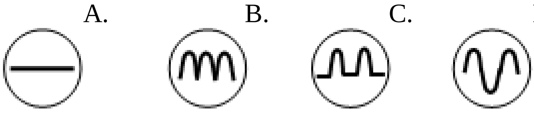
(c) With the aid of a diagram, describe how cathode rays are produced by thermionic emission.

13.



The wave form obtained when X and Y are connected to a cathode ray oscilloscope is:

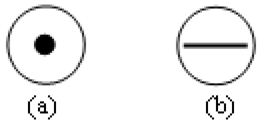
A. B. C. D.



14. A sinusoidal wave is observed on a cathode ray oscilloscope, when;

A. A cell is connected to the Y- plates with time base off.
B. A low frequency alternating voltage is connected to the Y-plates with time base on.
C. A high frequency alternating voltage is connected to the Y-plates with time base on.
D. A cell is connected to the Y- plates with the time base on.

15. The figure below, (a) shows a spot of light on the screen of a C.R.O.



The spot can be turned into a horizontal straight line shown in (b), by;

A. Switching off the time base.
B. Switching on the time base.
C. Making one of the plates positive.
D. Connecting the a.c voltage to the Y- plates

16. The cathode ray oscilloscope may be used to;

(i) Measure energy.
(ii) Measure potential difference.
(iii) Display wave forms.

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

17. Which of the following represent the appearance on the screen of a cathode ray oscilloscope when a d.c voltage is connected across the Y- plates with the time base switched on?

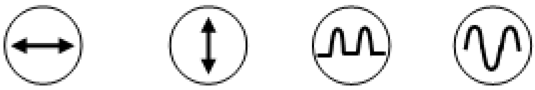
A. B. C. D.

18. The brightness on the screen of a T.V is determined by;

A. Darkness in the room.
B. Size of the screen.
C. Number of electrons reaching the screen.
D. Direction of the aerial.

19. Which one of the following sketches represents the appearance the wave form observed in a C.R.O connected across an a.c supply when the time base of the C.R.O is on?

A. B. C. D.



20. The brightness of the spot on a C.R.O screen is controlled by;

A. X – Plates. C. Grid.
B. Anode. D. Cathode.

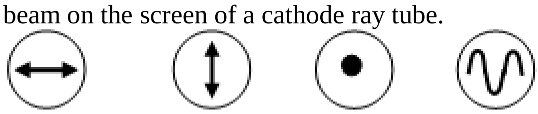
21. The X and Y – plates in a cathode ray oscilloscope make up the:

A. Electron gun. C. Deflection system
B. Focusing system. D. Accelerating system.

22. (a) (i) Draw a well labeled diagram of a cathode ray oscilloscope. (C.R.O).

(ii) State one function of each part you have labeled in (i) above.

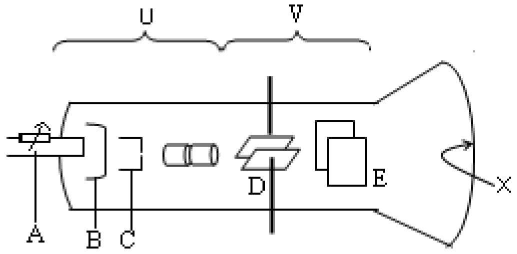
(b) The diagrams below show the traces of a cathode ray beam on the screen of a cathode ray tube.



Explain how each one may be obtained.

(c) Give two uses of a C.R.O.

23. The diagram below shows the main parts of a cathode ray oscilloscope (C.R.O).



(a) Name the parts labeled; A, B, C, D, E, U, V and X.
   (i) Explain why the C.R.O is evacuated.
   (ii) Describe briefly the principle of operation of a C.R.O.
   (iii) Describe how a bright spot is formed on the screen.

(b) Using diagrams, show what is observed when on the screen of the C.R.O when;
   (i) The CRO is switched on and no signal is applied to the Y - plates.
   (ii) The time base is switched on and no signal is applied to the Y - plates.
   (iii) An alternating signal is applied to the Y- plates while the time- box is switched off.

(c) Give two applications of a cathode ray oscilloscope.

24. Which of the following is the correct sequence of the energy conversions in an X – ray tube?

A. $\begin{matrix}\text{Electrical}\\\text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Heat}\\\text{energy}\end{matrix} \rightarrow \text{K.E} \rightarrow \begin{matrix}\text{Electro magnrtic}\\\text{energy}\end{matrix}$

B. $\begin{matrix}\text{Heat}\\\text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Electrical}\\\text{energy}\end{matrix} \rightarrow \text{K.E} \rightarrow \begin{matrix}\text{Electro magnrtic}\\\text{energy}\end{matrix}$

C. $\begin{matrix}\text{Electrical}\\\text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Heat}\\\text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Electro magnrtic}\\\text{energy}\end{matrix} \rightarrow \text{K.E}$

D. $\begin{matrix}\text{K.E}\\\text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Electrical}\\\text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Heat}\\\text{energy}\end{matrix} \rightarrow \begin{matrix}\text{Electro magnrtic}\\\text{energy}\end{matrix}$

25. Which of the following is true about X – rays?
   (i) Cause photographic emissions.
   (ii) Deflected by an electric field.
   (iii) Ionize matter
   (iv) Not deflected by a magnetic field.

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

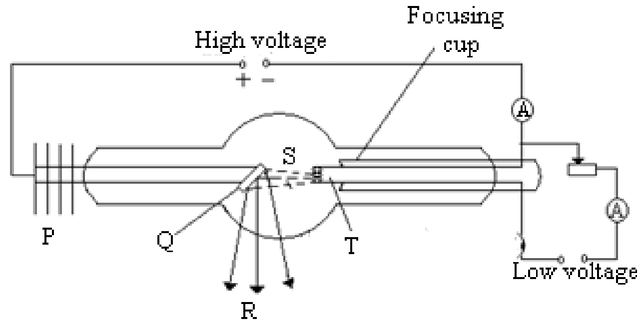
26. The following are some of the uses of X – rays except;
A. Detection of flaws in a material.
B. Detection of affected tissues in living organisms.
C. Destruction of cancer cells.
D. Preservation of cereals.

27. The difference between X – rays and ultra – violet rays is that X – rays have;
   (i) Greater velocity. (iii) Lower frequency.
   (ii) Shorter wavelength. (iv) More energy.

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

28. The difference between soft and hard X – rays is that;
A. Hard X- rays travel faster than soft X – rays.
B. Hard X – rays penetrate more than the soft X–rays.
C. Hard X – rays less dangerous than the soft X–rays.
D. Soft X – rays are produced at high potential differences.

29. The diagram below shows a hot cathode X – ray tube.



(a) Name the parts labeled P, Q, R, S and T.
(b) What is the purpose of the;
   (i) Low voltage.
   (ii) High voltage
(c) State two applications of X – rays .
(d) Explain why part Q must be cooled.

30. (a) What are X – rays?
(b) With the aid of a labeled diagram, describe the structure and mode of operation of an X – ray tube.
(c) Explain how each of the following can be increased in an X – ray tube:
   (i) Intensity of the X – rays.
   (ii) Penetrating power of the X – rays.
(d) Give two biological uses of X – rays.
(e) State any four ways in which X – rays are similar to gamma rays.

RADIOCTIVITY

Radioactivity is the spontaneous disintegration of heavy unstable nucleus to form stable nucleus accompanied by release of radiations.

Activity is the number of disintegrations (or break down emissions) per second.

The radiations emitted are:
Alpha particles ($\boldsymbol{\alpha}$), beta particle ($\boldsymbol{\beta}$) or gamma radiations ($\boldsymbol{\gamma}$). Elements that emit radiations spontaneously are said to be radioactive elements.
Radioactivity is considered as a random process because you can not tell which atoms of a molecule will disintegrate at a particular instant.

Properties of Radiations emitted

(a) Alpha particle

An alpha particle is a helium nucleus which is positively charged i.e. $^{4}_{2}\mathbf{H}$.

Properties

- It is positively charged with a charge of $+2$.
- It has a low penetrating power because of its relatively large mass and due to this; it can be stopped or absorbed by a thin sheet of paper.
- It can be deflected by both electric and magnetic fields because of its charge and it is deflected towards a negative plate.
- It has a high ionising power due to its high charge or great charge.
- It has a low range in air.

Note: When un stable nuclei emits an alpha particle, the mass number reduces by 4 and atomic number reduces by 2.
When a nuclide decays by release of an alpha particle, it loses two protons and two neutrons. This can be expressed as below:

$$\underset{\text{Parent nuclide}}{^{A}_{Z}\mathrm{X}} \longrightarrow \underset{\text{Daughter nuclide}}{^{A-4}_{Z-2}\mathrm{Y}} + \underset{\text{alpha particle}}{^{4}_{2}\mathrm{He}}$$

Example

(i) Uranium decays by emitting alpha particles to become thorium;

$$^{238}_{92}\mathrm{U} \longrightarrow {}^{206}_{82}\mathrm{Th} + {}^{4}_{2}\mathrm{He}$$

(ii) Polonium – 210 undergoes alpha decay to become lead – 206;

$$^{210}_{84}\mathrm{Po} \longrightarrow {}^{206}_{82}\mathrm{Pb} + {}^{4}_{2}\mathrm{He}$$

Question:

1. A radioactive substance $^{238}_{92}\mathbf{X}$ undergoes decay and emits an alpha particle to form nuclide Y. Write an equation for the process.

2. A radioactive substance $^{238}_{92}\mathbf{X}$ undergoes decay and emits two alpha particles to form nuclide Y. Write a balanced equation for the process.

(b) A beta particle

A beta particle is a high energy electron i.e. $^{-1}_{0}\mathbf{e}$.

Properties

- It is negatively charged with a charge of -1.
- It has a low ionising power because of its low charge (-1).
- It has a higher penetrating power because of its low mass and due to this; it can be stopped or absorbed by an aluminium foil (a few cm).
- It can also be deflected by both electric and magnetic fields at a higher angle and it is deflected towards a positive plate.
- It has a high range in air.

Note:
When a radioactive nuclei decays by emitting a beta particles. Its mass number is not affected but the atomic number increases by one.

When an element decays by emitting a beta particle, it loses an electron. This results from the decay of a neutron to a proton:

$$\underset{\text{neutron}}{^{1}_{0}\mathrm{n}} \longrightarrow \underset{\text{proton}}{^{1}_{1}\mathrm{P}} + \underset{\text{beta particle}}{^{0}_{-1}\beta}$$

Beta decay can be expressed as:

$$\underset{\text{parent nuclide}}{^{A}_{Z}\mathrm{X}} \longrightarrow \underset{\text{daughter nuclide}}{^{A}_{Z+1}\mathrm{Y}} + \underset{\text{beta particle}}{^{0}_{-1}\mathrm{e}}$$

Example

Radioactive sodium undergoes beta decay to become magnesium. This can be written as:

$$^{24}_{11}\mathrm{Na} \longrightarrow {}^{24}_{12}\mathrm{Mg} + {}^{0}_{-1}\mathrm{e}$$

Note: When a nuclide undergoes beta decay:
(i) Its atomic number increases by one.
(ii) Its atomic mass remains the same.

Questions:

1. An unstable nuclide $^{226}_{88}\mathbf{X}$ decays to form a stable nuclei **Y** by emitting a beta particle.
   (i) Write down an equation for the process.
   (ii) How would nuclide X be affected if a beta particle was emitted instead of the alpha particle?
   (iii) Compare the nature and properties of an alpha particle with those of a beta particle,

2. A radioactive nucleus $^{226}_{88}\mathbf{Ra}$ undergoes decay and emits two alpha particles and two beta particles to form nuclide **S**. State the atomic number and mass number of nuclide S.

3. (a) Consider the equation below.

$$^{210}_{82}\mathrm{X} \xrightarrow{(i)} {}^{206}_{80}\mathrm{Y} \xrightarrow{(ii)} {}^{206}_{81}\mathrm{Z}$$

Name the particle emitted at each of the stages (i) and (ii).

(c) Gamma Rays

These are neutral electromagnetic radiations with the shortest wave length.

Properties

They are neutral (not charged) and therefore can not be deflected by both electric and magnetic fields.

They have the highest penetrating power because of their light mass and due to this they can be stopped or absorbed by a lead metal or shield which has the highest density.

They can also cause ionisation of a gas by knocking off electrons from the neutral atoms but this is by small amounts.

They have the highest possible range in air.

Question:

1. (a) Describe the composition of the ${}^{23}_{11}\mathbf{Na}$ atom**.**

(b) ${}^{60}_{27}\mathbf{Co}$ is a radioisotope of Cobalt which emits a beta particle and very high energy gamma rays to form an element Y. Write a balanced equation for the nuclear reaction.

$$ {}^{60}_{27}Co \longrightarrow {}^{60}_{28}Y + {}^{0}_{-1}e + \gamma $$

2. A radioactive nuclide ${}^{230}_{90}\mathbf{X}$ emits 4 alpha particles, 2 beta particles and gamma radiations to turn into another nuclide, Y. Find the mass number and atomic number of Y.

3. A radioactive nuclide ${}^{230}_{90}\mathbf{X}$ decays to nuclide Z according to the decay process below.

$$ {}^{232}_{90}X \xrightarrow[A]{} {}^{228}_{88}Y \xrightarrow[B]{} {}^{228}_{89}Z \xrightarrow[C]{} {}^{228}_{89}Z $$

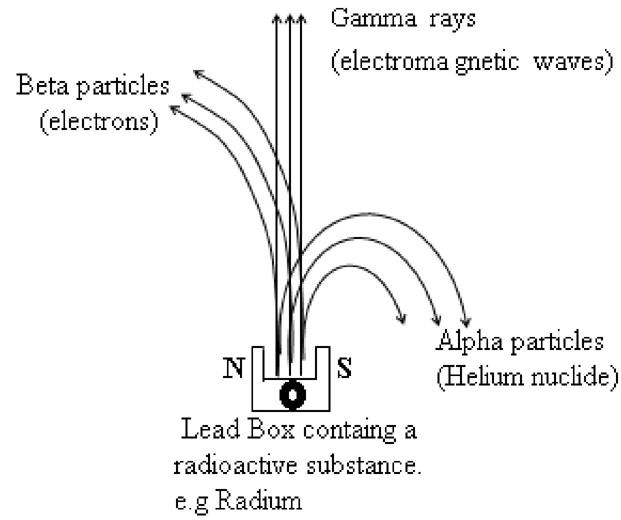
(a) Identify the particles or radiations A, B and C.
(b) State two differences between radiations A and B.

Note: In a chemical reaction or equation,

(i) The total mass number on the left must be equal to the total mass number on the right hand side.

(ii) The total atomic number on the left must be equal to the total atomic number on the right hand side.

Deflection of Alpha, Beta and Gamma radiations in electric and magnetic fields

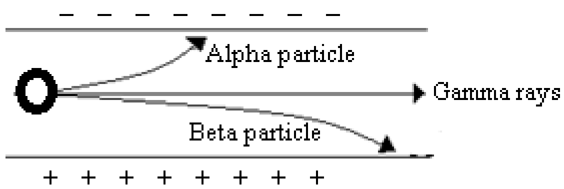


Alpha particles are deflected in a direction towards the South Pole while beta particles are deflected towards the North Pole.

Alpha particles are less deflected than beta particles implying that alpha articles are heavier than beta particles.

The gamma rays are not deflected in the magnetic field implying that they have no charge.

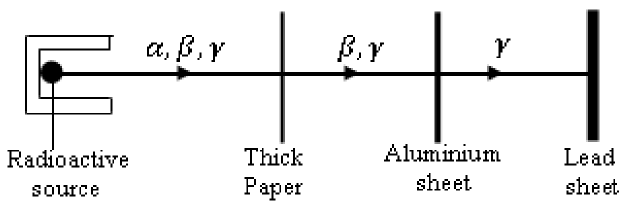
If the radiations are subjected to an electric field, the paths below are seen.



Alpha particles are deflected towards the negative plate since they are negatively charged, while beta particles are deflected towards the positive plate since they are negatively charge.

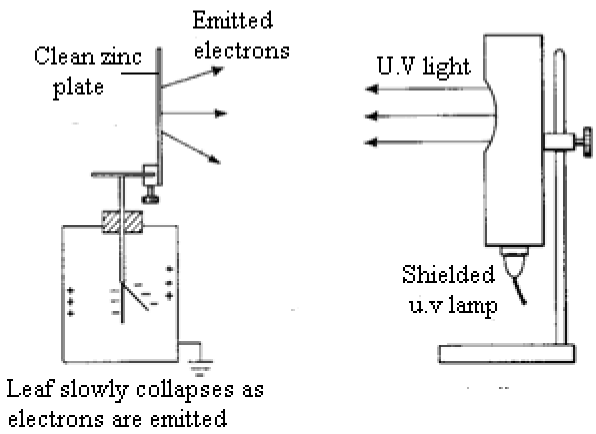
The gamma rays are not deflected in the electric field implying that they have no charge.

Penetration Power of Alpha, Beta and Gamma radiations



Ionising effects of the radiations

Ultra violent radiation is incident on a clean zinc plate resting on the cap of a charged G.L.E as shown below



- When a radioactive source is brought near the cap of a charge G.L.E , the leaf falls , this show that the G.L.E has been discharged as a of the ionization of air around the cap.
- If the G.L.E is positively charged negative ions or (electrons) from air attracted and the gold leaf falls and if is negatively charged, irons are attracted and leaf also falls.

Question:
Explain what is observed when;
(i) The G.L.E is positively charged.
(ii) Radio wave is used instead of ultra violent radiation.

Answer
(i) No further divergent of the leaf is observed because the ultra violent radiation eject electrons from the metal surface but the electrons are immediately attracted back hence no loss of charge.
(ii) Radio waves have low energy thus are unable to release electrons so there will be no effect on the leaf divergence of the electroscope.

Back ground radiation
These are radiations which are naturally existing even in the absence of radioactive source .they are caused by natural tracks of radioactive materials in rocks. Cosmic rays from outer space.
These cosmic rays are very high energetic radiated particles which come from deep in space. So the correct count rate = actual rate plus back ground count rate.

Example:
Given that the back ground rate is 2 counts per minute and the Geiger Muller count rate is 25, determine the approximate number of radiations present.

$$\text{Count rate} = 25 - 2$$
$$= 23\ \text{C min}^{-1}$$

Comparisons of the Radiations
(a) Similarities between alpha and beta particles.
- Both ionize gases.
- They both penetrate matter.
- They are both deflected by and magnetic fields.

(b) Differences between alpha and beta particles.

Property	Radiation	
	Alpha particle	**Beta particle**
Charge	Positive	Negative
Nature	Helium particles which have lost the electrons	High energy electrons
Deflection in fields	Towards negative plate and south pole	Towards positive plate and north pole
Penetrating power	Low: Penetrate thin paper but stopped by thick ones.	High: Penetrate thick paper and thin alluminium foil but stopped by thick alluminium sheets.
Ionizing power	High (Most)	Moderate
Absorbed by	Thick sheets of paper	5mm of alluminium

(c) Differences between Gamma rays and X-rays

	Gamma rays	X-rays
(i) Wave Length	Shorter wave length than X-rays.	Longer wave length than gamma rays.
(ii) Origin	From nuclei of atoms as a result of radioactivity.	From cathode rays suddenly stopped by matter.

(d) Comparison of Alpha, Beta and Gamma radiations

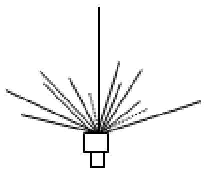
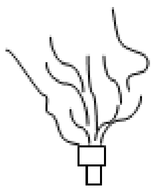
Property	Radiation		
	Alpha particle	**Beta particle**	**Gamma rays**
Charge	Positive (+2)	Negative (-1)	No charge (0)
Nature	Helium particles which have lost the electrons	High energy electrons	High energy electromagnetic radiation.
Deflection in fields	Towards negative plate and south pole	Towards positive plate and north pole	Not deflected
Penetrating power	Least	Moderate	Most
Ionizing power	Most	Moderate	Least
Absorbed by	Thick sheets of paper	5mm of alluminium	Thick sheet of lead
Range in air (in m)	0.05	3	100

Note:
(iii) Range of radiation is the maximum distance covered by a radiation in air before it is totally absorbed.
(iv) Ionisation is the process of changing the neutral atoms of a gas into positive and negative ions.

Detectors of the radiations
These include:
(i) Ionisation chamber
(ii) Geiger Muller Tube (G.M tube)
(iii) Cloud chamber (both expansion type and diffusion cloud chamber)
(iv) Scintillation counter

Cloud chamber tracks for the Alpha, Beta and Gamma radiations
When an ionising radiation from a radioactive source, enters the chamber the ions are produced.
Alcohol droplets in the cloud chamber will collect around these ions produced forming strings.
Using a strong illumination, the droplets can be photographed by using a camera.
The type of radiation depends on the thickness or length of the traces of ions formed.

Alpha particles produce, thick short, straight and continuous tracks, Beta particles produce longer but wavy tracks and Gamma rays have an irregular and faint tracks as shown below.

Alpha particle	Beta particle	Gamma rays
		
Short, straight and continuous tracks	Long and wavy tracks	Irregular and faint tracks

Dangers of radiations.
(i) Alpha particles;
Alpha particles are less dangerous unless the source enters the body.

(ii) Beta Particles and Gamma radiations:
These are very dangerous because they damage skin tissues and destroy body cells.
They cause:
(i) Radiation burns. (i.e. redness and sore on the skin).
(ii) Leukemia, (Blood cancer).
(iii) Sterility, (Inability to reproduce).
(iv) Blindness, (i.e. they damage the eye sight)
(v) Low body resistance to normal diseases, due to damage of blood corpuscles.
(vi) Mutation. (A harmful genetic change, that occurs during DNA replication and protein synthesis).
The effects of genetic mutations appear in the subsequent generations. E.g, a child may be born with one arm or both but when one is shorter than the other.

Safety precautions when dealing with radioactive sources
Radioactive sources should be handled with care. In that;
- They should be held with forceps or a pair of tongs and not with bare hands.
- Avoid eating, drinking or smoking where radioactive sources are in use.
- Radioactive sources must be kept in lead boxes when not in use.
- Wash hands thoroughly after exposing them to radioactive materials.
- Any cut on the body should be covered before dealing with radioactive sources.
- Operators should put on gloves and lead coats.
- During experiments with radioactive materials, the radiations should not be directed towards the people.

Applications of Radioactivity
(Uses of alpha , beta ,and gamma rays)
The uses in various fields are based on the following
- Gauge control and fault finding:

If a radioisotope is placed on one side of a moving sheet of material and a GM tube on the other, the count rate decreases if the thickness increases. Flows in a material can be detected in a similar way; the count-rate will increase where a flaw is present.
- Radioactive tracers:

A small amount of a weak radioisotope is injected into the system and traced by a GM tube or other detectors.
- Radiotherapy

Gamma rays are used in the treatment of cancer and detecting breakages in bones.

- Sterilization

Gamma rays are used to sterilize medical and industrial instruments and foods.

- Archaeology

Living plants and animals take in radioactive carbon. When a tree dies, no fresh carbon is taken and the carbon starts to decay. By measuring the residual activity of carbon containing material such as wood, charcoal the age of archaeological remains can be estimated.

(a) **Industrial uses:**
They are used;
- ✓ in tracer techniques to investigate the flow of liquids in chemical plants. (Identifying oil leakages in oil pipe lies).
- ✓ in the automatic control of thickness or uniformity of materials in industries. (e.g Cigarettes)
- ✓ In the study of wear and tear in machinery.
- ✓ To detect faults in thickness of metals sheets in welded joints. (gamma rays)
- ✓ in food preservations.
- ✓ to sterilize equipments in food industry
- ✓ to detect smoke
- ✓ in energy production: Nuclear reactors use radio isotopes to produce electricity.

(b) **Medical uses**
- ✓ Used to treat cancerous cells. (Radiotherapy).
- ✓ They are used to kill bacteria in food (x- rays).
- ✓ Used to sterilize medical surgical equipments.
- ✓ Locate broken bones
- ✓ Asses the amount of blood in a patient

(c) **Archeological uses**

- ✓ Used to determine the time that has elapsed since death of a certain organism occurred in a process called **carbon dating.**

(d) **Geology**

- ✓ They are used to determine the age of rocks.

(e) Biological uses

- ✓ Used to study the uptake of fertilizers by plants.
- ✓ Used to sterilize insects and hence eliminate pests that destroy crops.

(f) Defense

- ✓ Nuclear reactions of fusion and fission are used in manufacture of weapons of mass destruction like nuclear and atomic bombs.

Exercise:

1. Which one of the following radiations has the listed properties?

(i) Long range in air.
(ii) Not deflected by magnetic and electric fields.
(iii) Cause very little ionization of air molecules.

A. Alpha. C. Gamma
B. Beta. D. X - rays.

2. A radioactive source decays by emission of all the three radiation. The radiation enters normally into electric field as shown in figure 3.

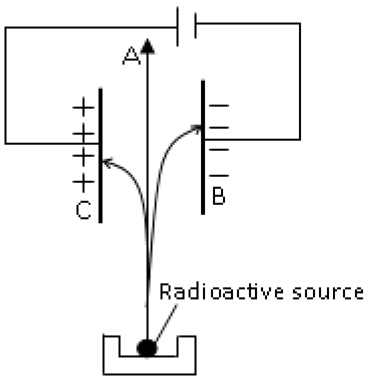
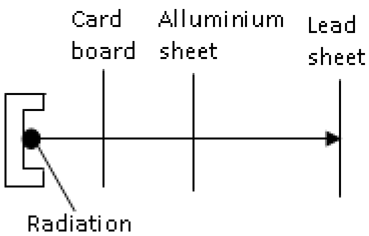


Fig. 3.

(a) Which radiation is most likely to detect at;
(i) Position A. (ii) Position B. (iii) Position C.

(b) (i) What can you deduce about the charges of the radiation?
(ii) State two differences between radiation A and B.
(iii) What happens when the radioactive source is completely covered with an ordinary sheet of paper.
(iv) Draw diagrams to show the paths of the particles named in (d) above.

(c) A radioactive source that emits all the three radiations is placed in front of the cardboard aluminum and lead sheets as shown in the figure above. Name the radiations likely to be between the card board.



(i) Cardboard and aluminum sheet.
(ii) Aluminum and the lead sheets

(d) (i) Name any three precautions which must be undertaken by one working with ionizing radiation.
(ii) Give 2 uses of radioactivity.
(iii) Name two health hazards of radioactivity.

(e) Name one;
(i) Industrial use;
(ii) Biological use of radio activity.

HALF LIFE

Half life is the time taken for a radioactive substance to decay to half of its original mass (or nuclei).

Half life can be measured in any unit of time, e.g seconds, minutes, hours, days, weeks, months and years.
It is not affected by physical factors like temperature and pressure.
It is different for different nuclides as shown for some nuclides in the table below.

Radioactive element	Symbol	Half life	Radiations
Polonium – 218	$^{218}_{84}\text{Po}$	3.05 minutes	α
Thorium – 234	$^{234}_{90}\text{Th}$	24.10 days	β, γ
Uranium – 234	$^{234}_{92}\text{U}$	2.47×10^5years	α, γ
Uranium – 238	$^{238}_{92}\text{U}$	4.51×10^9years	α, γ

Note:

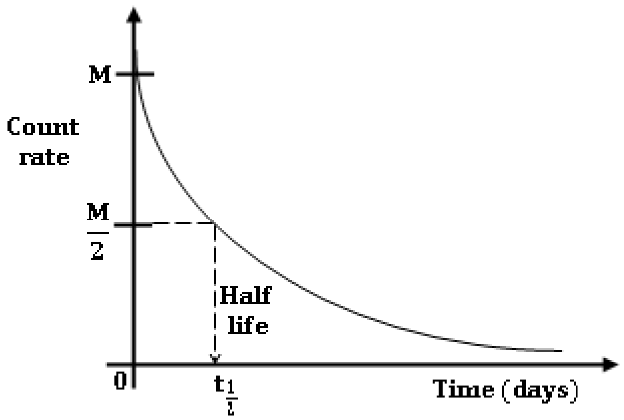
- ❖ These values are **not** to be memorized.
- ❖ The last two are called **Radioisotopes**. (Radioactive atoms of the same element with the same atomic number but different mass numbers).

Experiment to determine the half life of a radioactive nuclide.

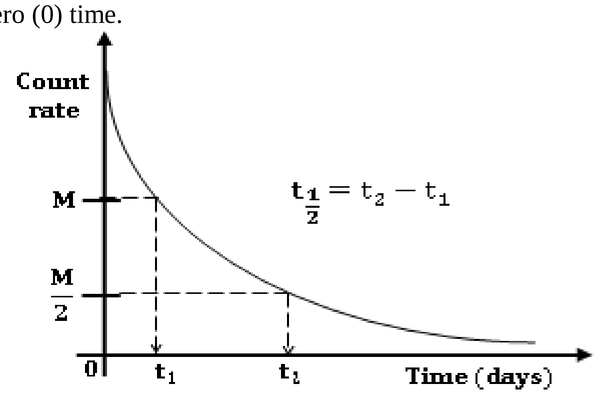
- ✓ Place the source of the radioactive nuclide into the ionization chamber or Geiger Muller tube.
- ✓ Note and record the count rate (Change in the intensity of radiations from the source with time).
- ✓ Plot a graph of intensity or number of nuclei remaining against time.
- ✓ Read off the half life from the graph.

How to read half life from the graph:

- ✓ Draw a horizontal line from half of the original amount (or count rate or original number of nuclei) to meet the curve.
- ✓ Draw a vertical line from the point on the curve to meet the time axis.
- ✓ Read the value of half life from where the vertical line meets the time axis.



In some cases, the original mass may not coincide with the zero (0) time.



Calculations of Half life:

Method I: Using a table

Time Taken, t	**Mass remaining, M_t**	**Mass Decayed $M_D = M_o - M_t$**
0	M_0	0
$t_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^1$	
$2t_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^2$	
$3t_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^3$	
-	-	
-	-	
$nt_{\frac{1}{2}}$	$M_o\left(\frac{1}{2}\right)^n$	

Where: $\mathbf{nt_{\frac{1}{2}} = t}$

Method II: Arrow Diagram (Crude method)

$$M_0 \xrightarrow{t_{\frac{1}{2}}} \frac{1}{2}M_0 \xrightarrow{t_{\frac{1}{2}}} \frac{1}{4}M_0 \xrightarrow{t_{\frac{1}{2}}} \frac{1}{8}M_0$$

$t = t_{\frac{1}{2}}$

$t = 2t_{\frac{1}{2}}$

$t = 3t_{\frac{1}{2}}$

The total time taken for the required amount to decay, is given by; $\mathbf{t = nt_{\frac{1}{2}}}$

Where, **n** is the number of half lives in a time, **t**

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n : Where, \ n = \frac{t}{t_{\frac{1}{2}}}}$$

Case I: Finding the half life when the final mass, M and time taken, t are given,.

- In this method, we continuously half the initial count rate or initial mass until the given count rate or final mass.
- Then we use the formula; $\mathbf{t = nt_{\frac{1}{2}}}$. Where, t is the time taken for the decal to half, $t_{\frac{1}{2}}$ is the half life and n is the number of half lives.

Example 1:

(1994 Qn. 15): The count rate of a radioactive isotope falls from 600 counts per second to 75 counts per second in 75 minutes. Find the half life of the radio isotope.

Solution:

Method I: Using a table

$M_0 = 600\ Cs^{-1}$; $M_t = 75\ Cs^{-1}$; $t = 75s$

Count rate(Cs^{-1})	Number of half- lives, n
$M_0 = 600$	0
300	1
150	2
$M_t = 75$	3

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$3t_{\frac{1}{2}} = 75.$

$t_{\frac{1}{2}} = 25$ minutes

Method II: Arrow Diagram (Crude method)

$$600 \xrightarrow{1t_{\frac{1}{2}}} 300 \xrightarrow{2t_{\frac{1}{2}}} 150 \xrightarrow{3t_{\frac{1}{2}}} 75$$

$\mathbf{t = 75\ minutes}$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$3t_{\frac{1}{2}} = 75.$

$t_{\frac{1}{2}} = 25$ minutes

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n : Where, \ n = \frac{t}{t_{\frac{1}{2}}}}$$

$M_t = M_o\left(\frac{1}{2}\right)^n$:

$75 = 600\left(\frac{1}{2}\right)^n$:

$75 = 600(2^{-1})^n$

$$(2)^{-n} = \frac{75}{600}$$

$$2^{-n} = \frac{1}{8}$$

$$2^{-n} = 2^{-3}$$

$$-n = -3$$
$$n = 3$$

Alternatively; At the stage of;

$$2^{-n} = \frac{1}{8}$$

Introducing logarithms to base 10 on both sides;

$\log 2^{-n} = \log 0.125$

$-n \log 2 = \log 0.125$

$-n = \dfrac{\log 0.125}{\log 2}$

$-n = -3$

$n = 3$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$$3t_{\frac{1}{2}} = 75.$$
$$t_{\frac{1}{2}} = 25 \text{ minutes}$$

Example 2:

(1987 Qn. 6): After 18 hours, a sixteenth of the original mass of a radioactive isotope remained. What is the half life of the isotope.

Solution:

Method I: Using a table

Let the initial amount be N;

$N = ?$; $N_t = \frac{N}{16}$; $t = 18$ Hours

Mass	Number of half- lives, n
$M_0 =$ N	0
$\frac{N}{2}$	$1\mathbf{t_{\frac{1}{2}}}$
$\frac{N}{4}$	$2\mathbf{t_{\frac{1}{2}}}$
$\frac{N}{8}$	$\mathbf{3t_{\frac{1}{2}}}$
$M_t = \frac{N}{16}$	$4\mathbf{t_{\frac{1}{2}}}$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$$4t_{\frac{1}{2}} = 18.$$
$$t_{\frac{1}{2}} = 4.5 \text{ hours}$$

Method II: Arrow Diagram (Crude method)

$$N \xrightarrow{1\mathbf{t_{\frac{1}{2}}}} \frac{\mathbf{N}}{\mathbf{2}} \xrightarrow{2\mathbf{t_{\frac{1}{2}}}} \frac{\mathbf{N}}{\mathbf{4}} \xrightarrow{3\mathbf{t_{\frac{1}{2}}}} \frac{\mathbf{N}}{\mathbf{8}} \xrightarrow{4\mathbf{t_{\frac{1}{2}}}} \frac{\mathbf{N}}{\mathbf{16}}$$

$$\mathbf{t = 18 \text{ Hours}}$$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$$4t_{\frac{1}{2}} = 18.$$
$$t_{\frac{1}{2}} = 4.5 \text{ hours}$$

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n}$**: Where,** $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$

$N_t = N\left(\frac{1}{2}\right)^n$:

$\frac{N}{16} = N\left(\frac{1}{2}\right)^n$:

$$\frac{1}{16} = \left(\frac{1}{2}\right)^n$$

$$2^{-n} = 2^{-4}$$

$$-n = -4$$
$$n = 4$$

Alternatively; At the stage of;

$$2^{-n} = \frac{1}{16}$$

Introducing logarithms to base 10 on both sides;

$\log 2^{-n} = \log 0.0625$

$-n \log 2 = \log 0.0625$

$-n = \dfrac{\log 0.0625}{\log 2}$

$-n = -4$

$n = 4$

Then from; $\mathbf{nt_{\frac{1}{2}} = t}$.

$$4t_{\frac{1}{2}} = 18.$$
$$t_{\frac{1}{2}} = 4.5 \text{ hours}$$

Case II: Finding the mass left when half life and time taken are given

- ❖ Half the original mass continuously until we reach the time given.
- ❖ The mass that corresponds to the time given is the mass left.

Example 3:

(1994 Qn. 6): The half life of a radioactive element is 2 minutes. What fraction of the initial mass is left after 8 minutes?

Solution:

Method I: Using a table

Let the initial amount be N;

$N = ?$; $N_t = \frac{N}{16}$; $t_{\frac{1}{2}} = 2$ minutes; $t = 8$ minutes;

Mass	Number of half- lives, n	Time taken, t (minutes)
$M_0 =$ N	0	0
$\frac{1}{2}$N	$1\mathbf{t_{\frac{1}{2}}}$	2
$\frac{1}{4}$N	$2\mathbf{t_{\frac{1}{2}}}$	4
$\frac{1}{8}$N	$3\mathbf{t_{\frac{1}{2}}}$	6
$M_t = \mathbf{\frac{1}{16}}$N	$4\mathbf{t_{\frac{1}{2}}}$	**8**

From the table, the fraction left after 8 minutes $= \dfrac{1}{16}$

Method II: Arrow Diagram (Crude method)

$$N \xrightarrow{1t_{\frac{1}{2}}} \frac{N}{2} \xrightarrow{2t_{\frac{1}{2}}} \frac{N}{4} \xrightarrow{3t_{\frac{1}{2}}} \frac{N}{8} \xrightarrow{4t_{\frac{1}{2}}} \frac{N}{16}$$

$$t = 8 \text{ minutes}$$

$$N \xrightarrow{2} \frac{N}{2} \xrightarrow{4} \frac{N}{4} \xrightarrow{6} \frac{N}{8} \xrightarrow{8} \frac{N}{16}$$

$$t = 8 \text{ minutes}$$

From the above, the fraction left after 8 minutes $= \frac{1}{16}$

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$\mathbf{M_t = M_o \left(\frac{1}{2}\right)^n}$ **: Where,** $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$

$$n = \frac{t}{t_{\frac{1}{2}}} = \frac{8}{2} = 4$$

$$N_t = N\left(\frac{1}{2}\right)^n :$$

$$N_t = N\left(\frac{1}{2}\right)^4 :$$

$$\frac{N_t}{N} = \left(\frac{1}{2}\right)^4$$

$$\frac{N_t}{N} = \frac{1}{16}$$

Thus, the fraction left after 8 minutes $= \frac{1}{16}$

Example 4:

(1994 Qn. 6): The half life of Uranium is 24 days. Calculate the mass of Uranium that remains after 120 days if the initial mass is 64g.

Solution:

Method I: Using a table

Let the initial amount be N;

$M_0 = 64\text{ g}$; $M_t = ?$; $t_{\frac{1}{2}} = 24$ days; $t = 120$ days;

Mass (g)	Number of half- lives, n	Time taken, t (days)
$M_0 = 64$	0	0
32	$1\mathbf{t_{\frac{1}{2}}}$	24
16	$2\mathbf{t_{\frac{1}{2}}}$	48
8	$3\mathbf{t_{\frac{1}{2}}}$	72
4	$4\mathbf{t_{\frac{1}{2}}}$	96
$M_t =$ **2**	$5\mathbf{t_{\frac{1}{2}}}$	**120**

From the table, the mass left after 120 days $= \mathbf{2\ g}$

Method II: Arrow Diagram (Crude method)

Try using the crude method, you will still get themass left after 120 days $= \mathbf{2\ g}$

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$\mathbf{M_t = M_o \left(\frac{1}{2}\right)^n}$ **: Where,** $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$

$$n = \frac{t}{t_{\frac{1}{2}}} = \frac{120}{24} = 5$$

$$N_t = N\left(\frac{1}{2}\right)^n :$$

$$N_t = 64 \times \left(\frac{1}{2}\right)^5 :$$

$$N_t = 64 \times \frac{1}{32}$$

$$N_t = 2 :$$

Thus, the mass left after 120 days = 2 g

Case III: Finding the mass decayed when half life and time taken are given

- Half the original mass continuously until we reach the time given.
- The mass that corresponds to the time given is the mass left.
- Find the mass decayed from the expression:

Mass decayed = Original mass − Mass left

Where**:** Original mass = mass at a time t = 0.

Mass left = mass corresponding to the given time

Example 5:

(2001 Qn. 4) (e) : The half life of a radioactive substance is 24 days. Calculate the mass of the substance which has decayed after 72 days, if the original mass is 0.64g.

Solution:

Method I: Using a table

Let the initial amount be N;

$M_0 = 0.64\text{ g}$; $M_t = ?$; $t_{\frac{1}{2}} = 24$ days; $t = 72$ days;

Mass (g)	Number of half- lives, n	Time taken, t (days)
$M_0 = 0.64$	0	0
0.32	$1\mathbf{t_{\frac{1}{2}}}$	24
0.16	$2\mathbf{t_{\frac{1}{2}}}$	48
$M_t = 0.08$	$3\mathbf{t_{\frac{1}{2}}}$	72

From the table, the mass left after 72 days = 0.08 g

Mass decayed = Original mass − Mass left

Mass decayed = 0.64 − 0.08

Mass decayed $= \mathbf{0.56\ g}$

Method II: Arrow Diagram (Crude method)

Try using the crude method, you will still get the mass left after 72 days $= \mathbf{0.08\ g}$ and Mass decayed $= \mathbf{0.56\ g}$

Method III: Using the formula

The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by;

$$\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n : Where,\ n = \frac{t}{t_{\frac{1}{2}}}}$$

$$n = \frac{t}{t_{\frac{1}{2}}} = \frac{72}{24} = 3$$

$$N_t = N\left(\frac{1}{2}\right)^n \quad :$$

$$N_t = 0.64 \times \left(\frac{1}{2}\right)^3 :$$

$$N_t = 0.64 \times \frac{1}{8}$$

$$N_t = 0.08 \quad :$$

$$\text{Thus, the mass left after 72 days} = 0.08\ g$$

$$\mathbf{Mass\ decayed = Original\ mass - Mass\ left}$$

$$\text{Mass decayed} = 0.64 - 0.08$$

$$\text{Mass decayed} = \mathbf{0.56\ g}$$

Example 6:

(2002 Qn. 23): The half life of a radio active substance is 10s. How long will it take for a mass of of 16g of the substance to reduce to 2g? **[Ans: t = 30s].**

Example 7:

(2008. Qn.8) (c): A radioactive element has a half life of 4 minutes. Given that the original count rate is 256 counts per minute,

(i) Find the time taken to reach a count rate of 16 counts per minute. **[Ans: t = 16 minutes]**

(ii) What fraction of the original number of atoms will be left by the time the count rate is 16 counts per minute?

[Ans: Fraction left $= \frac{1}{16}$**]**

Example 8:

(a) The table below shows results obtained in an experiment to determine the half life of a radioactive substance.

Count rate	250	175	76	38	25
Time (min.)	0	5	10	15	20

Draw a graph of count rate against time and use it to determine the half life of the radioactive substance.

(b) Explain why radioactive substances must be stored in thick lead containers.

(c) The nuclide $^{220}_{84}\mathbf{X}$ has a half life of 3000 years and decays to nuclide Y by emission of an alpha particle. and three beta particles

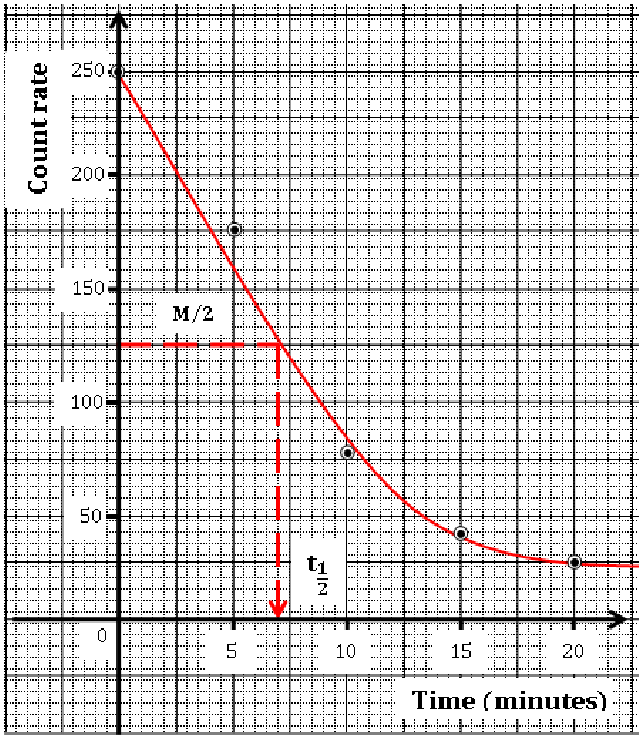
(i) State the meaning of the statement "Half- life of a nuclide is 3000 years."

(ii) Write a balanced equation for the decay process.

(iii) What percentage of the original sample of the nuclide, remains after three half lives.

Solution:

(a)



From the graph above, half life,

$$t_{\frac{1}{2}} = 5 + 4(0.5)$$

$$= \mathbf{7minutes}$$

(b) Radioactive materials emit radiations, alpha, beta particles and gamma rays which are harmful to human life. Lead containers absorb these radiations and prevent them from coming into contact with people.

(c) (i) The element takes 3000 years to decay to half its original mass.

(ii)

$$^{220}_{84}X \longrightarrow {}^{216}_{85}Y + {}^{4}_{2}He + 3\,{}^{0}_{-1}e$$

(iii)

Method I: Using a table

%age mass	Number of half- lives
100	0
50	1
25	2
12.5	3

Therefore, 12.5% of the original mass will remain after 3 half lives.

Method II: Arrow Diagram (Crude method)

$$220 \xrightarrow{t_{\frac{1}{2}}} 110 \xrightarrow{t_{\frac{1}{2}}} 55 \xrightarrow{t_{\frac{1}{2}}} 27.5$$

Thus the percentage of the original sample that remains after 3 half lives is given by;

$$= \frac{\text{Mass left}}{\text{Original mass}} \times 100\%$$

$$= \frac{27.5}{220} \times 100\%$$

$$= 12.5\%$$

Method III: Using the formula
The mass remaining after a time t, M_t, when an original sample of mass M_o decays with a half- life of $t_{\frac{1}{2}}$ is given by; $\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n}$ **: Where,** $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$

$M_t = M_o\left(\frac{1}{2}\right)^n$: $M_t = 220\left(\frac{1}{2}\right)^3$: $M_t = 220 \times \frac{1}{8}$: $M_t = 27.5\ g$	Thus the percentage of the original sample that remains after 3 half lives is given by; $= \frac{\text{Mass left}}{\text{Original mass}} \times 100\%$ $= \frac{27.5}{220} \times 100\%$ $= 12.5\%$

Exercise:

1. If a radioactive element of mass 32 decays to 2g in 96days .calculate the half life.

2. A certain radioactive substance takes 120years to decay from 2g to 0.125g. Find the half life.

3. The half life of substance is 5days. Find how long it takes for its mass to disintegrate from 64g to 2g.

4. A radioactive sample has a half life of 3×10^3 years. Find how long it takes for three quarters of the sample to decay.

5. The activity of a radioactive element with a half life of 30 days is 2400 counts per second. Find the activity of the element after 120 days.

6. The count rate from a radioactive source is 138 counts per minute when the back ground rate is 10 counts per minute. If the half life of the source is 6 days, find the count rate after 18 days.

7. A radioactive element has a half life of 4years .if after 24hours 0.15g remains calculate the initial mass of the radioactive material.

8. A certain mass of a radioactive material contains 2.7×10^{24} atoms, how many atoms decayed after 3200years if the half life of material is 1600years?

[**Ans:** 2.025×10^{24} atoms]

9. (a) The activity of a radioactive source decreases from 4000 counts per minute to 250 counts per minute in 40 minutes. What is the half life of the source?

(b) A carbon source initially contains 8×10^6 atoms. Calculate the time taken for 7.75×10^6 atoms to decay.

10. The table below shows the count rates of a certain radioactive material.

Count rate (s^{-1})	6400	5380	3810	2700	1910	1350
Time (min)	0	1	3	4	7	9

Plot a suitable graph and use it to find the half life of the material.

11. The following values obtained from the readings of a rate meter from a radioactive isotope of iodine

Time (min)	0	5	10	15	20
Count rate (min^{-1})	295	158	86	47	25

Plot a suitable graph and find the half life of the radioactive iodine.

12. The following figures were obtained from Geiger miller counter due to ignition if the sample of radon gas

Time (min)	0	102	155	….	300
Rate (min^{-1})	1600	…	200	100	50

(a) i) Plot a graph of count rate against time
ii) determine the half life
iii) Find the missing values

(b) (i) what is the count rate after 200 minutes
(ii) after how many minutes is the count rate 1000 minutes

13. The following figures were obtained from Geiger miler counter due to ignition of the sample of radon gas

Time (min)	0	102	155	208	300
Rate (min^{-1})	1600	1400	200	100	50

a) Plot a graph of count rate against time.
b) Determine the half life.
c) What is the count rate after 200 minutes?
d) After how many minutes is the count rate 1000 minutes?

NUCLEAR REACTIONS:

A **nuclear reaction** is a process in which energy is produced by either splitting a heavy nucleus or combining two lighter nuclei at high temperatures.
A nuclear reaction takes place in a nuclear reactor.

Types of nuclear reactions:

(i) Nuclear fission

This is the splitting of a heavy unstable nucleus into two lighter nuclei with the release of energy.
This process can be started by bombardment of a heavy nucleus with a fast moving neutron. The products of the process are two light atom and more neutrons which can make the process continue.

Example:
When Uranium – 235 is bombarded with slow moving neutrons, Uranium – 236 is formed.
Uranium – 236 then under goes nuclear fission to form Barium, (Ba) and Krypton, (Kr) with the release of neutrons and energy according to the equation below.

$$\mathbf{{}^{235}_{92}U + {}^{1}_{0}n \rightarrow {}^{236}_{92}U \rightarrow {}^{144}_{56}Ba + {}^{92}_{36}Kr + 2{}^{1}_{0}n + Energy}$$

The energy released in a single nuclear fission reaction of a single Uranium atom is about **200 MeV.**

Conditions for nuclear fission to occur:
- Low temperatures.
- Fast moving neutrons

Application of nuclear fission:
- Used in making atomic bombs.

- Used to generate electricity.
- Used to generate heat energy on large scale.

Note: Nuclear reactors make use of controlled nuclear fission while **atomic bombs** make use of un controlled nuclear fission.

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(ii) **Nuclear fusion:**

This is the union (or combining) of two light nuclei at high temperatures to form a heavy nucleus with the release of energy.

Example:

When two Deuterium (Heavy hydrogen) nuclei combine at very high temperature (of about 10^8K), Helium – 3 and a neutron are produced accompanied by the release of energy according to the equation below.

$$\mathbf{{}^{2}_{1}H + {}^{2}_{1}H \rightarrow {}^{3}_{2}He + {}^{1}_{0}n + Energy}$$

Reactions of this type occur in the in the sun and stars and are the source of the sun's or star's energy.

Conditions for nuclear fission to occur:

- Very high temperatures.
- The light nuclei should be at very high speed to over nuclear division.

Application of nuclear fission:

- Used to produce hydrogen.
- Used in making atomic bombs.
- Used to generate electricity.
- Used to generate heat energy on large scale.

Similarities between nuclear fission and nuclear fusion.

- In both nuclear reactions, nuclear energy is released which can be used to generate electricity, heat or in atomic bombs.
- Energy changes in a nuclear reactor:

$$\begin{pmatrix}\text{Nuclear}\\\text{energy}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Chemical}\\\text{energy}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Kinetic}\\\text{energy}\end{pmatrix} \rightarrow \begin{pmatrix}\text{Electrical}\\\text{energy}\end{pmatrix}$$

Differences between nuclear fission and nuclear fusion.

Nuclear fission	**Nuclear fusion**
Is the disintegration of a heavy nucleus into two lighter nuclei..	Is the combining of two lighter nuclei to form a heavy nucleus.
Requires low temperature.	Requires high temperatures
Requires slow neutrons for bombardment	Neutrons are not required. For fusion to occur
High energy is released	Lower energy is released
Results into 4 products	Results into 3 products

Exercise:

1. (a) What is meant by radio activity?

(b) The equation below shows a reaction which takes place in a nuclear reactor.

$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{236}_{92}\text{U} \rightarrow {}^{141}_{x}\text{Ba} + {}^{y}_{36}\text{Kr} + 3{}^{1}_{0}\text{n} + \text{Energy}$$

(i) Name the reaction represented by the equation
(ii) Find the values of x and y.

2. **(1991 Qn. 1).** The process whereby the nuclei of alight elements combine to form a heavy nuclei is called?

A. Fission B. Fusion
C. Ionisation D. Radioactivity

3. **(1993 Qn. 22).** The process by which a heavy nucleus split to form lighter nuclei is called?

A. Fission B. Fusion
C. Ionisation D. Radioactivity

4. **(1994 Qn. 18).** ${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{144}_{56}\text{Ba} + {}^{92}_{36}\text{Kr} + 2x$

The equation above represents a nuclear reaction. Identify ***x.***

A. Proton B. Neutron
C. Alpha particle D. Beta particle

5. **(2000 Qn. 7).** In the atomic bomb, energy is produced by:

A. Fission B. Fusion
C. Thermionic emission D. Radioactivity

6. **(2001 Qn. 17).** When Uranium – 235 is bombarded with a neutron, it splits according to the equation;

$${}^{235}_{92}\text{U} + {}^{1}_{0}\text{n} \rightarrow {}^{\text{M}}_{\text{N}}\mathbf{P} + {}^{92}_{36}\text{Kr} + 3{}^{1}_{0}\text{n}$$

M and N on P represent;

	M	N
A	56	141
B	141	56
C	199	36
D	107	128

7. (a) (i) Distinguish between nuclear fission and nuclear fusion.

(ii) two conditions necessary for each to occur.

(b) State **one** example where nuclear fusion occurs naturally.
(c) State **one** use of nuclear fission.

(d) The following nuclear reaction takes place when a neutron bombards a sulphur atom.

$$\mathbf{{}^{34}_{6}S \quad + \quad {}^{1}_{0}n \quad \rightarrow \quad {}^{a}_{b}Y}$$

(i) Describe the composition of nuclide Y formed.
(ii) Nuclide Y decays by emission of an alpha particle and a gamma ray. Find the changes in mass and atomic number of the nuclide.

8. MAGNETISM AND ELECTROMAGNETISM

MAGNETISM

Magnetism is the force exerted by a magnetic field.
A **magnet** is a piece of metal that attracts other metals. It has two poles i.e. North Pole and South Pole.
A magnet is a substance which has the capacity of attracting and holding the other substance e.g iron, steel, Nickel etc.

Examples of magnets include Lodestone magnet, which is a form of Iron (ii) oxide called magnetite which is a naturally occurring magnet.
It always points in north and south directions if it is freely suspended.

Types of material	**Definition and magnetic properties.**	**Examples**
(a) Magnetic material	This is a material which has the property of being attracted or repelled by a magnet.	iron, steel, nickel, e.t.c.
(i)Ferro-magnetic materials	These are materials which are strongly attracted by a magnet. ❖ Their magnetic dipoles line up more readily. ❖ When placed in a magnetic field, they retain their magnetism after the external field is removed.	iron, cobalt and nickel, Gadolinium (Gd)
(ii)Non Ferro-magnetic materials.,	These are materials which are weakly attracted by a magnet? e.g. iron, cobalt and nickel	
❖ Para-magnetic materials	These are materials that are slightly or weakly attracted by a strong magnetic field. ❖ They become more magnetic when they are very cold.	Aluminium, Wood, brass, copper, platinum, uraniumetc.
❖ Dia-magnetic materials	These are materials that are weakly repelled by a strong magnetic field ❖ When in a strong magnetic field, they become weakly magnetized in a direction opposite to the magnetizing field.	Zinc,, gold, Bismuth, sodium chloride, mercury, Benzene, water e.t.c.
(b) Non-magnetic materials	These are materials which cannot be attracted or repelled by a magnet e.g. copper, brass, wood, plastic, wood, rubber etc.	

Note: Magnets strongly attract ferromagnetic materials, weakly attract paramagnetic materials and weakly repel diamagnetic material.

Hard and soft magnetic materials

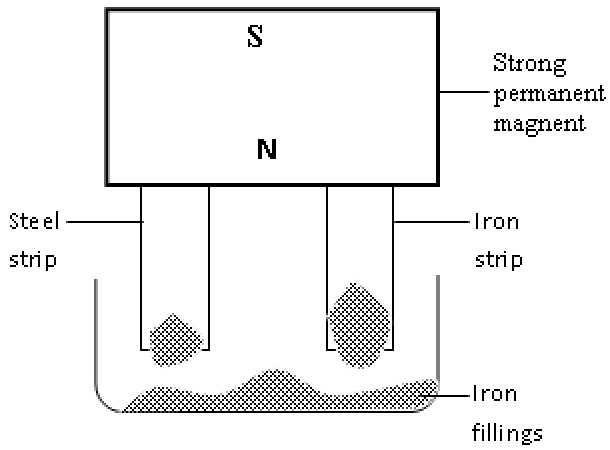
(i) Hard magnetic materials.

These are ferro-magnetic materials which are not easily magnetized but retain their magnetism for a long period. E.g steel
Hard magnetic materials are used for making permanent magnets used in instruments like
- ✓ Electricity meter
- ✓ Radio loudspeaker
- ✓ Telephone receiver

(ii) Soft magnetic materials

These are ferro-magnetic materials which are easily magnetized but lose their magnetism easily. E.g iron
Soft magnetic materials are used in
- ➢ Transformer
- ➢ Magnetic keepers
- ➢ Making of temporary magnets used in: electric bells, relays, electromagnets, dynamos, motor armatures, etc

Experiment to distinguish between hard and soft magnetic materials



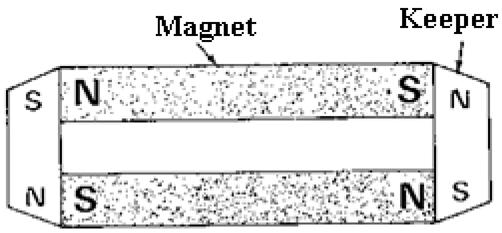
Procedure
Two strips of iron and steel are attracted to a magnet as shown above
The arrangement is then dipped in the iron fillings.

Observations:
(i) More iron fillings are attracted to the iron strip than the steel strip. This is because the induced magnetism in iron strip is stronger than that in steel. Iron is easily magnetized than steel.
(ii) On removing the permanent magnet almost all iron fillings on iron fall off and very few if any fall from steel. Steel.
This is because the induced magnetism in iron is temporary while induced magnetism in steel is permanent.

Conclusion
Iron is a soft magnetic material i.e temporarily magnetized while steel is permanently magnetized and thus hard magnetic material.

Assignment: give some differences between steel and iron as magnetic materials

Storing magnets
Magnets tend to become weaker with time due to repulsion of the free like poles of molecular magnets near the ends. This upsets the alignment of the atomic dipoles.
To prevent this self demagnetization of magnets, bar magnets are stored in pairs with un like poles put together and pieces of soft iron called magnetic keepers are placed at the end as shown below.



Explanation
How magnetic keepers are used to store magnets
- Magnetic keepers become induced magnets and their poles neutralize the poles of the bar magnets. In other words, the keepers and the bar magnets form a closed loop with no free poles thus eliminating self demagnetization.

Uses of magnets
- **Used** in industries to lift heavy loads
- **Ta**pes and tape recorders use a special type of magnetic materials with very fine powder where each particle can be magnetized
- Used in electric motors and generators to rotate the wheels of a machine
- Used in a relay reed switch and as a circuit breakers
- Used in telephone receivers and loud speakers. etc

Polarity of a magnet
Polarity of a magnet refers to the points at the ends of a magnet that have opposite magnetic properties where the magnetic strength is more powerful. The points are called poles.
Magnets are never found as monopoles. (Single magnetic poles). Every magnet has two poles called North pole(N) and South pole (S).
The North Pole is the pole which is attracted to the geographic north and the South Pole is the pole which is attracted to the geographic south.

Law of magnetism:
It states that, unlike poles attract and like poles repel.
Note: The attraction or repulsion between two magnets depends on the strength of the magnets and the distance between them.
The further apart the magnets are, the less they attract or repel one another.

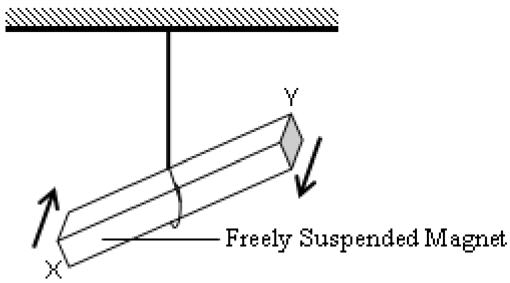
Properties of magnets
- Magnets attract only certain materials.
- Magnets have two ends called magnetic poles. Its at these ends where the attractive forces are strongest
  {Assn. Describe an experiment to show that attractive forces of a magnet are strongest at its ends}
  This is shown by dipping a magnet into a container of iron fillings.
  Iron fillings are seen in large numbers at the magnetic poles than in the middle of the magnet.

- Magnets with two poles i.e. North Pole & South Pole when freely suspended come to rest in the north-south direction.
  {Assn. Describe an experiment to show that a freely suspended magnet comes to rest in the north-south direction}

- Magnets have a basic law which states that unlike poles attract while like poles repel.
  {Assn, Describe an experiment to verify the law of magnetism}

Testing polarity/magnetism [**How to identify the pole of a magnet]**

(a) By suspension method

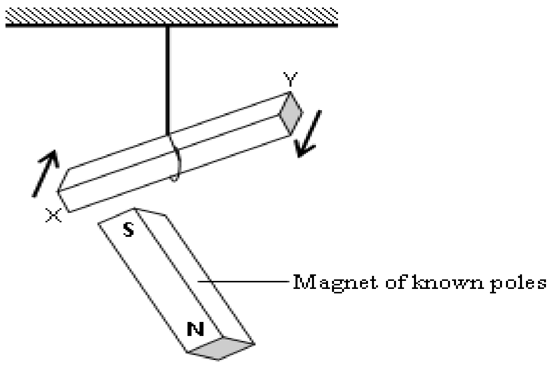


Procedures:
- ✓ Suspend a given un marked magnet with a help of a thread so that it can rotate freely.
- ✓ Wait until the magnet comes to rest.

Observation:
The magnet points in north-south direction.

Conclusion:
The end facing the geographic north is the North pole and the end facing the geographic south is the south pole.

(b) Using a magnet of known poles



Procedures:

- ✓ Suspend an iron bar and mark its ends X & Y
- ✓ Bring the N-pole of a magnet slowly towards the end X and after towards end Y. Note the observations in each case.

- ✓ **Repeat** the above procedures using the S- pole of a known pole magnet.

Observations

(i) Attraction: Probably due to attraction between unlike poles or due to attraction between a magnet and a magnetic material.
Therefore we cannot make a conclusion here.

(ii) Repulsion: It is due to like poles. If repulsion occurs, then the unknown pole is similar to the known pole of the magnet.
In this case we can make our conclusion of the unknown pole.

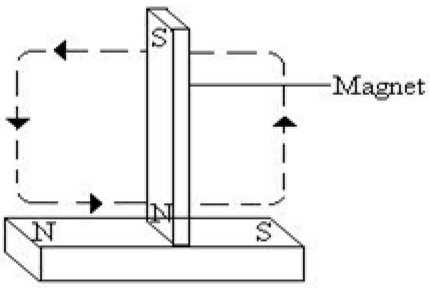
	North Pole	South Pole	Magnetic Substance
North Pole	**Repulsion**	Attraction	Attraction
South Pole	Attraction	**Repulsion**	Attraction
Magnetic Substances	Attraction	Attraction	No effect

Note: Repulsion is the only sure way of testing for the polarity of a magnet and not attraction because attraction occurs for both magnets and magnetic materials.

Methods of magnetizing a magnet

(i) Single touch/stroke method
(ii) Divided/double touch/stroke method.
(iii) Electrical method using direct current.
(iv) Induction method.
(v) Absolute method

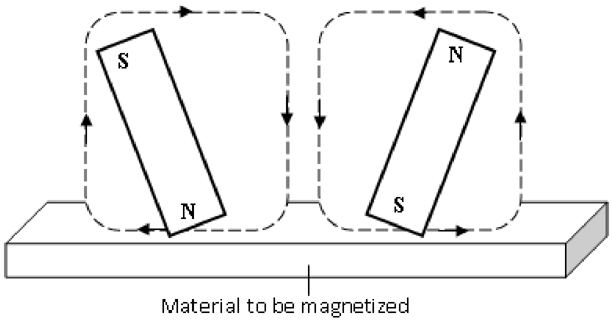
Single touch method



In this method, the steel bar is stroked from end to end several times in one direction with one pole of a permanent magnet.

The polarity produced at the end of the bar is of the opposite kind to that of the stroking pole.

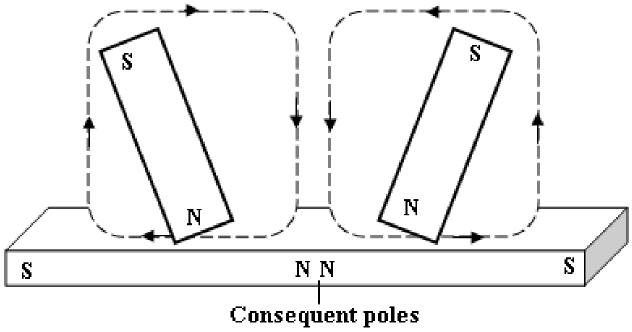
Double touch method



In this method, the steel bar is stroked several times from the centre outwards with unlike poles of the two permanent magnets.
After each stroke, the stroking pole should be raised higher and higher to avoid weakening of the induced magnetism in the steel bar.
The polarity produced at the end of the bar is also of the opposite kind to that of the stroking pole.

Consequent pole magnet.
Consequent poles of a magnet are double like poles both at the centre and at the ends.

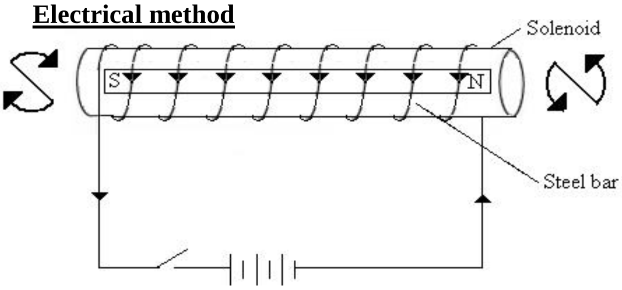
Consequent poles are obtained when a steel bar is double stroked using two like poles from the centre outwards as shown below.



If such a magnet is freely suspended in air, it does not come to rest.

Qn. (a) What is a consequent pole magnet?
(b) Briefly describe how a consequent pole magnet is made..

Electrical method



The material to be magnetized is inserted into a solenoid to which a steady d.c is connected to flow.

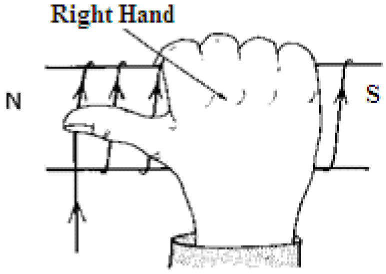
The current is switched on for a few minutes and then off. When the steel bar is removed, it is found to be magnetized.

The current flowing in the same direction makes the atomic magnets in the Domains to point in same direction.

Determining the polarity of the magnet produced.
The polarity of the magnet produced depends on the direction of the current at the ends of the solenoid.
It can be established by using one of the following methods:

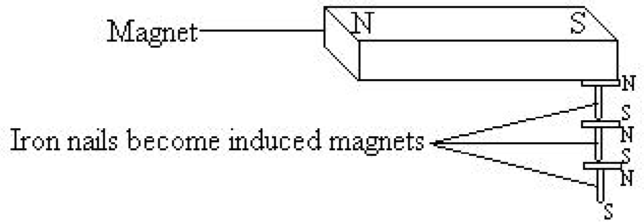
(i) Using the direction of flow of current.
Look at the ends of the solenoid;
- ❖ If the current is flowing in a clockwise direction, that will be a **South Pole.**
- ❖ If it is flowing in an anti-clockwise direction, then that will be the **North Pole.**

(ii) Using the Right hand grip rule.
Grip the solenoid such that the fingers point in the direction of current in the solenoid. Then, the thumb points in the North pole.



Absolute method.
In this method, the steel bar is heated to red hot, hammered and allowed to cool while facing in the north- south direction.

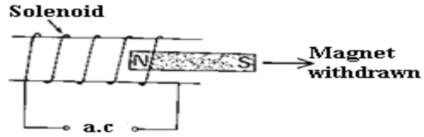
Induced magnetism
A piece of un-magnetized steel/iron becomes magnetized when its either near or in contact with a pole of a magnet. This is a process called induced magnetism or magnetization by magnetic induction. The end nearest to the pole of the magnet acquires an opposite pole.



Magnetic saturation

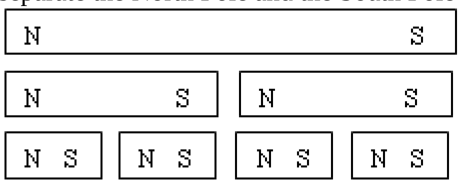
When a magnetic material is magnetized, it reaches a point where it cannot be magnetized further. This is called **magnetic saturation.**

❖ **Demagnetization**
It is the process by which a magnet loses its magnetism. i.e. the atomic magnets are now in a random arrangement and facing in different directions.
It can be demagnetized by:

Method	Explanation
(i) Hammering	The magnet is hammered while lying in the E-W direction.
(ii) Dropping	The magnet is dropped on a hard surface several times.
(iii) Heating	The magnet is heated until it becomes red hot and then allowed to cool while lying in the East-West direction.
(iv) Using Alternating current	 -The magnet is placed in a solenoid whose ends are connected to an a.c supply. -It is then withdrawn from the solenoid slowly so that the changing magnetic flux destroys the order of alignment of the atomic magnets.

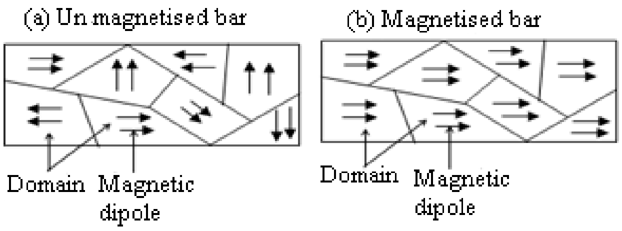
Note: the demagnetized magnet should be removed in an East-West direction to avoid magnetization by the earth field.

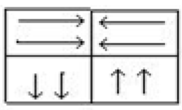
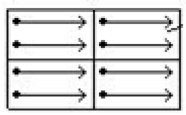
The domain theory of magnetism
A magnet is made up of small magnets lined up with their north poles pointing in the same direction; this is illustrated when the magnet is broken into two pieces intending to separate the North Pole and the South Pole as shown below.



No matter how many times the magnet is broken, the small pieces will still be magnets. These atomic magnets are called magnetic di- poles.
In a magnetic substance e.g magnetized steel bar, there are a number of magnetized region called domains. Domains are a grip of atoms which are tied magnets called dipoles.

Domain theory states that in an un magnetized substance the dip holes in all domains are not aligned, so when the magnet is made, the domain are aligned in the same direction
Once they are all aligned, the substance can't be magnetized any further and it is said to be magnetically saturated.



Magnetic dipole (molecular magnet)	Magnetic material in un magnetized state	Magnetic material in magnetized state
		

QN. Explain in terms of the molecular theory how a steel bar gets magnetized and demagnetized.
When a magnet is stroked on the steel bar the magnet domain are forced to align in the direction of the magnetic field from the magnet. They do so and remain in that direction hence the bar gets magnetized.
However, when a magnet is heated strongly, dropped on a rough surface or alternating current passed through it, the domain is set to point in opposite directions which aren't north – south hence weakening the magnet. This is called demagnetization.

Magnetic saturation:
Is the limit beyond which the strength of a magnet can't be increased at constant temperature.

QN. Explain why increase in temperature destroys the magnetism of a magnet.
When a substance is heated, molecules vibrate with greater energy, these increased vibrations destroy alignment of tiny magnets in the domain and the magnetism is decrease.

MAGNETIC FIELDS

A magnetic Field is a region or space in which:

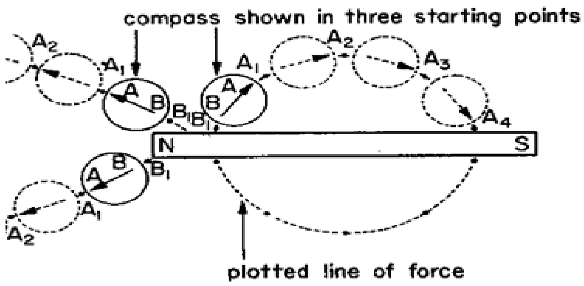
- A magnetic dipole (magnet) experiences a force.
- A current carrying conductor experiences a force or a moving charge experiences a force.
- An emf is induced in a moving conductor.

Magnetic flux.
Magnetic flux is a group of magnetic field lines passing through a certain area.

Field lines are used to represent the direction and magnitude of the magnetic field. The strength of the magnetic field is proportional to the density of the field lines.
The direction o the magnetic field is represented by the magnetic field lines. The magnetic field lines are taken to pass through the magnet, emerging from the North Pole and returning via the South Pole. The lines are continuous and do not cross each other.

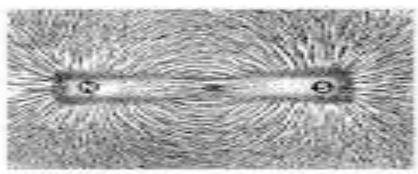
Magnetic lines of force do not intersect or touch and can pass through a non-magnetic substance.

Methods of locating magnetic flux
(i) Using a plotting compass.



-Place a magnet on a flat surface and then place a piece of paper on top of the magnet.
-Place a plotting compass near one pole of the magnet, note and mark the position of the North pole of the compass needle using a pencil dot.
-Move the compass needle onto the dot marked on the paper and make a second dot.
-Continue the process until you reach the south pole of the magnet.
-Join the dots to give a line of force and show the direction of the force using an arrow.

(ii) Using Iron fillings.

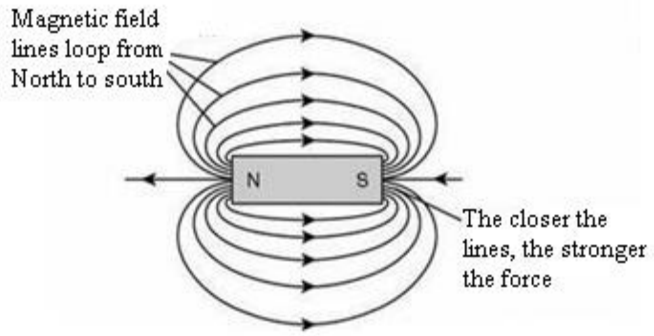


-Place a magnet on a flat surface and then place a piece of paper on top of the magnet.
-Sprinkle iron fillings all over the paper.
-Tap the paper gently

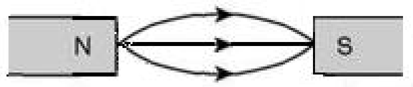
Observation: The iron fillings re-arrange themselves as shown above.

Magnetic flux patterns

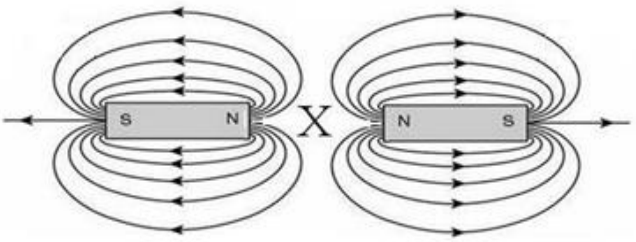
(a) Isolated bar magnet



(b) Unlike poles close together (attraction)

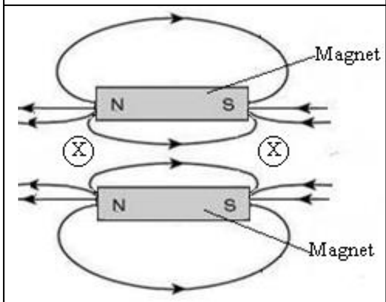


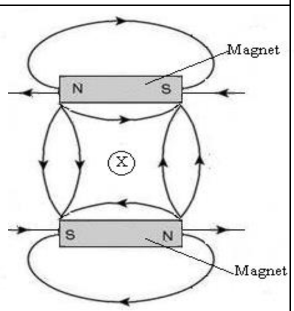
(c) Two like poles (repulsion)

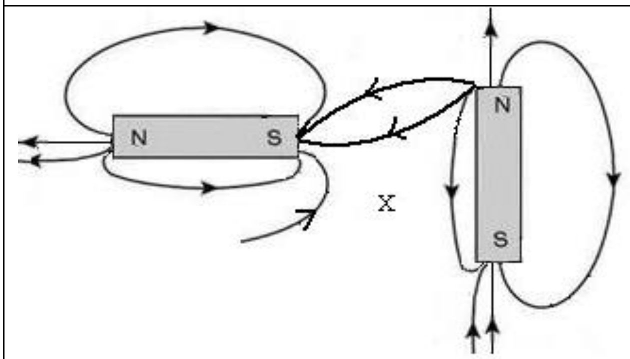


A neutral point in a magnetic fields

A neutral point is a point in a magnetic field where the resultant magnetic field strength is zero (0). The opposing magnetic fields are of equal strength and therefore cancel out.





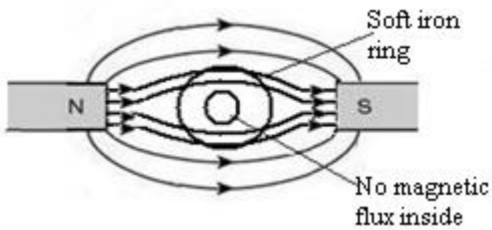


Magnetic shielding or screening

This is the creation of a magnetically neutral space or region in the neighbour hood of the magnetic field irrespective of the strength of the field.

Iron has the ability of drawing and concentrating all the flux from its surroundings through itself. It is thus said to be more **permeable** to the magnetic flux than air.

Iron in form of a ring causes the lines of force to pass through its walls and no magnetic flux passes the surrounding ring.
The space inside the ring is said to be shielded or screened from magnetic flux.



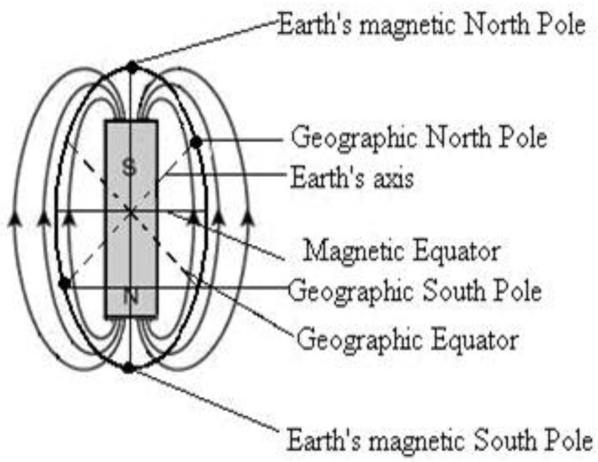
All lines of force incident on the ring induce magnetism into it. These create a neutral region inside the ring
Magnetic shielding can be applied

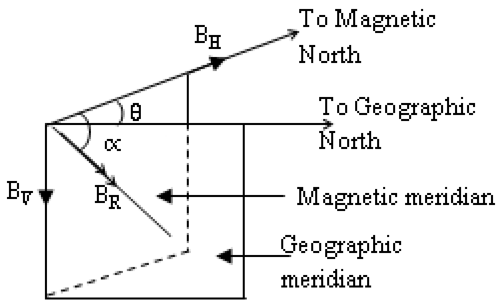
- In non digital watches
- In T.V tubes and cathode ray tubes
- In electron beams

They are used to shield them from external magnetic field by placing a strong iron cylinder along the neck of the tube.

The earth's magnetic field

A freely suspended bar magnet always comes to rest pointing in the North-South direction.
This is due to the magnetic field of the earth
The earth behaves as though it contains a short bar magnet inclined at a small angle to its axis of rotation with its South Pole in the northern hemisphere (geographic North) and the North Pole pointing to the Southern hemisphere (geographic South).





θ = Angle of declination or angle of variation
α= Angle of dip
B_V = Vertical component of earth's field
B_H = Horizontal component of earth's field

Magnetic meridian: this is the vertical plane containing or passing through the earth's magnetic north and south poles

Geographical meridian: This is the vertical plane passing through the geographical north and south directions

Angle of Dip, : This is the angle between the earth's magnetic field and the horizontal; **OR** Angle of dip is the angle that the axis of a freely suspended bar magnet makes with the horizontal when the magnet sets.

Angle of declination (Magnetic variation) is the angle between the earth's magnetic and geographical meridian
This is the angle between geographic North Pole and the magnetic north pole.

Magnetic axis: is the imaginary line passing through the earth's magnetic north and south poles.

Geographical axis: This is the imaginary line through the center of the earth and passing through the geographical north and south

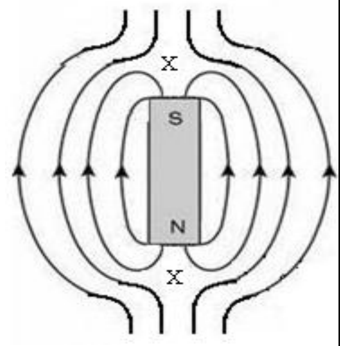
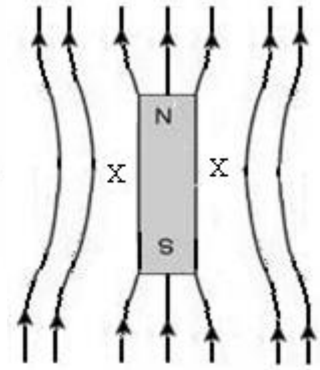
Variation of Angle of dip, as one moves from the magnetic equator up to the North Pole
Magnetic Equator: This is the greatest circle in a horizontal plane perpendicular to the magnetic meridian where a freely suspended bar magnet experiences zero magnetic dip.

Explanation
At the magnetic equator, the earth's magnetic field lines are parallel to the horizontal; therefore the angle of dip at the equator is zero,
As one moves along a given longitude towards the North Pole, the resultant magnetic field lines meet the earth's surface at angles greater than 0^0 but less than 90^0 thus the angle of dip at such a position is also greater than zero but less than $90^{0.}$
i.e.
At the North Pole, the magnetic field lines are normal to the surface of the earth, thus they are perpendicular to the horizontal. Therefore the angle of dip at the North Pole equals 90^0 i.e. .

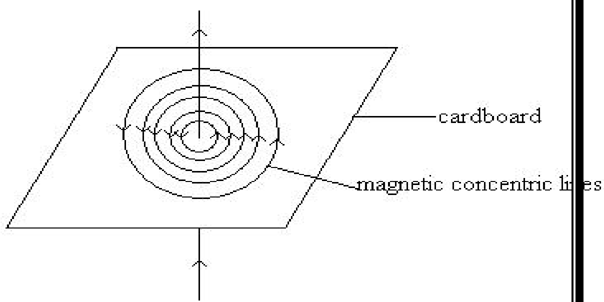
Generally, the angle of dip increases from at the equator up to at the North Pole

Earth's magnetic field;
This is the series of parallel lines running from geographic south to geographic north as shown below.

Interaction of earth's field with a bar magnet.

(a) When the South Pole of the bar magnet is pointing north and the magnet is in the magnetic meridian	(b) When the North Pole of the bar magnet is pointing north and the magnet is in the magnetic meridian
	

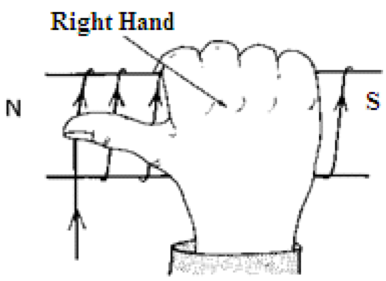
Magnetic effect of an electric current.
Any straight conductor carrying current experiences a magnetic field around it.
The field pattern obtained can be studied by using iron fillings or plotting compass.
It is found that the magnetic lines of force form concentric circles with the wire as the centre.



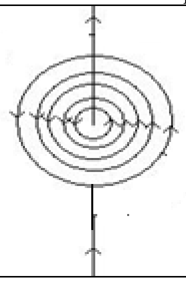
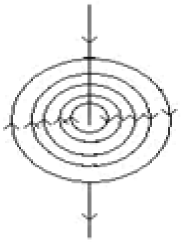
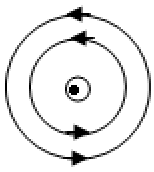
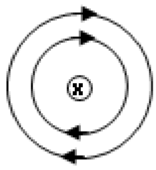
The direction of a magnetic field around the conductor is given by the right hand grip rule. which states that imagine a conductor to be griped in the right hand with the thumb pointing in the direction of the magnetic field, then the fingers will point in the direction of the current.

Right hand grip rule
It states that imagine a conductor to be griped in the right hand with the thumb pointing in the direction of the magnetic field, then the fingers will point in the direction of the current.

Grip the soft iron bar with the right hand figure, following the direction of current. The end where the thumb points is the north pole.

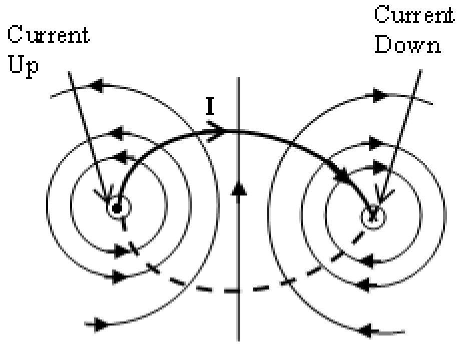


(i) Magnetic fields due to a straight wire carrying current

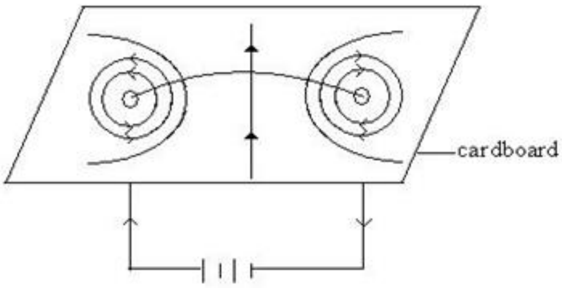
Current out of the page	Current into the page
	
Current out of paper 	Current into paper 

Maxwell's right hand rule:
This is used to find the direction of the field.
If one grasps the current carrying straight wire in the right hand with the thumb pointing in the direction of current, then the fingers curl pointing in the direction of the magnetic field.

(ii) Magnetic field due to a current carrying circular coil.

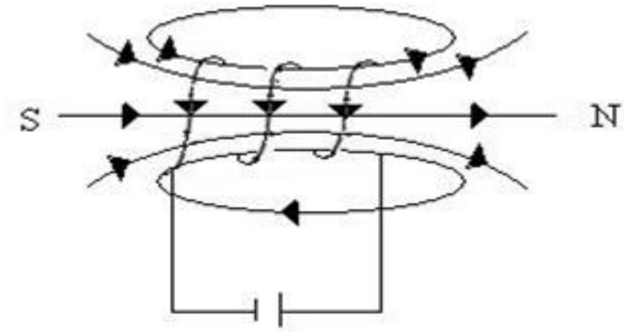


Alternatively the field lines of a current carrying circular coil can be sketched as follows;



The field lines around each side are concentric circles. Magnetic fields near the center of the circular coil are uniform hence the magnetic field lines are nearly straight and parallel

(iii) Magnetic flux due to a current in a solenoid
A solenoid is a coil whose diameter is smaller than its length.



The field pattern due to a solenoid is similar to that of a bar magnet when current is switched on.

The direction of the field is determined as follows:"if the coil (solenoid) is viewed from one end and the current flows in an anticlockwise direction at that end, then the end is a North Pole and if the current flows in a clockwise direction, then that end is a south pole"

The strength of the flux density depends on:

- The current in the solenoid
- Number of turns

Exercise:
1. (1991 Qn. 23).
SECTION A

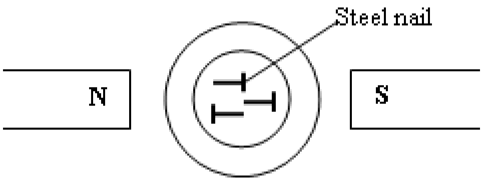
1994 Qn. 1	1993 Qn. 37	1997 Qn. 29	1998 Qn. 32
2000 Qn. 36	2002 Qn. 20	2004 Qn. 8	2006 Qn. 14
2008 Qn. 18	1991 Qn. 23		

SECTION B
2. **(2008 Qn. 3).** (a) Define the following terms as applied to magnetism:
(i) Ferromagnetic material.
(ii) Neutral point
(b) Sketch he magnetic field pattern around a bar magnet whose axis lies along the magnetic north.
(c) (i) State one method of magnetizing a magnet.
(ii) What is meant by a magnetically saturated material?

3. **(1995 Qn. 7).** (a) With the aid of a diagram, explain how a piece of iron can be magnetized by a single touch method.
(b) How can you determine the polarity of a magnet?
(c) Explain why a magnet loses its magnetism when placed in a coil of wire carrying alternating current.

4. **(2004 Qn. 41).** (a) List two ways by which a magnet may lose its magnetic properties.

(b) The figure below shows an iron ring between two opposite magnetic poles.

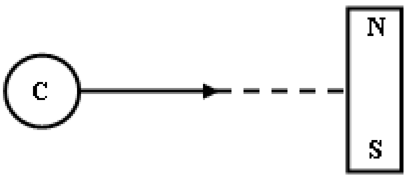


(i) Sketch the magnetic lines of force on the diagram.
(ii) Explain what happens to the steel nails.

5. (2004 Qn. 4). (a) (i) What is a magnetic field?
(ii) State the law of magnetism
(b) Sketch the magnetic field pattern of two bar magnets whose north poles are facing each other.

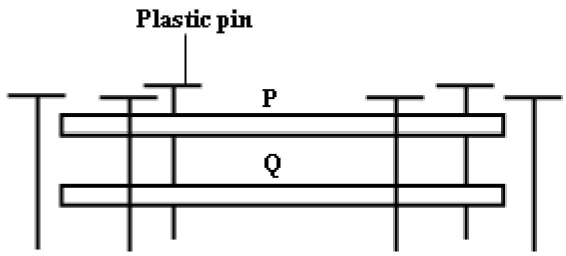
6. (2006 Qn. 3). (a) Distinguish between angle of dip and angle of declination.
(b) Draw a diagram to show the magnetic field pattern around a bar magnet placed in the earth's field with the north pole of the magnet pointing to the earth's magnetic south.

(c) Describe what happens to the compass needle, C, as it is moved closer to the bar magnet along the dotted line shown below.



7. (2002 Qn. 6). (a) What happens when a magnet is ;
(i) Dipped in iron filings.
(ii) Freely suspended in air.

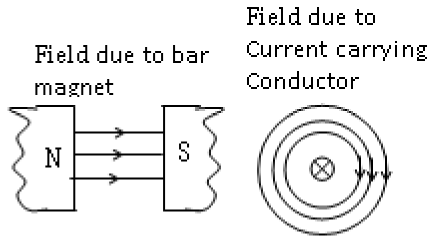
(b). A powerful magnet Q is placed on a soft board. Plastic pins are firmly stuck in the soft board around the magnet. An identical magnet P, is held in the space surrounded by the pins above the magnet Q. When the magnet P is released, it floats above the magnet Q as shown below.



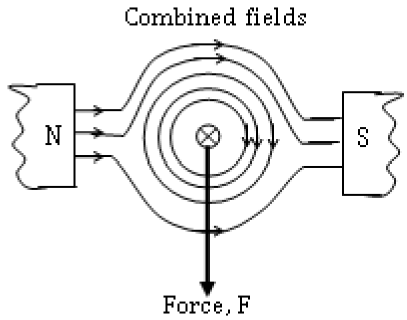
Explain;
(i) why P floats above Q.
(ii) why are plastic pins used instead of steel pins.
(iii) What would happen to magnet to magnet P if all the pins were removed at the time.
(c) Explain in terms of the domain theory how a steel bar gets magnetized by stroking.

FORCE ON A CURRENT CARRYING CONDUCTOR IN A MAGNETIC FIELD

(a) Origin of the force that causes motion of a current carrying conductor placed across a magnetic field.
When a current carrying conductor is placed across a magnetic field (e.g between the poles of a powerful magnet), it sets up a magnetic field around itself.
The two fields then interact with each other causing a resultant force.
If the field or the current is reserved, the direction of the force also reverses.



The combined field exert a force on the current carrying conductor. The force is towards the region with fewer field lines (i.e less flux density).



On one side of the conductor, the magnetic fields oppose each other and some cancel out resulting in formation of a relatively weaker field there.

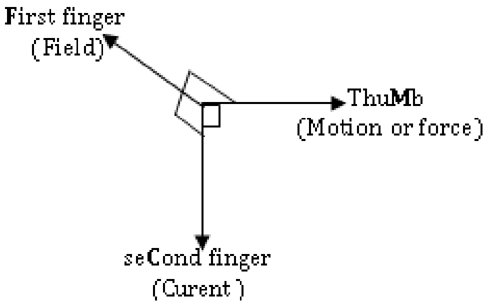
On the other side of the conductor, the applied magnetic field lines are forced to curve or concentrate resulting in formation of a strong magnetic field there.
There are more field lines above the wire since both fields act in the same direction.

A force is therefore exerted on the conductor that moves it from a region of strong magnetic field to a weaker magnetic field.

If we suppose field lines to be a stretched elastic material, these below will try to straighten out and in so doing will exert a down ward force on the wire.
[See the kicking wire experiment for verification]

Fleming's Left Hand Rule (Motor rule)
The direction of the force in a current carrying conductor placed across a magnetic field is predicted by the Fleming's Left Hand Rule.

It states that if the thumb, first and second fingers of the left hand are held mutually at right angles with the thu**M**b pointing in the direction of magnetic force (or Motion), the **F**irst finger indicates the direction of the field while the seCond finger indicates the direction of <u>current</u> in the conductor.



(b) <u>Factors affecting the magnitude of a force on a current carrying conductor.</u>

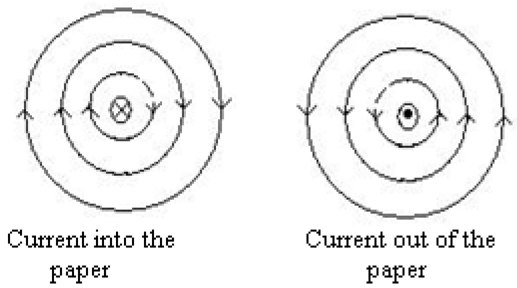
Experiments show that the magnitude of the force exerted is proportional to the:-

(i) Current I in the conductor
(ii) Length, *l*, of the conductor
(iii) Strength of the magnetic field by a quantity called magnetic flux density, B.
(iv) Number of turn in the conductor, N
(iv) The angle θ, where θ is the angle between the conductor and the magnetic field.

All these factors can easily be generated from the expression for the force on a current carrying conductor below.

$$F = NBILSin\theta$$

Note: current flowing into the paper is donated by (**X**) and current flowing out of the paper is denoted by, (•)



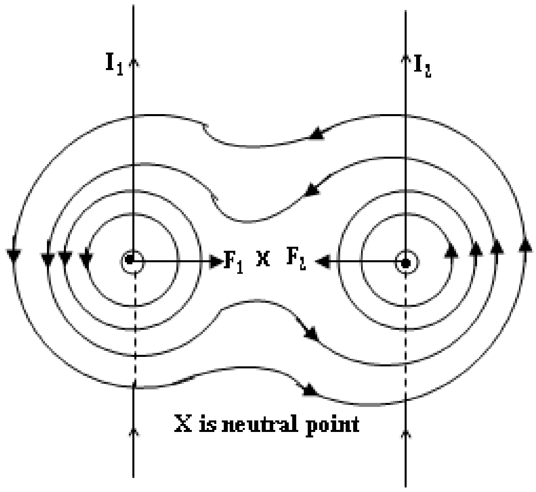
Force between two straight conductors carrying current in a vacuum

Two current carrying conductors (wires) exert a force on each other due to the interaction of the magnetic fields set up around each conductor.

Depending on the direction of the currents, in the two conductors, the force exerted can be;

(i) Attractive (Same direction of current)
(ii) Repulsive (Different directions of current)

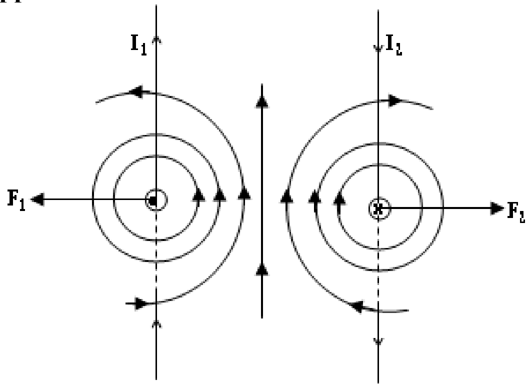
Magnetic field due to two straight wires carrying current in the same direction



The fields in the middle of the conductors are in opposite directions. Hence they attract each other.

A force on each wire acts from a region of strong field hence straight parallel wires carrying current in the same direction attract. i.e. “like currents attract”

Magnetic field due to straight wires carrying current in opposite directions



“Unlike currents repel”

The fields in the middle of the conductors are in the same direction. Hence they repel each other.

A force on each wire acts from a region of strong field hence straight parallel wires carrying current in opposite direction repel. i.e. “Unlike currents repel”

<u>Applications of Electromagnets</u>

An electromagnet is any current carrying conductor which acts as a magnet.

If a soft iron is placed in a solenoid, it will be strongly magnetized only when the current is flowing.

When the current is switched off, all the magnetism acquired is lost.

The soft iron inside the solenoid is acting as an electromagnet. The strength of the field of an electromagnet can be increased by:

- Placing an iron core inside the coil.
- Increasing the magnitude of the current.
- Increasing the number of turns in the coil.

Applications of electromagnets

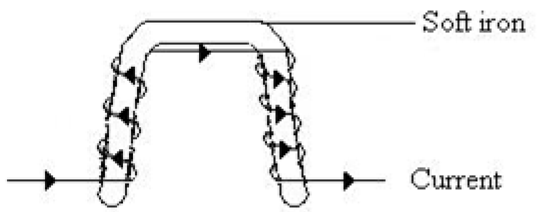
Electromagnets are used in:

- Lifting magnets
- Electric bells
- Moving coil loud speaker
- Telephone receivers
- Magnetic Relays, e.t.c.

(i) **Lifting magnets**

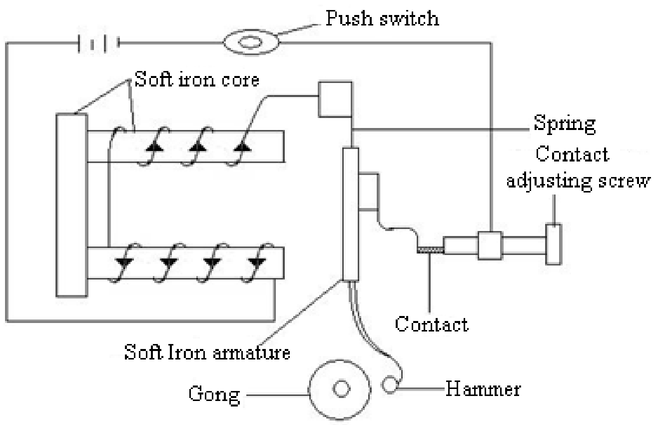
They are mainly used for lifting and transporting heavy steel from one place to another in a factory. The coils are made of insulated copper wire wound on a U-shaped soft iron so that opposite polarity is produced. The opposite adjacent poles increase the lifting power of the electromagnet.

The coil is wound in opposite directions on each of the soft iron.



(ii) **Electric bell**

It consists of a hammer, a gong, soft iron armature, contact adjusting screw, a push switch, steel spring and an electromagnet made of two coils wound in opposite directions on the iron cores.

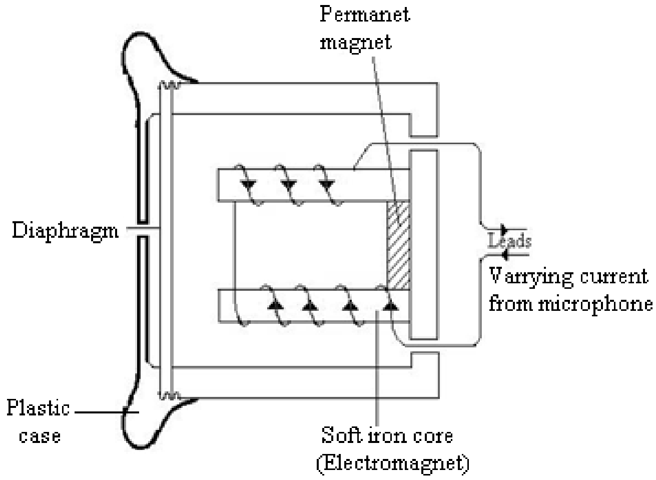


Action

- ❖ When the switch is pressed, current flows through the electromagnet which becomes magnetized.
- ❖ It attracts the soft iron armature and hence breaking the contacts.
- ❖ This causes the hammer to strike the gong and sound is heard.
- ❖ As the armature moves, the current is broken causing the electromagnet to lose its magnetism. The spring pulls the armature again to its original position and contact is made again.
- ❖ The process is repeated on and on hence a continuous sound will be heard.

(iii) **Telephone receiver**

It consists of an electromagnet which is mad e of two coils wound in opposite directions on two soft iron cores, a diaphragm and a permanent magnet which attracts the diaphragm and keeps it under tension.

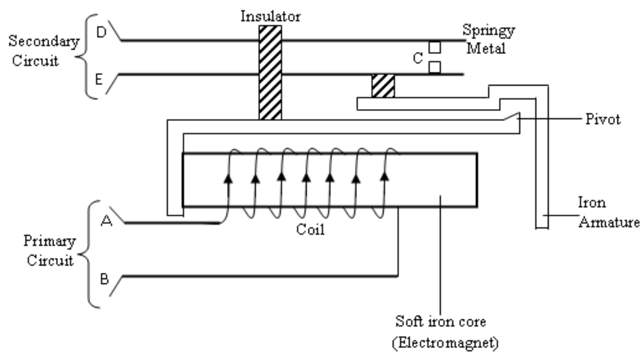


Action:

- ❖ When the phone is lifted, a steady current flows through the solenoids. However when a person speaks into the microphone on the other end, the sound energy is converted into varying electrical energy of the same frequency as the original sound.
- ❖ This is transferred through the cables to the receiver and magnetizes the electromagnet.
- ❖ The strength of the electromagnet varies according to the magnitude of the electric current which also depends on the original sound.
- ❖ This causes the magnetic alloy diaphragm which is under tension to have a varying pull. As a result, the diaphragm vibrates reproducing the vibration of the speech and so the speech is reproduced.

(iv) **Magnetic relay**

A magnetic relay switch uses a small current in the primary circuit to control a larger current in the secondary circuit.



When current flows in the coil from the primary circuit AB, the soft iron core is magnetized and hence attracts the L-shaped iron armature.

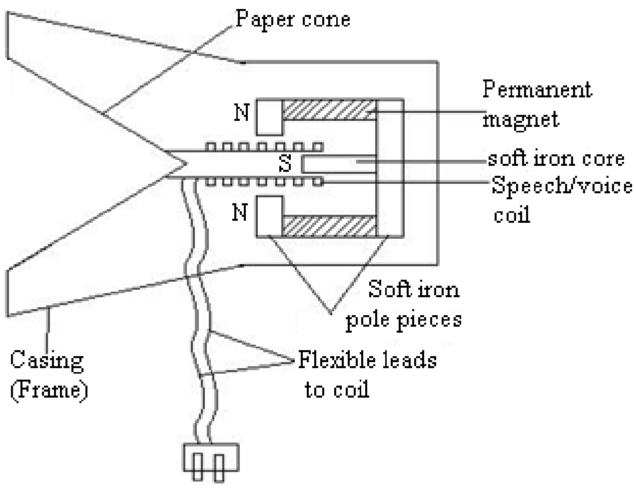
As the armature is attracted, its top rises making it rock on its pivot hence closing the contacts at C in the secondary circuit. Connected to DE.

The relay is then said to be energized or on.

(v) **The moving coil loud speaker**

It converts electrical energy into sound energy. It is used in radio receivers, record players, etc.

Structure



It consists of a light coil of wire known as a speech coil wound tightly round a cylindrical former to which a large thin cardboard cone is rapidly attached. The coil is in a radical magnetic field provided by the permanent magnet which has circular pole.

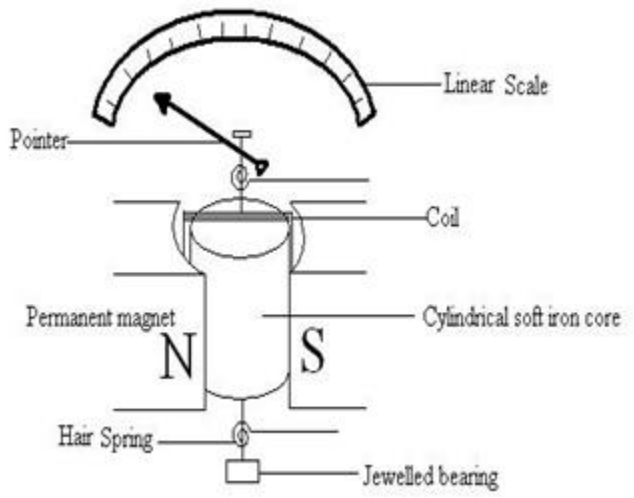
Action

- ❖ Varying electric currents from an amplifier flows continuously in the speech coil through the leads.
- ❖ The varying current produces a varying electromagnetic force on the coil making it to vibrate at the same frequency as the current.
- ❖ This makes the frame and the paper cone to vibrate at the same frequency sending the surrounding air in vibration hence a loud note (sound) is heard.
- ❖ The greater the electrical energy supplied to the coil, the louder the note produced.

<u>Applications of the force on a current carrying conductor</u>

(a) **Moving coil Galvanometer**

It is used to detect and measure an electric current and potential difference.



It consists of a rectangular coil with many insulated turns wound on an aluminum former, soft iron cylindrical core between the curved poles of a powerful permanent magnet, the springs which control the rotation of the coil, a pointer and a linear scale. The current is led in and out by two hair springs.

Action:

When the current to be measured flows through the coil, a resultant magnetic field is set up. By Fleming's left hand rule, two equal and opposite parallel forces act on the two vertical sides of the coil. The two forces together form a deflection couple causing the coil to rotate until the deflecting couple is just balanced by the opposing couple setup by the hair springs.

As the coil rotates, the pointer moves with it and hence the magnitude of the current can be obtained from the linear scale.

<u>Sensitivity of the moving coil galvanometer</u>

A galvanometer is said to be sensitive if it can detect very small currents.

The sensitivity can be increased by;

- Using very strong magnet to provide a strong magnetic field
- Using very weak hair springs
- Suspending the coil so that it can turn freely
- Using a coil with many turns

<u>Advantages</u>

(i). It has a linear scale because of the uniform field provided by the radial field.

(ii). It can be made to measure different ranges of current and potential difference.

(iii). External field around the galvanometer has no influence because the magnetic field between the magnets and the soft iron is very strong.

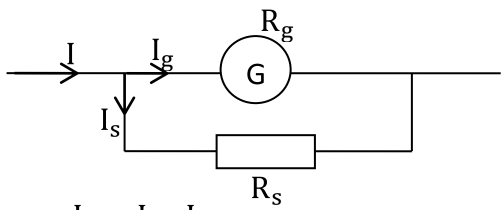
Conversion of a moving coil galvanometer into an ammeter and voltmeter.

(i). <u>Conversion of a galvanometer to an ammeter</u>

Use of shunts

An ammeter is constructed in such a way that it has a very low resistance so that a large current passes through it.

To convert a galvanometer into an ammeter, a low resistance called a shunt is connected in parallel with it.



$I_s = I - I_g$

I_g is the full-scale deflection of the galvanometer

P.d across the shunt = P.d across galvanometer

$$\Leftrightarrow \mathbf{(I - I_g)R_s = I_gR_g}$$

Most of the current will pass through the shunt and only a small part through the galvanometer.

Example:

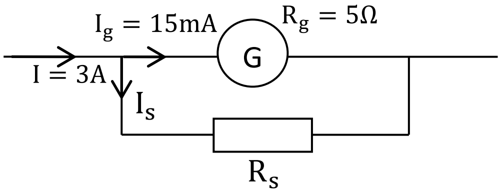
A moving coil galvanometer has a resistance of 5Ω and gives a full deflection of 15mA. How can it be converted into an ammeter to measure a maximum of 3A?

(i).

Solution

(i)

Let Rs be the resistance of the shunt required.



$\text{P.d across the shunt} = \text{P.d across galvanometer}$

$\Leftrightarrow (I - I_g)R_s = I_gR_g$

$\Leftrightarrow (3 - 0.015)R_s = 0.015 \times 5$

$2.985\ R_s = 0.075$

$\mathbf{R_s = 0.025\ \Omega}$

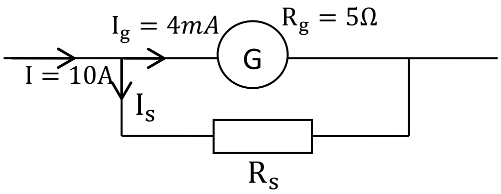
Thus a low resistance resistor of $0.025\ \Omega$ should be connected in parallel with the galvanometer.

Example1.

A moving coil galvanometer gives a full scale deflection of 4mA and has a resistance of 5Ω.How can such instrument be converted into an ammeter giving a ful-scale deflection of 10A?

Solution:

Let Rs be the resistance of the shunt required.



$\text{P.d across the shunt} = \text{P.d across galvanometer}$

$(I - I_g)R_s = I_gR_g$

$\Leftrightarrow (10 - 0.004)R_s = 0.004 \times 5$

$\mathbf{R_s = 0.002\Omega}$

Thus a low resistance resistor of 0.002Ω should be connected in parallel with the instrument.

Examp2.

A moving coil galvanometer gives a full scale deflection of 6mA and has a resistance of 4Ω.How can such instrument be converted into;

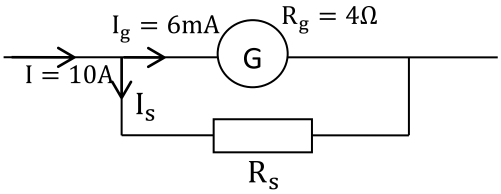
(i). an ammeter giving a ful-scale deflection of 15A?

(ii). A voltmeter reading up to 20V?

Solution:

(i)

Let Rs be the resistance of the shunt required.



$\text{P.d across the shunt} = \text{P.d across galvanometer}$

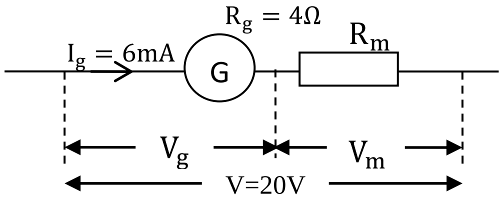
$\Leftrightarrow (I - I_g)R_s = I_gR_g$

$\Leftrightarrow (15 - 0.006)R_s = 0.006 \times 4$

$\mathbf{R_s = 0.016\Omega}$

Thus a low resistance resistor of 0.0016Ω should be connected in parallel with the instrument.

(ii)



$V = \begin{pmatrix}\text{P.d across} \\ \text{the multiplier}\end{pmatrix} + (\text{P.d across galvanometer})$

$V = V_m + V_g$

$V = I_gR_m + I_gR_g$

$R_m = \dfrac{V - I_gR_g}{I_g}$

$R_m = \dfrac{20 - 0.006(4)}{0.006}$

$\mathbf{R_m = 3329\Omega}$

Example 3.

A moving coil galvanometer of resistance5Ω and current sensitivity of 2 divisions per milliampere, gives a full-scale deflection of 16 divisions. Explain how such an instrument can be converted into;

(i). An ammeter reading up to 20A?

(ii). A voltmeter in which each division represents 2V?

Solution:

(i)

$\text{Current sensitivity} = 2\text{div/mA}$

$\text{Full scale deflection} = 16\text{div.}$

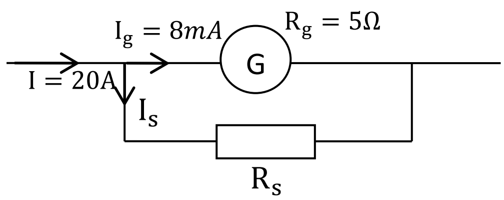
$2\text{div} \rightarrow 1\text{mA}$

$16\text{div} \rightarrow x$

On cross multiplying, we get;

$2x = 16mA$

$x = 8mA = 8 \times 10^{-3}A = 0.008A$



$\text{P.d across the shunt} = \text{P.d across galvanometer}$

$\Leftrightarrow (I - I_g)R_s = I_gR_g$

$\Leftrightarrow (20 - 0.008)R_s = 0.008 \times 5$

$\mathbf{R_s = 0.002\Omega}$

Thus a low resistance resistor of 0.0016Ω should be connected in parallel with the instrument.

$\text{Voltimeter sensitivity} = 1\text{div}/2\text{V}$

$\text{Full scale deflection} = 16\text{div.}$

$1\text{div} \rightarrow 2\text{V}$

$16\text{div} \rightarrow y$

On cross multiplying, we get;

$y = 16 \times 2 = 32V$

$R_m = \dfrac{V - I_gR_g}{I_g}$

$$R_m = \frac{32 - 0.008(5)}{0.008}$$

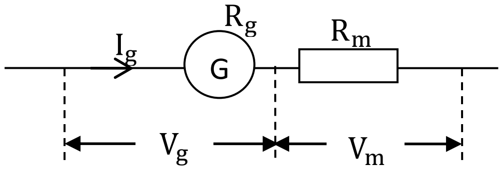
$$\mathbf{R_m = 3995\Omega}$$

(i). <u>Conversion of a galvanometer to a voltmeter</u>

A voltmeter has a high resistance so that no current passes through it.

To convert a galvanometer to a voltmeter, a high resistance called a multiplier is connected in series with it.

Use of multipliers



$$V = V_m$$

$$V = \begin{pmatrix}\text{P.d across the}\\ \text{multiplier}\end{pmatrix} + \begin{pmatrix}\text{P.d across}\\ \text{galvanometer}\end{pmatrix}$$

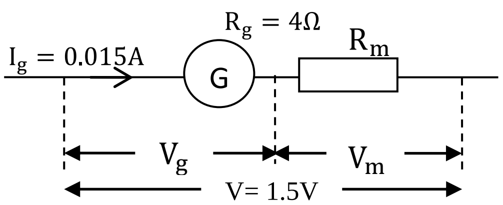
$$V = V_m + V_g$$

$$V = I_gR_m + I_gR_g$$

$$\mathbf{V = I_g(R_m + R_g)}$$

Example

(ii) In the above example, if the galvanometer is to measure a maximum p.d of 1.5V, the value of R can be obtained as below.



$$V = \begin{pmatrix}\text{P.d across}\\ \text{the multiplier}\end{pmatrix} + (\text{P.d across galvanometer})$$

$$V = V_m + V_g$$

$$V = I_gR_m + I_gR_g$$

$$R_m = \frac{V - I_gR_g}{I_g}$$

$$R_m = \frac{1.5 - 0.015(5)}{0.015}$$

$$\mathbf{R_m = 95\Omega}$$

Thus resistance of 95Ω must be connected in series with the galvanometer.

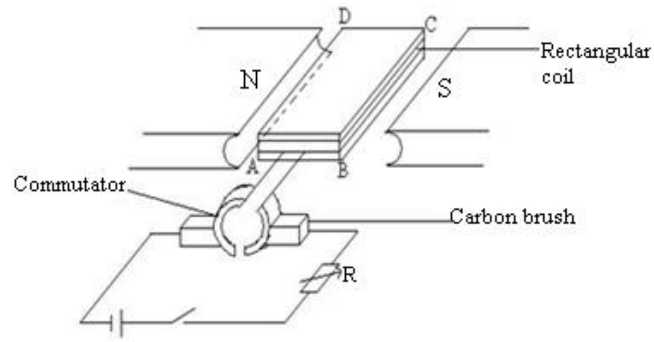
(b) The simple direct current (d.c) motor

The d.c motor changes electrical energy to mechanical energy.

Structure:

It consists of a rectangular coil which can rotate about a fixed axis in a magnetic field provided by the permanent magnet. The ends of the coil are soldered to two halves of a copper ring (commutator).

Two carbon brushes press lightly against the commutators.



Action

- ❖ When current flows in the coil, side BC experiences a downward force and AD an upward force. (Fleming's left hand rule).
- ❖ The two forces constitute a couple which rotates the coil.
- ❖ When the coil reaches the vertical position, the brushes lose contact with the commutator and current is cut off. However the coil continues to rotate past this vertical position because of the momentum gained.
- ❖ The current in the coil reverses as the brushes change contact with the commutator, side AD now experiences a downward force and BC an upward force. Thus the coil continues to rotate as long as the current is flowing.

<u>Energy losses in a d.c motor</u>

1. Energy losses in the winding of the armature (I^2R)
2. Eddy current losses.
3. Energy losses due to friction e.g. between the brushes and the commutator. These can be minimized by;

   (i) Using low resistance copper wire

   (ii) Eddy currents are minimized by winding the coil on a laminated core.

   (iii) Energy losses due to friction are minimized by lubrication,

Exercise:

1. **(1994.Qn. 2).** (c) A moving coil galvanometer, has a coil of resistance 4Ω and gives a full scale deflection when a current of 25mA passes through it. Calculate the value of the resistance required to convert it to an ammeter which reads 15A at full scale deflection.[Ans: $6.68 \times 10^3\Omega$.]

2. **(1999.Qn. 10).** A galvanometer has a resistance of 5Ω and range 0-40mA. Find the resistance of the resistor which must be connected in parallel with the

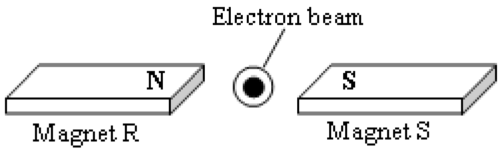
galvanometer if a maximum current of 10A is to be measured. [Ans: 0.02Ω]

3. **(1994.Qn. 2).** A galvanometer of reads 0.05A at full scale deflection and has resistance of 2.0Ω. Calculate the resistance that should be connected in series with it to convert it to a voltmeter which reads 15V at full scale deflection. [Ans: 298Ω]

4. A galvanometer of internal resistance100Ω gives full a fsd of 10mA. Calculate the value of the resistance necessary to convert it to:
(a) Voltmeter reading up to 5V. [400Ω]
(b) Ammeter reading up to 10A. [0.1Ω]

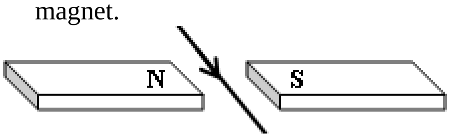
Exercise:

1. **(1988.Qn. 24).**



An electron beam is incident into the page at right angles to the magnetic field formed between two magnets R and S as shown in the above diagram. The beam will be deflected.
A. Down wards. B. Towards magnet R
C. Towards magnet S. D. Upwards.

2. **(1991 Qn. 13).** The diagram below shows a beam of electrons directed to pass between the poles of a magnet.

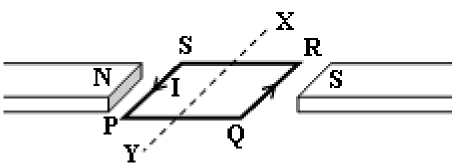


The electron beam would be;
A. deflected towards the S-pole. B. deflected downwards
C. Slowed down. D. reflected backwards.

3. (2003 Qn. 22). Which of the following factors affect the magnitude of force on a current –carrying conductor in a magnetic field?
(i) Direction of current.
(ii) Amount of current
(iii) Direction of the magnetic field
(iv) Strength of the magnetic field.

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

4. (1997 Qn.31). The figure below shows a current carrying coil PQRS pivoted about XY between two magnets.



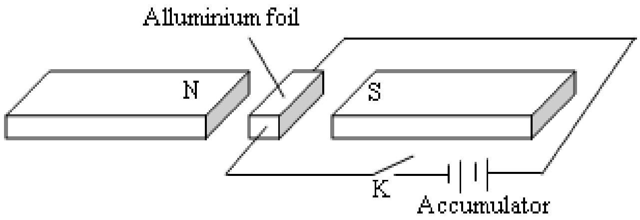
Which of the following statements are true about the coil?
(i) The sides PS and QR shall experience a force.
(ii) As seen from X, the coil will rotate anticlockwise.
(iii) The force on the coil can be increased by increasing the number of turns.
(iv) The coil will come to rest with PQ at right angles to the magnet field.

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

5. (2005 Qn. 2). The direction of motion of a conductor carrying current in a magnetic field can be predicted by applying ;
A. Faraday's law. B. Maxwell's screw rule
C. Fleming's left hand rule. D. Fleming's right hand rule.

(1990 Qn. 4), 1994 Qn. 38, 1995 Qn. 40, 1998 Qn. 31.
SECTION B

6. (1992 Qn. 10). An Alluminium foil carrying a current is placed in a magnetic field as shown below.



ELECTROMAGNETIC INDUCTION

Electromagnetic induction is the producing of an electromotive force (electric current) in a circuit from magnetism by varying the magnetic flux linked with the circuit.

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An electric current produces a magnetic field around the conductor through which it flows. Similarly, a magnetic field induces a current in a conductor when the conductor cuts the field. This effect is called **electro magnetic induction**.

The means that current or (e.m.f) can be induced when;

- The magnetic field strength around an electromagnet is increased and decreased.
- Constantly moving a permanent magnet in and out of a coil of wire.
- Constantly moving a conductor near a stationary permanent magnet.

Electromagnetic induction forms the basis of working of power generation, dynamos, generators etc.

Types of electromagnetic induction:

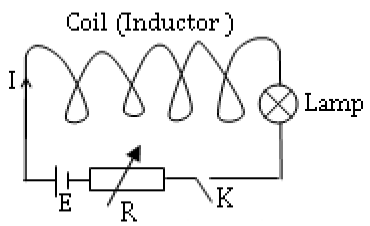
- Self induction
- Mutual induction.

Self induction

Self induction is the process where an e.m.f is induced in a coil (or circuit) due to a changing current in the same coil.
The flux due to the current in the coil links that coil and if the current changes, the resulting flux change induces an emf in the coil itself.
When current flows in a coil, it sets up a magnetic field within the coil and when it is switched off, the magnetic field collapses (changes). A current is induced in the coil to oppose the change.
This effect is called self induction. The coil is said to have self inductance, (L) and the coil is said to be an inductor.
Back e.m.f is the e.m.f induced in a coil (or circuit) due to a changing current in the same coil (or circuit).
The induced e.m.f tends to oppose the growth of current in the coil.

Demonstration of self induction

Consider a coil of known number of turns connected in series with the battery and switch k as shown below.



-Switch k is closed, current, I flows in a coil and the bulb (lamp) lights up slowly to maximum brightness.
-The magnetic flux linking the turns of the coil changes hence inducing an e.m.f in the coil .
-This e.m.f tends to oppose the growth of current in the coil.
Alternatively;
-The current, I is varied by using a variable resistor, R.
-The magnetic flux linking the turns of the coil changes hence inducing an e.m.f in the coil.
-This e.m.f tends to oppose the growth of current in the coil.

-Switch k is opened, current, I decays out from the coil and the bulb (lamp) first lights up brightly and then gradually goes off.
-The magnetic flux linking the turns of the coil changes hence inducing an e.m.f in the coil.
-This e.m.f tends to oppose the decay of current in the coil.

Note: Just as self induction opposes the growth of current in a circuit when K is closed; it also opposes its decay when K is opened.

Mutual induction

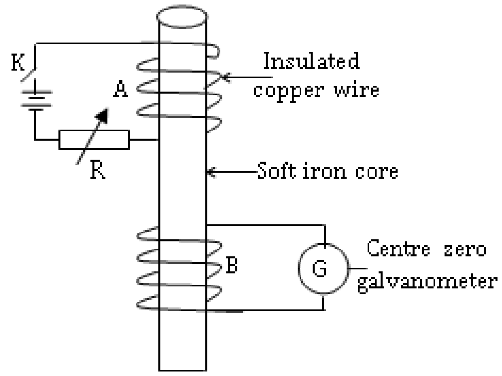
This is the generation of an e.m.f in one coil due to change in current in the nearby coil.
A magnet can be used to induce current in a coil. A secondary coil carrying current can be used instead of the magnet to induce current

Assignment; describe briefly an experiment to show mutual induction with the aid of a diagram.

Demonstration of Mutual induction

a) Based on changing magnetic field.
Experiment to show that the induced current (or e.m.f) is as a result of a changing magnetic field.
(a) Coil-coil experiment

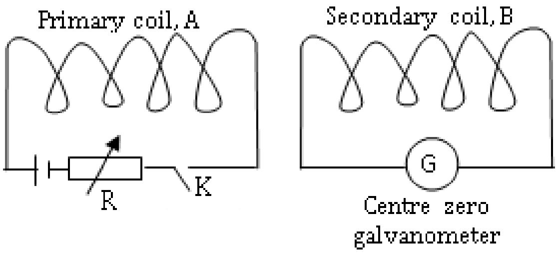
- Consider cols A and B wound on a soft iron rod as shown below.



- When switch, K is closed, current flows in the primary coil, A and the galvanometer momentarily deflects in one direction and no more deflection there after as the switch remains closed.
- When the rheostat, R is adjusted so as to decrease the resistance (hence increasing current), a deflection on one side of the galvanometer is obtained.
- When the rheostat, R is adjusted so as to increase the resistance (hence decreasing current), a deflection on the opposite side of the galvanometer is obtained.

- When the switch is opened (at a break), the galvanometer deflects in the opposite direction and no more deflection there after as the switch remains open.

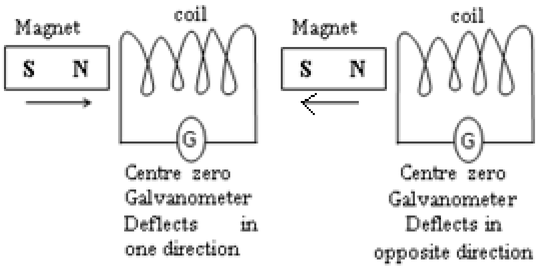
(b) Similar observations above could be made when the coils are arranged as shown below.



i) Larger deflections are obtained when a bunch of soft iron is inserted into the coil compared to hard solid iron bar or air cored coil.

ii) The deflection obtained in the secondary coil (coil B) depends on the induced e.m.f in it, which depends on the;
- Number of turns in coils A and B
- Area of coils A and B.
- Proximity of the two coils (distance between the coils)

Similar observations above could be made when there is relative motion between a magnet and a coil as shown below.



❖ When both the magnet and coil are stationary (or moved with the same velocity in the same direction), there is no deflection. This is because, there is no varying magnetic field created hence no e.m.f is induced in the coil, and so the galvanometer does not deflect.

❖ When the coil is fixed and the magnet moved into the coil or when the magnet is fixed and the coil moved towards the magnet. The magnet experiences an opposing force. This is because the induced e.m.f flows in such a direction that the magnetic flux due to it opposes that due to the magnet.

A varying magnetic field is created which induces an e.m.f in the coil, hence the galvanometer deflects in one direction.

❖ When the magnet is withdrawn from the field, the magnet experiences an attracting force. Magnetic flux threading the coil decreases. The induced e.m.f flows in such a direction that the magnetic flux due to it enhances that due to the magnet. The galvanometer deflects in the direction opposite to the first one.

Observations from the above experiments:

(i) Whenever there is relative motion between a coil and a magnet, the galvanometer shows a certain deflection. This indicates that current is induced in the coil.

(ii) The deflection is temporary. It lasts so long as the relative motion between the coil and the magnet continues.

(iii) The deflection increases with increase in relative motion.

(iv) The direction of the deflection is reversed when either the pole of the magnet is reversed or the direction of motion of either the magnet or coil is reversed.

Assignment; describe briefly an experiment to show mutual induction with the aid of a diagram.

Laws of electromagnetic Induction:

(i) Faraday's law.

❖ Whenever a conductor moves through a magnetic flux or whenever there is a change in magnetic flux linked with a circuit, an e.m.f is induced.

❖ The magnitude of induced e.m.f in a circuit is directly proportional to the rate of change of the flux linking it.

(ii) Lenz's law.

The direction of the induced current is such as to oppose the change causing it.

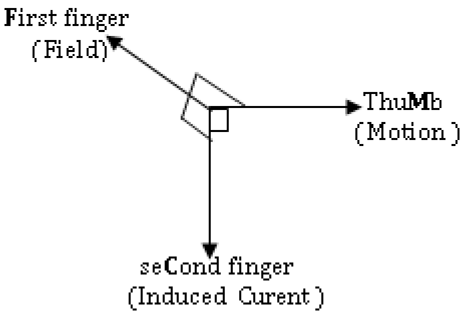
It followed Faraday's law when Lenz studied the direction of the induced current in a complete circuit.

Direction of induced e.m.f

The direction of induced e.m.f (or induced current) is obtained by using Lenz's law.

However, if the current is being induced by the motion of a conductor in a magnetic field, it is more convenient to use the Cork's screw rule or Fleming's Right hand Rule (dynamo rule).

Fleming's right hand rule



It states that: "When the thumb, first finger and second finger of the right hand are held mutually at right angles, with the thumb pointing in the direction of motion, the first finger in the direction of the magnetic filed, then the second finger points in the direction of the induced current".

In summary; thu**M**b – motion, **F**irst finger – field ,se**C**ond finger – current.

Note: we use the **R**ight hand for **D**irection of **C**urrent produced or (RDC).

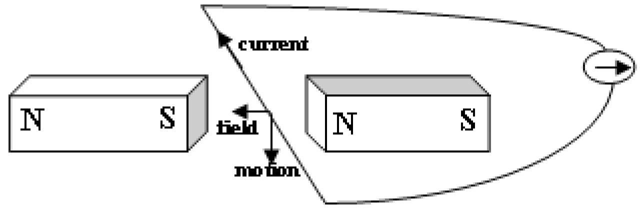
Direction of the induced current in a straight wire.

A wire is placed between the poles of a permanent magnet and connected to a galvanometer. The wire is moved up and down at right angles to the magnetic flux.

➢ It's observed that when the wire is moved down, the galvanometer deflects to the right meaning that induced current is flowing in the clockwise direction.

➢ When the wire is moved up, the deflection is reversed indicating that the current is reversed. (anticlockwise)

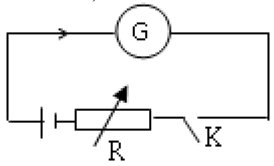
The above observation can be verified using Fleming's right hand rule as shown below.



Assignment: draw a coil in a magnetic field and show its rotation when current is moving in different direction.

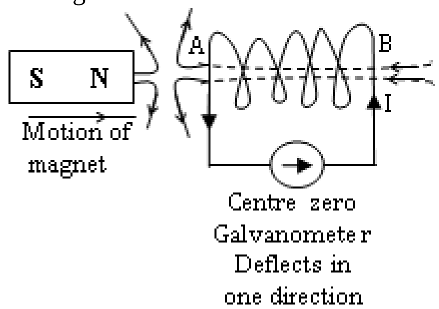
Experiment to verify Lenz's law

(Illustration of Lenz's law)



-A battery is connected in series with a galvanometer and a mega ohm resistor. Switch K is closed and the direction of flow of current is noted from the deflection of the galvanometer.

-The battery is then replaced by a coil AB of known sense of winding as shown below.



- ❖ When the North Pole of the magnet is moved towards the coil, the current induced in the coil flows in the direction such that the magnetic flux due to the coil opposes that due to the magnet (i.e it flows in a direction that makes end, A a north pole). The galvanometer deflects in the clockwise direction. End A of the coil becomes the North Pole. (Like poles repel).

- ❖ When the magnet is moved away from the coil, the galvanometer deflects in the opposite direction. The induced current flows in a direction such that the magnetic flux due to the coil reinforces that due to the magnet. (i.e it flows in a direction that makes end, A a south pole).. The galvanometer deflects in the ant-clockwise direction. Thus end A of the coil becomes the South Pole.

- ❖ In both cases, the induced current flows in a direction so as to oppose the change in flux causing it. This is Lenz's law.

Lenz's law and conservation of energy

Lenz's law is an example of conservation of energy. In order not to violate the principle of conservation of energy, the effect of the induced e.m.f must oppose the motion of the magnet, so that the work done by the external agent in moving the magnet is the one converted to electrical energy.

Other wise the induced magnetic field would increase the velocity of the magnet thereby increasing its kinetic energy. However, there is no source for this energy. Thus if the induced e.m.f helped rather than opposed, the principle of conservation of energy would be violated.

Applications of Electromagnetic Induction.

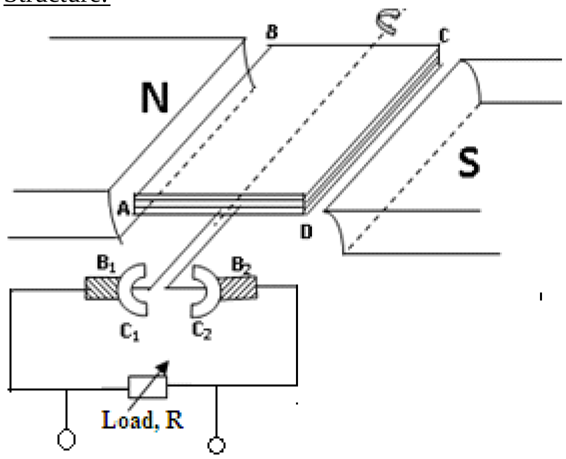
1. Generators
2. Transformers
3.Induction coils

1) GENERATORS

A generator transforms mechanical energy into electrical energy.

(a) D.C generator

Structure:



The d.c generator is a device used for producing direct current energy from mechanical energy.

Part	Function
(i)Permanent magnet poles	Provide a strong radial magnetic field.
(ii)Armature (Rectangular coil)	It's the moving part in the radial field. It brings about electromagnetic induction in the generator.
(iii) Commutator (C_1 and C_2).	Two half rings from which current is tapped by brushes.
(iv) Carbon brushes	Blocks of carbon which convey current between the moving and the stationary parts of the generator.

Mode of operation

-When the coil rotates with uniform angular velocity in the magnetic field, in accordance to Fleming's Right Hand rule. The magnetic flux density linked with it changes and an emf is induced in the coil.

The induced emf is led away by means of the slip rings S_1 and S_2.

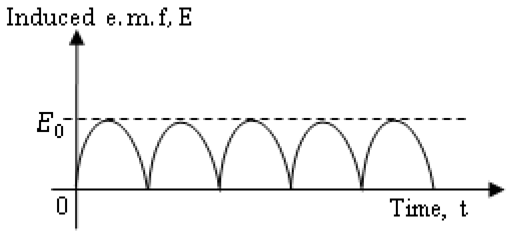
-Applying Fleming's right hand rule, the induced current enters the coil via, AB and leaves the coil via CD.

-When the coil passes over the vertical position, after half the rotation, the slip ring changes contact. C_1 goes into contact with $B_2$and C_2 goes into contact with B_1.

-The forces on the sides of the coil change, thus the current in the coil is reversed. The current flowing through the load thus continues to flow in the same direction.

-Hence the direction of the induced e.m.f doesn't change in the external circuit during one complete revolution of the amateur coil. The output of the generator is unidirectional.

Variation of induced e.m.f, E of a D.C generator with time

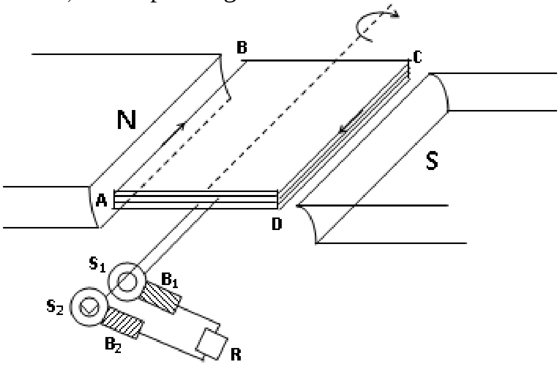


Note:
-The induced e.m.f and hence current are maximum when the plane of the coil is horizontal. This is because cutting between the coil sides and the magnetic field lines are greatest.
-The induced e.m.f and hence current are minimum (zero) when the plane of the coil is vertical. This is because there is no cutting between the coil sides and the magnetic field lines.

A simple A.C generator (Alternator)

Structure

-The simple a.c generator consists of a rectangular coil, ABCD, mounted between, N, S- pole pieces of a strong magnet and freely to rotate with uniform angular velocity.
-The ends of the coil are connected to copper slip rings S_1 and S_2, which press against carbon brushes B_1 and B_2.



Mode of operation

- ❖ When the coil rotates with uniform angular velocity in the magnetic field, in accordance to Fleming's Right Hand rule. The magnetic flux density linked with it changes and an emf is induced in the coil. The induced emf is led away by means of the slip rings S_1 and S_2.

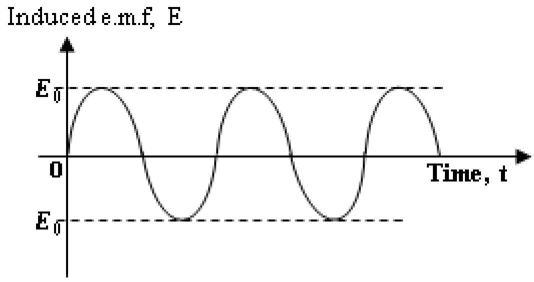
- ❖ When sides AP and CD interchange positions, the current in the terminals X and Y reverse the direction and the coil continues rotating in the clockwise direction.

- ❖ Therefore, the induced e.m.f generated flows following a sinusoidal wave.

Factors affecting the magnitude of e.m.f induced in a rotating coil.

- Number of turns on the coil.
- Area of the coil
- Magnetic flux density (field strength)
- Position of the coil
- Frequency of rotation of the coil.

Variation of induced e.m.f, E of an A.C generator with time



Structural modifications to convert A.C generator to a D.C generator:

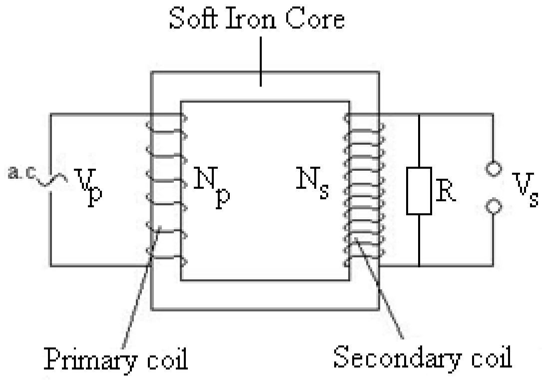
-Replace the slip rings with two halves of slip rings (commutators)

2) **THE TRANSFORMERS**

This is a device which transfers electrical energy from one circuit to another by Mutual electromagnetic induction.

Structure

-It consists of a laminated soft iron ring around which primary and secondary coils are wound.
-Ideally the primary coil has zero resistance and the secondary coil has high resistance.



Action:

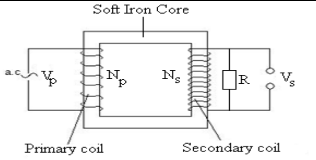
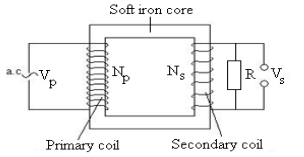
- ❖ An alternating voltage, V_p is applied to the primary coil at some instant and an alternating current I_p flows in the primary coil.
- ❖ This sets up a varying magnetic field in the soft iron core, which links up the secondary coil.
- ❖ The magnetic flux density B, is changing hence an e.m.f is induced in the secondary coil.

The induced e.m.f is proportional to the number of turns in the secondary coil.

Types of Transformers:

There are two types of mains transformers;
(i) Step Up transformers
(ii) Step down transformers.

(i) **Step-up transformer**	(ii) **Step-up transformer**
It has more turns in the primary circuit than in the secondary.	It has more turns in the secondary circuit than in the primary.

 This is usually installed in power stations and transmission stations. It changes the voltage to a higher value by using more turns in the secondary coil than in the primary to the ratio of the output voltage required If $N_s>N_p$, $V_s>V_p$, $I_s < I_p$ and the transformer is called step-up.	 This is stationed near the consumers and in electrical appliances. It changes the output voltage to a lower value. The number of turns in the secondary coil is less than those in the primary coil. If $N_s<N_p$, $V_s<V_p$, $I_s > I_p$ and the transformer is called step-down.

For an **ideal transformer**, (A transformer which is 100% efficient), the power in the primary is equal to the power developed in the secondary i.e. $\mathbf{V_pI_p = V_sI_s}$, where I_p and I_s are flowing in the primary and secondary coils respectively.

Note:

- Transformers operate only on a.c and not dc because dc does not produce changing magnetic flux in the and therefore no emf is induced in the secondary coil.
- In practice, transformers are not 100% efficient because of the energy losses.

Electric power transmission

- Electricity has to be transmitted over long distances from generating power stations to the consumers. This causes some power loss in the transmission lines.
- This loss can be minimized if the power is transmitted at **high voltage (or low current).**
- Electric power is stepped up before transmission and stepped down at the consumers' end by using transformers.

Causes and remedies of power losses in transformers

Cause of Energy or power loss	**How it is minimized**
(i) Resistance in the windings: -Some of the energy is dissipated as heat due to the resistance of the coil (joule-ohmic energy loss), hence power loss through the $\mathbf{I^2R}$ mechanism.	Use thick copper wires of low resistance.
(ii) Eddy currents Eddy currents are currents induced in the soft iron core due to the changing magnetic flux linking the core.. They cause unnecessary heat in the transformer through the $\mathbf{I^2R}$ mechanism and therefore reduce the amount of electrical power transferred to the secondary.	Use a laminated core made of thin strips or laminars separated from each other by a layer of insulating varnish.
(iii)Hysteresis(Magnetic reversal): The core or frame of iron ring is constantly magnetized and demagnetized. Each time the direction of magnetization of the frame is reversed, some energy is wasted in overcoming internal friction. When a core which can not be easily magnetised and demagnetised is used, power losses occur.	Use a soft iron core, which can easily be magnetised and demagnetised
(iv) Magnetic flux leakage Flux leakage occurs when all the magnetic flux due to the currents in the primary coil do not link up with the secondary coil. A small amount of flux associated with the primary coil fails to pass through the secondary coil.	(i) Wind one coil on top of the other. (ii) Use E- shaped cores.

Transformer Equation

$$\frac{\textbf{Secondary voltage}}{\textbf{Primary voltage}} = \frac{\textbf{Number of Secondary turns}}{\textbf{Number of Primary turns}}$$

$$\frac{\mathbf{V_s}}{\mathbf{V_p}} = \frac{\mathbf{N_s}}{\mathbf{N_P}}$$

Efficiency a transformer

$$\textbf{Efficiency} = \frac{\textbf{Power out put}}{\textbf{Power in put}} \times \mathbf{100}$$

Power out put = Power in secondary circuit = $\mathbf{I_sV_s}$
Power in put = Power in primary circuit = $\mathbf{I_PV_P}$

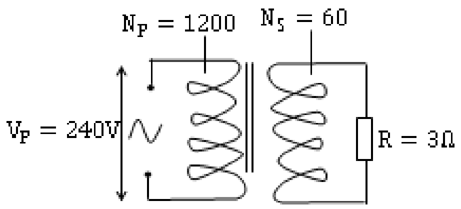
$$\textbf{Efficiency} = \frac{\mathbf{I_sV_s}}{\mathbf{I_PV_p}} \times \mathbf{100}$$

No machine (No transformer) is perfect/ ideal and therefore the value of efficiency cannot be 100% because of the energy losses discussed earlier.

Example. 1

1. A transformer whose secondary and primary coils have 60 and 1200 turns respectively has its secondary coil connected to a 3.0Ω resistor. If the primary is connected to a 240V a.c supply. If the transformer is 80% efficient, calculate the current flowing in the primary circuit.

Solution:



$\frac{V_s}{V_p} = \frac{N_s}{N_P}$ $\frac{V_s}{240} = \frac{60}{1200}$	$\text{Efficiency} = \frac{P_o}{P_{in}} \times 100$ $\frac{80}{100} = \frac{46}{P_{in}}$

$1200V_s = 240 \times 60$	$0.8P_{in} = 46$
	$P_{in} = 57.5W$
$1200V_s = 14400$	
$V_s = 12\ V$	$P_{in} = I_P V_P$
	$57.5 = I_P \times 240$
$V_s = I_s R$	$I_P = 4.174\ A$
$12 = I_s \times 3$	
$I_s = 4A$	
$P_o = I_s V_s$	
$P_o = 4 \times 12$	
$P_o = 46\ W$	

Exercise:

1. UNEB 1998:

A transformer is designed to work on a 240V, 60W supply. It has 3000turns in the primary and 200 turns in the secondary and it is 80% efficient. Calculate the current in the secondary and primary coils.

$\frac{V_s}{V_p} = \frac{N_s}{N_P}$	$\text{Efficiency} = \frac{P_o}{P_{in}} \times 100$
$\frac{V_s}{240} = \frac{200}{3000}$	$\mathbf{P_o = \eta P_{in}}$
$3000V_s = 240 \times 200$	$60 = \frac{80}{100} P_{in}$
$V_s = 16\ V$	$P_{in} = 75W$
$P_s = I_s V_s$	$P_{in} = I_P V_P$
$60 = I_s \times 16$	$75 = I_P \times 240$
$I_s = 0.27\ A$	$I_P = 0.3125\ A$

2. UNEB 1999 37, 2000 No. 6 (c), 2002 No. 5 (c), 2004 No. 5 (d),

Example

1. A transformer connected to 240 V A.C mains is used to light a 12V, 26 W lamp.
   (i) What current does the lamp need to light correctly?
   (ii) If the efficiency of the transformer is 75%, what current is taken from the mains?
   (iii) Calculate the magnitude of the series resistor that would be necessary if the lamp were connected directly to the mains.

2. A transmission line between a power station and a factory has resistance of 0.05 Ω in each of the two wires. If 100 A is delivered at 100 V.
   (i) What useful power is delivered into the load.
   (ii) How much power is wasted is wasted during transmission.
   (iii) What total power must be supplied by the generator?

3. A transformer with a ratio of **5:2** and efficiency of 90% has a primary voltage of 240V. If a current of 2.5A flows through the primary coil, determine the current through the secondary coil.

4. A step up transformer is designed to operate from a 20 V supply and delivers energy at 250 V. If it is 90% efficient,
   a) Determine the primary and secondary currents when the output terminals are connected at 250V, 100W lamp.
   b) Find the ratio of the primary turns to the secondary turns..

Assignments;

1. a) Describe with the aid of a diagram the operation of a transformer.

b) A 240 V step down mains transformer is designed to light ten 12 V, 20 W ray box lamps and draws a current of 1 A in the primary coil. Calculate the:
   i) Power supplied to the primary coil.
   ii) Power delivered in the secondary coil
   iii) Efficiency of the transformer.

2. A transformer connected to 240 V A.C mains is used to light a 12 V 26 W lamp.
   a) What current does the lamp need to light correctly?
   b) If the efficiency of the transformer is 75%, what current is taken from the mains?
   c) Calculate the magnitude of the series resistor that would be necessary if the lamp were connected directly to the mains.

3. A transmission line between a power station and a factory has resistance of 0.05 Ω in each of the two wires. If 100 A is delivered at 100 V.
   a) What useful power is delivered into the load.
   b) How much power is wasted is wasted during transmission.
   c) What total power must be supplied by the generator?

Calculating the value of alternating current.

The maximum value of an alternating current is known as its **peak value** which is reached momentarily, twice for every revolution of the coil.

We need to obtain the mean square value and then root-mean square value (r.m.s) value of the alternating voltage (or current) in order to avoid zero average.

The peak value is related to the root-mean square value by an equation;

$$\mathbf{r.m.s = \frac{peak\ value}{\sqrt{2}}}$$

1. Peak value is the maximum value of alternating current or voltage.

Peak value is just momentarily reached twice every complete revolution. It is therefore greater than the effective value of the supply.

2. Root –mean square value is the effective value of alternating current or voltage.

It is equivalent to the direct current (or direct voltage) which would dissipate the same amount of power when passing through a resistor as the alternating current of peak value.

Example. 1
In Uganda, the A.C mains voltage is 240 V. calculate the peak value of the mains.

$$\text{peak value} = 240\text{V}$$

$$\text{r.m.s} = \frac{\text{peak value}}{\sqrt{2}}$$

$$240 = \frac{\text{peak value}}{\sqrt{2}}$$

$$V_0 = 240 \times \sqrt{2}$$
$$= 339.4$$

Advantages of a.c over d.c
- A.C is easy to generate.
- A.C is is easy to transmit to around the country with minimal power loss.
- Alternating current can easily be stepped up and down for home consumption.

Disadvantages of a.c over d.c
- A.C cannot be used to charge a battery.
- A.C cannot be used in electroplating.
- A.C cannot be used in electrolysis.

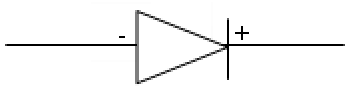
Rectification is the converting of A.C to D.C which is already discussed under electronics in modern physics.

Similarities between a.c and d.c.
Both can be cause:
-Magnetisation
-Heating
-Lighting

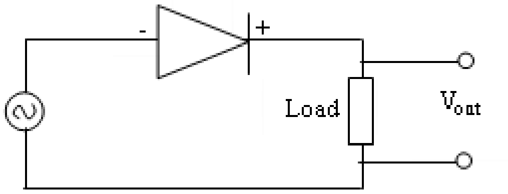
Differences between a.c and d.c.

D.c	A.c
-Can be used in electrochemical processes. E.g electro plating	-Ac is useless in this aspect
-Can be used in electric trains for locomotion.	-The train would simply move forward and backwards at the frequency of the a.c supply.
-Can't be stepped up or down	-Can easily be stepped up and down by using transformers.
-cannot	-Can be transported for long distances with minimum power loss
-D.c can't be conducted by capacitors	-A.c can be conducted by capacitors
-D.c is already rectified	-A.c can easily be converted to d.c using rectifiers

RECTIFICATION
Rectification is the process by which a.c is converted to d.c. During rectification, a diode which shows low resistance to the flow of current in one direction and a very high resistance to current flow in the opposite direction is used.

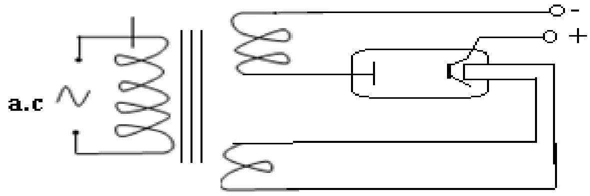


Types of Rectification:
(a) Half-wave rectification
This is where a.c is converted to d. c such that current in the second half cycle is blocked by the diode.

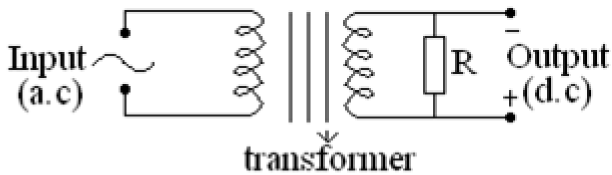


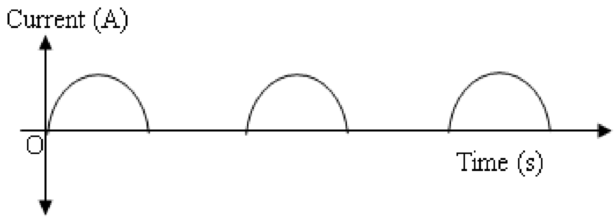
-When current flows clockwise, the resistance of the diode is low.
-In the 2nd half cycle, when current would be flowing in the opposite direction (anti- clockwise), the resistance of the diode is very high and so current is switched off.
-The energy in the switched off half cycle appears as heat energy and warms up the diode.

Alternatively, we can use a vacuum- tube.
When the anode becomes positive, electrons are attracted from the cathode hence current flows in the circuit.
And when the anode becomes negative, electrons from the cathode are repelled and therefore no flow of current.
The result is that the current in the circuit is uni-directional.



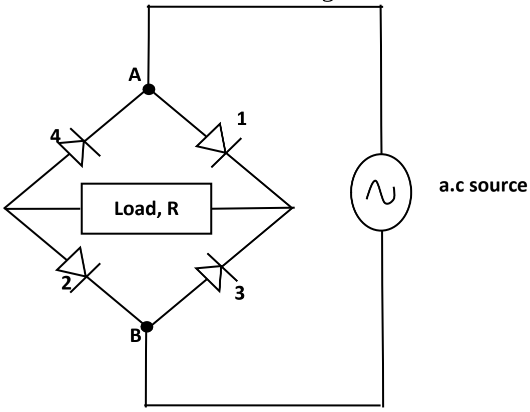
Or:



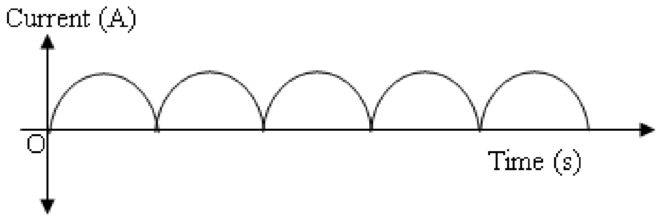


A moving coil galvanometer can be used to measure the average value of the current, $< I >$.

(b) Full-wave rectification:
Although current has been rectified and made to flow in one direction, during half wave rectification, half of the energy is lost.
To over come this problem, we use full- wave rectification in which four diodes are arranged in a circuit bridge below.



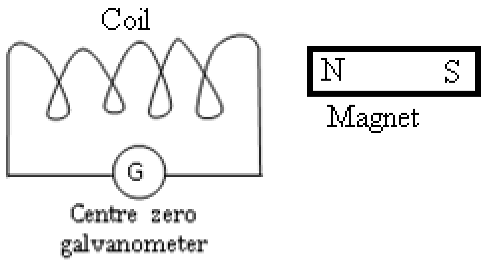
- During the 1st half cycle, point A is positive relative B. Thus current flows through diodes 1 and 2. Diode 2 takes back the current to the source.
- During the 2nd half cycle, point B is made positive relative B. Thus current flows through diodes 3 and 4. Diode 4 takes back the current to the source.
- Thus there is always a current flowing in the same direction through the load, R.



A moving coil galvanometer can be used to measure the average value of the current, $< I >$.
From the definition of mean value;

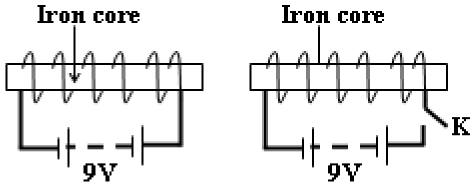
EXERCISE

13. (2000 Qn.6): The arrangement in figure below is used to produce an e.m.f. what causes the e.m.f?



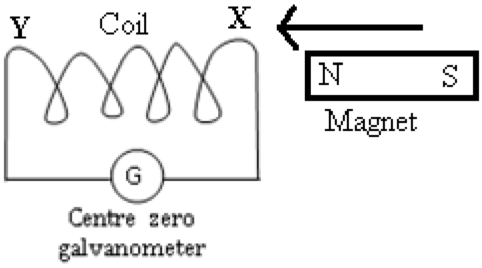
   A. The attraction between the coil and the magnet
   B. The magnetic field outside the coil
   C. The magnet placed close to the coil.
   D. The variation of magnetic lines linking the coil.

14. (2000 Qn.22): In figure 6 below when switch K is closed, the two soft iron cores will;



   A. Repel each other all the time
   B. Attract each other all the time.
   C. Attract each other for just a brief moment
   D. Have no force of attraction or repulsion between them.

15. (2002 Qn.5): The figure below shows a coil connected to a center zero galvanometer G.



The poles produced at the ends X and Y of the coil when the north pole of the magnet approaches it , is;
   A. X- north pole Y-south pole
   B. X-south pole Y-north pole
   C. X-north pole Y-north pole
   D. X-south pole X-south pole

16. (2002 Qn.40): The induced current in a generator
   A. Is a maximum when the coil is vertical
   B. Is a minimum when the coil is horizontal
   C. Changes direction when the coil is horizontal
   D. Increases when the speed of rotation increases

17. (2004 Qn.9): Which of the following is the correct order of energy changes or conversions in a generator
   A. Heat energy in cylinder →
   kinetic energy in piston → electrical energy

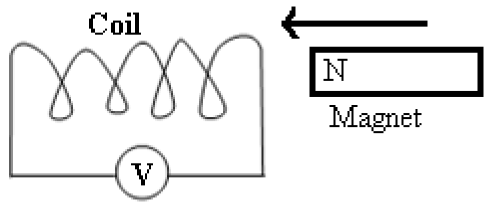
   B. chemical energy from fuel →
   heat energy from cylinders →
   kinetic energy in pistons →
   rotational kinetic energy in dynamo →
   electrical energy

   C. chemical energy from fuel →
   rotational kinetic energy in a dynamo →
   rotational kinetic energy in piston →
   electrical energy.

   D. electrical energy →
   rotational kinetic energy in dynamo →
   rotational kinetic energy in pistons →
   sound energy.

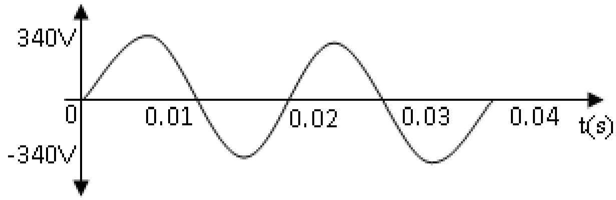
18. (2004 Qn.42):
   a) State two differences between a.c and d.c generators.

   b)



Briefly describe what happens when a magnet is moved into a coil as shown in figure above.

19. (2001 Qn.47):
    a) State **one** advantage of a.c over d.c in a main supply.
    b)



The graph in figure above sows the variation of an a.c with time. Find;

(i) The peak value.
(ii) The frequency

20. (1999 Qn.37): A transformer is used to step down an alternating voltage from 240V to 12V. Calculate the number of turns on the secondary coil if the primary coil has 1200 turns.
    A. . 3 B. 5 C. 60 D. 100

21. (1995 Qn.31): A transformer has twice as many turns in the secondary as in the primary coil. The a.c input to the primary is 4V. Find the output voltage.
    A. . 2 V B. 8 V C.4 V D. 16 V

22. (1997 Qn.10): A transformer whose efficiency is 80% has an output of 12 W. Calculate the input current if the input voltage is 240 V. (Ans: 0.0625A).

23. (2003 Qn.6): A transformer is connected to 240V a.c mains is used to light a 12 V, 36 W. What current does the lamp draw?
    A. 20.0 A B. 6.7A C. 3.0 A D. 0.33A

24. Which of the following is true about a transformer
    A. The efficiency is 100%
    B. The magnitude of e.m.f induced in the secondary does not depend on the e.m.f induced in the primary coil.
    C. There are no power losses as the core is well laminated.
    D. Passing direct current through the primary has no effect on the secondary coil.

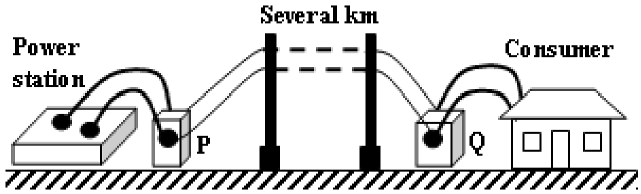
25. Which one of the following would be suitable to use in the construction of a transformer core?
    A. Lead C. Copper
    B. Soft iron D. Aluminium

26. The main function of a step-up transformer
    A. Change a.c to d.c C. Change d.c to a.c
    B. Increase the current D. Increase voltage

27. A transformer can't function normally with a d.c because a d.c
    A. Has an extremely high heating effect
    B. Reduces the efficiency of the transformer
    C. Cannot produce a changing magnetic field
    D. Cannot provide voltages required for power transmission.

28. An a.c input voltage of 250V is connected to a transformer with 100 turns. Calculate the number of turns in the secondary coil, if an output of 15V is required.
29. Which one of the following is the most economical means of transmitting electricity over a long distance?
    A. At a high voltage and a low current
    B. At a high voltage and a high current
    C. At a low voltage and a low current
    D. At a low voltage and a low current.

30. The figure below shows a transmission line from power station to a consumer several kilometers away.



Which one of the following is the correct type of transformers at P and Q?

	P	Q
A	Step-up	Step-up
B	Step-down	Step-down
C	Step-up	Step-down
D	Step-down	Step-up

31. When transmitting energy, electrical power over long distances, the voltage is stepped up in order to
    A. Transmit it
    B. Reduce power loss
    C. Increase current for transmission
    D. Prevent electric shocks.

32. Power loss due to eddy currents in the core of a transformer can be minimized by
    A. Laminating the core
    B. Using thick copper wires in the windings
    C. Using soft iron core
    D. Winding the secondary coil on top of the primary coil

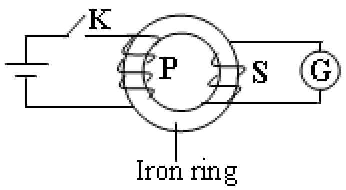
33. A voltage of 440V is applied to a primary coil of a transformer of 2000 turns. If the voltage across the secondary is 11kV, what is the number of turns in the secondary coil?
    A. 50 C. 80
    B. 5×10^4 D. 8.0×10^4
34.
    a) Give the advantages of alternating current over direct current in power transmission
    b) Describe, with the aid of a diagram, the construction and action of a transformer

c) A transformer is designed to operate at 240V mains supply and deliver 9V. The current drawn from the mains is 1.0A. if the efficiency of the transformer is 90%, calculate;
   (i) The maximum output current
   (ii) The power loss

d) State the possible causes of the power loss in © (ii) above

35.
(i) Explain briefly what is meant by mutual induction
(ii) Mention the causes of energy loss by a transformer and state how the loss can be minimized
(iii) A transformer has 200 turns on the primary coil. Calculate the number of turns on the secondary coil if 240V is to be stepped to 415 V

36.
a) What is a transformer?
b) The diagram in fig below shows a model of a transformer in which the primary coil **P** is connected to d.c and the secondary coil, **S** is connected to a galvanometer.

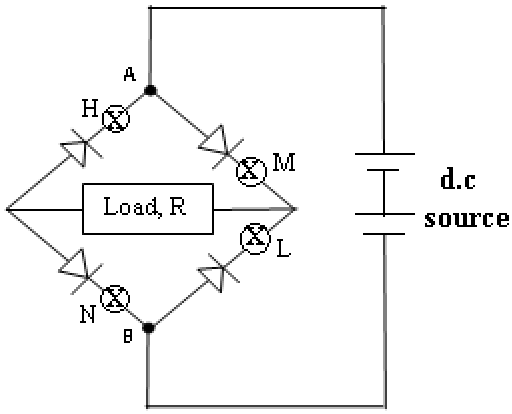


(i) What is observed just as the switch K is closed?
(ii) What would be the effect of closing switch K very fast in (i) above?
(iii) What is observed when the switch K is closed?
(iv) What is observed just as switch K is opened?
(v) What would be observed if the d.c source is replaced by an a.c source of a low frequency.

c) A transformer of efficiency 80% is connected to 240Va.c supply to operate a heater of resistance 240Ω. If the current flowing in the primary circuit is 5A,
(i) Calculate the potential difference (p.d) across the heater.
(ii) If the transformer is cooled by oil of specific heat capacity $2100Jkg^{-1}K^{-1}$ and the temperature of the oil rises by 20^0C in 3 minutes, find the mass of the oil in the transformer

37.
a) Describe briefly the structure and action of a transformer.
b) (i) State any three causes of energy losses in a transformer.
(ii) How are these losses reduced in a practical transformer?
c) Explain why it is an advantage to transmit electrical power at high voltage.
d) Electrical power is generated at 11kV. Transformers are used to raise the voltage to 440kV for transmission over large distances using cables. The output of the transformer is 19.8MV and they are 90% efficient. Find the;
(i) Input current to the transformer.
(ii) Output current to the cables

38. The circuit below shows diodes and bulbs connected to a d.c supply.



Which of the following pairs of bulbs will light up?
A. M and N
B. M and L
C. N and H
D. H and L

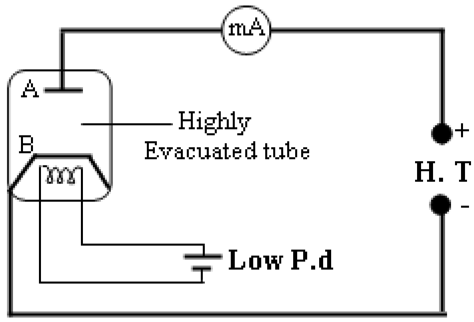
39. Rectification of alternating current means
A. Stepping up alternating current by a transformer
B. Converting alternating current into direct current
C. Stepping down alternating current by a transformer
D. Generating alternating current from a dynamo.

40. What device could be connected to the secondary of a transformer in order to get d.c in the output ?
A. Diode
B. Rheostat
C. Resistor
D. Thermostat

41. A rectifier is used to?
A. Step up an a.c voltage
B. Step up an a.c current
C. Change an a.c voltage to a d.c voltage
D. Change a d.c voltage to an a.c voltage

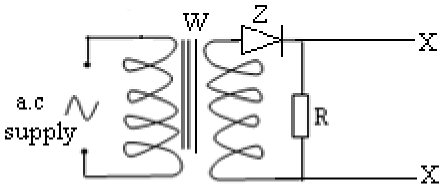
42. The number of rectifiers used in a full-wave rectification is?
A. 1 B. 2 C. 3 D. 4

43. The diagram below shows the current circuit of a thermionic diode.



a) Name the parts labeled A and B
b) Why the thermionic diode is is highly evacuated?
c) Describe briefly the action of a thermionic diode.

44. The figure below shows a charging circuit.



a) Name and state the use of each parts labeled;
   (i) W
   (ii) Z
b) Sketch the wave form that is obtained from terminals XX.

DON'TS IN AN EXAMINATION

❖ *Don't cross out work that may be partly correct*

Avoid this unless you have finished replacing it with something better.

❖ *Don't write out the question. This wastes time.*

The marks are for your solution!

❖ *What are the examiners looking for?*

The most common compliant of the examiner is "candidate failing to answer the question" This complaint is expressed in a number of ways, e.g.

- *Answer too short*
- *Answer too long*
- *Irrelevant material included*
- *Relevant material left out*
- *Answer suffers from lack of substance, absence of diagram(s) graphs / Calculations which are clearly asked for, entire parts of questions missing*
- *Failure to give correct responses to questionbeginning with the direct words (or key words) e.g.define,state, explain, describe, etc.*

DIRECTION WORDS USED BY EXAMINERS IN INSTRUCTIONS

Examiners use certain direction words in their instruction to let you know what they are expecting in the answer. Make sure that you know what they mean so that you give the right response.

Questions in physics examinations may use any of the following direction –words define, state, write down, mention, list, calculate, find, determine, deduce, hence, explain, describe, draw, sketch, what is meant by, etc. Interpreting this word wrongly can be very expensive in terms of marks or time lost. To determine how long an answer should be, a student can use:

❖ *Direction (key) word used, e.g. State, explain, etc.*

❖ *Marks allocated to the question*

1. **Define** (the term (s)……)

This only requires a formal statement, definitions must be absolutely precise

There cannot be a nearly correct definition.

Problem:

Define a newton?

Anewton is the force which gives a mass of 1kg an acceleration of 1ms^{-2}

2. **State**

This requires a concise answer with no supporting argument. You can write your answer without having to show how it was obtained. Physical laws and principals must be stated in a precise form.

Problem:

State Boyle's law

Boyle's law states thatthe volume of a fixed mass of a gas is inversely proportional to its pressure if temperature is constant.

3. **What is meant by** ……?

This normally requires a definition, together with some relevant comment and the terms concerned.

The amount of additional comment intended should be interpreted in the light of indicated mark value

Problem:

What is meant by dispersion of light?

Solution

Dispersion of light is the splitting of white light into its components colours by a glass prism.

This is because glass (prism) has different refractive indices for the different colours of white light.

4. **Explain**

This requires a candidate to make a given term or piece of information clear. Some laws and principal may be applied. Sometime a diagram or a graph may be useful.

Problem:

Explain how heat is transferred in metals..

Solution

Heat is transferred in metals by conduction.

When a metal is heated at one place, the electrons there gain more kinetic energy and therefore move faster towards the cooler part. They collide with other electrons and atoms in the cooler part to which, they pass on their energy. In this way, heat is transferred in the metal.

5. **Describe**

This require a candidate to state in words (with the aid f diagram where appropriate) the main points of the topic. It is often used with reference either to a particular phenomenon or to a particular experiment.

In the former case, the answer should include reference to observations associated with the phenomenon.

In the letter case, full details of the method, measurements, apparatus and treatment of result are required.

Problem

Describe an experiment to verify Hook's law using a spring.

Solution:See question 3(c) ,2002 P_2

Note: The candidate must be careful to cut back on the details if the question asks to "describe briefly" or to "describe concisely". Here the candidate's ability to isolate the key feature of the experiment / topics is being tested.

Problem

With the aid of a diagram, describe briefly how a pure spectrum is produced

Solution:See question 6(b), 2004/2

6. List

This requires a number of points with no collaboration. If the number of points is specified, this should not be exceeded.

Problem

List ***three*** *properties of alpha- particles*

Solution:

- *They carry a positive charge*
- *They are deflected towards the negative plate in an electric field.*
- *They are deflected in a magnetic field.*

<u>It should be noted that in this case only the first three properties given whether correct or wrong will be considered.</u>

7. **Calculations.**

The following steps are suggested in questions involving calculations

✓ Summaries the information given in the question. Use standard symbols (Clearly define any symbol which is not standard) and convert quantities too S1 units.

- ✓ A sketch diagram may sometimes be helpful.
- ✓ Spot the law or principle and equations which relate to the situation. If necessary, make reasonable assumptions or approximations and show clearly where it is done.
- ✓ Write down all your working [Remember that marks are given for the correct working even if the final answer is wrong!
- ✓ Evaluate your answer to the lowest form. Do not give answer like $\frac{g}{5}$ unless you are running out of time
- ✓ Indicate units on your final answer.
- ✓ Check that your final answer is sensible with the context of the question.

Problem
A sound wave has a velocity of 330ms^{-1} and a wavelength of 1.5m. Calculate its frequency
Solution:
- ❖ *(Summaries the given information using standard symbols and with correct units)*

Given:
V = 330ms^{-}, ^{1}x = 1.5 m, F =?

- ❖ *(Write down the relevant equation)*

Using the wave equation:
V = fʎ

- ❖ *(Show your working)*

330 = f x 1.5

$$\frac{1.5f}{1.5} = \frac{330}{1.5}$$

f = 220Hz

- ❖ *(Final answer with units)*

Hence the frequency of the wave is 220Hz.

USEFUL INFORMATION IN PHYSICS

❶ MECHANICS	
Mass	Mass is the quantity of matter which a body contains.
Volume	Volume is the amount of space occupied by an object
Density	Density is mass per unit volume of a substance $\text{Density} = \frac{\text{Mass}}{\text{Volume}}$
Relative density	Relative density is the ratio of the density of a substance to the density of an equal volume of water. RelativeDensity $= \frac{\text{Density of asubstance}}{\text{Density of equal vol. water}}$ $= \frac{\text{Mass of substance}}{\text{Mass of equal Volume of water}}$ $= \frac{\text{Weight of substance}}{\text{Weight of equal Volume of water}}$

UNEB sample Questions:		
1993 Qn.5 2002 Qn.29 2004 Qn.17 2004 Qn.39	2007 Qn.1 1997 Qn5 1999 Qn.12 2000 Qn.24	2001 Qn.11 2003 Qn.11 2006 Qn.10

Diffusion	Is the spreading of molecules from a region of higher concentration to a region of lower concentration.
Brownian motion	Is the random movement of particles due to collision with invisible air molecules which are in a state of random motion.

UNEB sample Questions:		
Particulate nature 1987 Qn36 1997 Qn.13 1999 Qn.23 2006 Qn.19	2007 Qn.25 1987 Qn.2 2001 Qn.43 2003 Qn.3 2005 Qn.49	**Size of oil molecule** 1987 Qn.7 1992 Qn.31 2004 Qn.40 1993 Qn.7 2002 Qn 45

Scalar quantity	A scalar quantity is a quantity which has magnitude only.
Vector quantity	A vector quantity is a quantity which has both magnitude and direction.
Resultant vector	Is the sum of two or more vector quantities.
Force	Force is a physical quantity which changes a body's state of rest or of uniform motion in a straight line. $\mathbf{F = ma}$
A newton	A newton is a force which gives a mass of 1kg an acceleration of 1ms^{2}.
Acceleration due to gravity	Is the rate of change of velocity of a freely falling body.
Weight	Weight of a body is the force of gravity on it. OR: Weight is the force which a body exerts on anything which freely supports it. $\mathbf{weight = mg}$ Centripetal force is the force which keeps a body moving in a circular path.
Friction	Friction is the force that opposes motion between two surfaces in contacts.
Static friction	Static friction is the friction between two surfaces at rest.
Kinetic friction	Kinetic or sliding friction is the friction between two surfaces that are moving relative to each other.
Limiting friction	Is the friction force between two surfaces which are at the verge of sliding over each other.

Coefficient of static friction	Is the ratio of limiting friction to the normal reaction.
Cohesion force	**Cohesion** is the force of attraction between molecules of the same substance.
Adhesion force	**Adhesion** is the force of attraction between molecules of different substance.
Surface tension	**Surface tension** is the tangential force acting normally per unit length across any line in the surface of a liquid. **Or** It is the force which causes the surface of a liquid to behave like a stretched elastic membrane.
Centripetal force	Is the force acting on a body moving in a circle and directed towards the centre of the circular path
Up thrust	Is the upward force which acts on bodies in fluids.

UNEB sample Questions:

Particulate nature 1987 Qn36 1997 Qn.13 1999 Qn.23 2006 Qn.19	2007 Qn.25 1987 Qn.2 2001 Qn.43 2003 Qn.3 2005 Qn.49	**Size of oil molecule** 1987 Qn.7 1992 Qn.31 2004 Qn.40 1993 Qn.7 2002 Qn45

MOMENTS

Moment	<u>**Moment of a force** is the product of</u> the force and the perpendicular distance of its line of action from the point. $\begin{pmatrix}\text{Moment}\\ \text{of a force}\end{pmatrix} = \text{force X} \begin{pmatrix}\text{perp.}\\ \text{distance}\\ \text{from}\\ \text{pivot}\end{pmatrix}$ ***<u>Principle Moments:</u>*** *When a body is in equilibrium the sum of the clockwise moment about ay point equal the sum of the anti clock wise moment.* **<u>For parallel forces in equilibrium</u>** ❖ *Sum of upward force = sum of downward forces* ❖ *Sum of anticlockwise moments = Sum of clockwise moments*
Couple	<u>A Couple: Is a pair of equal but opposite parallel forces.</u> • It causes rotation of the body • It cannot be replaced by a single fore. It can only be balanced by an equal but opposite couple. <u>A torque:</u> Is the moment of a couple.
Centre of gravity	**Centre of gravity** of a body is the point of application of the resultant force due to the earth's attraction on it.

UNEB sample Questions:

Moments and centre of gravity 2003 Qn.5 1987 Qn.10 1988 Qn.2	1988 Qn.7 1989 Qn.15 1989 Qn.38 1991 Qn.30 1993 Qn.14 2000 Qn.11	2002 Qn.11 2003 Qn.5 2007 Qn.17 2000 Qn.2 2007 Qn.5

WORK, ENERGY AND POWER

Work	Work is the product of force and distance moved in the direction of the force. **Work = Force X Distance** **i.e.W= F X d** <u>A joule</u> is the work done when a force of 1N moves through a distance of 1m. Heat is a form of energy which is transferred from one place to another due to a temperature difference between them.
Energy	Energy is the ability to do work. <u>Kinetic energy</u> is the energy which a body has because of its motion. $\mathbf{K.e = \frac{1}{2}mv^2}$ <u>Potential energy</u> is the energy which a body has because of its position or condition. $\mathbf{P.e = mgh}$ <u>Principle of conservation of energy</u>*:* *Energy is neither created nor destroyed but changes from one form to another*
Power	Is the rate of doing work $\text{Power} = \frac{\text{work done}}{\text{Time}}$ Power is the rate of transfer of energy $\text{Power} = \frac{\text{Energychanged}}{\text{Timetaken}}$

UNEB sample Questions:

Work, Energy and Power 1994 Qn.17 1989 Qn.29 2007 Qn.33 1987 Qn.24 1993 Qn.18 2006 Qn.6 1993 Qn.4	1994 Qn.5 1995 Qn.9 1987 Qn.3 1991 Qn.11 1992 Qn.11 1997 Qn.9 1997 Qn.10 1999 Qn.8	2000 Qn.23 2001 Qn.26 2003 Qn.15 2007 Qn.6 1993 Qn.4 1999 Qn.2 2005 Qn.45

MACHINES

Machine	**A machine** is a device which enables force acting at one point to overcome force acting at some other point.

Mechanical Advantage	Mechanical advantage is the ratio of the load to effort. $\text{MechanicalAdvantage(M.A)} = \frac{\text{Load}}{\text{Effort}}$
Velocity ratio	Velocity ratio is the ratio of distance moved by effort to distance moved by the load in the same time. $\text{Velocity Ratio(V.R)} = \frac{\text{Effortdistance}}{\text{Loaddistance}}$ V.R of aninclined Plan $= \frac{\text{lengthoftheplane}}{\text{heightoftheplane}} = \frac{l}{h}$ V.R of ascrew $= \frac{\text{circumferanceofcirclemadebyeffort}}{\text{Pitchofthescrew}} = \frac{2\pi r}{P}$ V.R of awheel and axle $= \frac{\text{circumferanceofwheel}}{\text{Circumferenceofaxle}}$ $= \frac{2\pi R}{2\pi r} = \frac{R}{r}$
Efficiency	Efficiency is the ratio of useful work done by a machine to the total work put into in the machine. $\text{Efficiency} = \frac{\text{workoutput}}{\text{workinput}} \times 100\%$ $\text{orEfficiency} = \frac{\text{M.A}}{\text{V.R}} \times 100\%$

UNEB sample Questions:

Machines		
1999 Qn.2	1988 Qn.34	1992 Qn.6
1994 Qn.8	1991 Qn.26	2001 Qn.42
1987 Qn.36	1998 Qn.6	2007 Qn1
	2006 Qn.4	

PRESSURE

Pressure	**Pressure** is the force acting normally per unit area. $\text{Pressure} = \frac{\text{Force}}{\text{Area}}$ i.e $\mathbf{P} = \frac{\mathbf{F}}{\mathbf{A}}$ Pressureinliquid $= \begin{pmatrix}\text{height of}\\ \text{liquid}\\ \text{column}\end{pmatrix} \times \begin{pmatrix}\text{Density}\\ \text{of liquid}\\ \text{column}\end{pmatrix} \times$ Acceleration due to gravity $\mathbf{P = h\rho g}$
	In a manometer: $\begin{pmatrix}\text{Gas}\\ \text{pressure}\end{pmatrix} = \begin{pmatrix}\text{atmosp.}\\ \text{pressure}\end{pmatrix} + h\rho g$ ***Pascal`s principle*** It states that pressure in an enclosed fluid is equally transmitted through out the fluid in all directions.
Pascal	Is the pressure exerted when a force of 1N acts on an area of $1m^2$.

UNEB sample Questions:

Pressure		
1994 Qn.25	2001 Qn.10	1993 Qn.20
2003 Qn.10	1999 Qn.17	1994 Qn16
1992 Qn.33	1994 Qn.3	1997 Qn.11
1988 Qn.13	1993 Qn.1	2002 Qn.9
1991 Qn.5	1987 Qn.40	2007 Qn.27
1995 Qn.15	1989 Qn.12	2007 Qn.30
1996 Qn.39	1990 Qn.17	2000 Qn.2
2002 Qn.9	1991 Qn.3	2003 Qn. 43
2001 Qn.27	1993 Qn.2	1995 Qn. 2

Archimedes's principle	***Archimedes's principle*** *When a body is wholly or partially immersed in a fluid it experiences an upthrust equal to the weight of the fluid displaced.* *Upthrust = weight of fluid displaced* $U = m_f g$ $\boldsymbol{U = (\rho_f V_f)}$
Principle of flotation	***Principle of flotation*** *A floating body displaces its own weight of the fluid.* *Upthrust = weight of the floating body* $U = m_b g$ $\boldsymbol{U = (\rho_b V_b) g}$ $\begin{pmatrix}\textbf{Density of}\\ \textbf{floating}\\ \textbf{object}\end{pmatrix} = \begin{pmatrix}\textbf{Fraction}\\ \textbf{submerged}\end{pmatrix} \times \begin{pmatrix}\textbf{Density}\\ \textbf{of}\\ \textbf{liquid}\end{pmatrix}$ $\text{Relative density} = \frac{\text{Fraction}}{\text{submerged}}$

UNEB sample Questions:

Archimedes principle and Floatation		
1991 Qn.7	1990 Qn.8	1990 Qn.5 PP2
1995 Qn.7	1990 Qn.9	1989 Qn.4
1988 Qn.11	2000 Qn.16	2001 Qn.2
	2001 Qn.40	

MOTION

Displacement	Displacement is the distance moved in a specified direction

Speed	Speed is the rate of change of distance moved with time. $\text{Speed} = \frac{\text{Distance}}{\text{Time}}$
Velocity	Velocity is the rate of change of displacement. OR: Velocity is the rate of change of distance moved with time in a specified direction.
Uniform velocity	Is the constant rate of change of displacement
Acceleration	Acceleration is the rate of change of velocity with time.
Uniform acceleration	<u>Uniform Acceleration</u>is the constant rate of change of velocity.
	Equations of motion 1^{st}: $\boldsymbol{v = u + at}$ 2^{nd}: $\boldsymbol{s = ut + \frac{1}{2}at}$ 3^{rd}: $\boldsymbol{v^2 = u^2 + 2as}$ $\boldsymbol{s = \frac{1}{2}gt^2}$(for a free fall) $\boldsymbol{F = ma}$

UNEB sample Questions:

Motion

1993 Qn.25	2003 Qn.26	1992 Qn.23
1997 Qn.2 PP2	1987 Qn.12	1993 Qn.25
1996 Qn.1 PP2	1987 Qn.25	1994 Qn.10
2000 Qn.1 PP1	1989 Qn.1	1994 Qn.26
1998 Qn1(b)		1996 Qn.24
2000 Qn.20		2001 Qn.25
1995 Qn.10		2006 Qn.9
		1991 Qn2
		1993 Qn5 PP2
		1999 Qn.1PP2

Newton's laws of motion	***1st law*** *A body continues in its state of rest or of uniform motion in a straight line unless an external force makes it behave differently.* ***2nd law*** *The rate of change of momentum of a body is proportional to the applied force and takes place in the direction of the force.* ***3rd law*** *To every action there is an equal and opposite reaction*
Momentum	Momentum of a body is the product of its mass and velocity **Momentum = Mass × Velocity** <u>Principle of conservation of momentum:</u> When two or more bodies act on one another, their total remains constant, provided no external force acts. Momentum before collision = Momentum after collision <u>Inelastic collisions:</u> This is where the colliding bodies stick together and move with a common velocity, V after the collision. i.e. $\mathbf{m_1u_1 + m_2u_2 = (m_1 + m_2) V}$ <u>Elastic collisions:</u> This is where the colliding bodies separate and move with different velocities after the collision. i.e. $\mathbf{m_1u_1 + m_2u_2 = m_1u_1 + m_2u_2}$
Inertia	Inertia is the tendency of a body to remain at rest or, if moving, to continue its motion in a straight line.

UNEB sample Questions:

Momentum and Newton's laws of motion

2001 Qn.1	2006 Qn.32	2000 Qn.16
1988 Qn.9	2007 Qn.24	2001 Qn.40
1994 Qn.5	1992 Qn.2	1990 Qn.5 PP2
1995 Qn.8	1994 Qn.3	1989 Qn.4
1988 Qn.20	1990 Qn.8	2001 Qn.2
2003 Qn2	1990 Qn.9	

Elasticity	<u>Elasticity</u>is the ability of a substance to recover its original shape and size after distortion. <u>An elastic material</u> is one which recovers its originals shape and size after the force deforming it has been removed. ***Hook's law:*** *The extension of a material is directly proportional to the applied force provided elastic limit is not exceeded.* Force = k(extension) $\Leftrightarrow \frac{\text{Force}}{\text{extension}} = \text{k} \Leftrightarrow \frac{\text{F}_1}{\text{e}_1} = \frac{\text{F}_2}{\text{e}_2} = \text{k}$ *or* $\frac{\mathbf{F_1}}{\mathbf{F_2}} = \frac{\mathbf{e_1}}{\mathbf{e_2}}$
Strength	Is the ability of a material to withstand forces which try to break it. OR Strength is the ability to resist the application of force without breaking.
Brittle Material	Is a material which bends very little and breaks suddenly when a tensile force acts on it.

Ductile material	Is a material which stretches first classically and then plastically before it breaks when a force acts on it.
Concrete	Is a mixture of cement, sand, gravel and water.
Stress	$\text{Stress} = \frac{\text{Force}}{\text{crosssectionalArea}} = \frac{\mathbf{F}}{\mathbf{A}}$
Strain	$\text{Strain} = \frac{\text{extension}}{\text{originallength}} = \frac{\boldsymbol{e}}{\boldsymbol{l_0}}$ $\text{Young's modulus} = \frac{\text{stress}}{\text{strain}}$
Tie	**A tie** is a girder which is in tension.
Strut	**A strut** is a girder which is in compression.

UNEB sample Questions:

Mechanical Properties of matter

1993 Qn10 1997 Qn19 1989 Qn.10 1994 Qn.4	2002 Qn.47 1996 Qn.21 2006 Qn.8 2007 Qn.40	1987 Qn.9 1990 Qn.5 1994 Qn.5

❷ HEAT

Heat	**Heat** is a form of energy which is transferred from one place to another due to a temperature difference between them.
Temperature	**Temperature** is the degree of hotness of a substance. T in Kelvin is obtained using: $\boldsymbol{T = 273 + \theta}$ **Lower fixed point** is the temperature of pure melting ice.
Lower fixed point	Is the temperature of pure melting ice
Upper fixed point	Is the temperature of the steam above water boiling at standard atmospheric pressure of 760mmHg.
Fundamental Interval	Is the length between the upper and lower fixed points.
	To obtain unknown temperature θ we use: $\frac{\boldsymbol{\theta}}{\mathbf{100}} = \frac{\boldsymbol{l_\theta - l_0}}{\boldsymbol{l_{100} - l_0}}$ $\boldsymbol{\theta} = \frac{x}{y} \times \mathbf{100}$ Where $\boldsymbol{x}$ is the length of mercury thread at temperature $\boldsymbol{\theta}$and **y** is the distance on the stem between the upper and lower fixed points (***fundamental interval***).
Conduction	**Conduction** is the flow of heat through matter from the places of higher to places of lower temperature without movement of matter as a whole.
Convection	**Convection** is the flow of a fluid from the places of higher to places of lower temperature by movement of a fluid itself.
Radiation	**Radiation** is the flow of heat from one place to another by means of electromagnetic waves.

UNEB sample Questions:

Heat, temperature and expansion

1997 Qn3 PP2 2002 Qn38 1996 Qn31 1997 Qn17 1998 Qn8 1999 Qn16 2003 Qn30 Section B 1997 Qn3 2003 Qn44	**Heat transfer** 1988 Qn12 1988 Qn18 1988 Qn31 1991 Qn4 1994 Qn33 1999 Qn9 2004 Qn11	2004 Qn33 2006 Qn17 2007 Qn36 Section B 1989 Qn2 1994 Qn1 1998 Qn3 1998 Qn5

Gas laws	❖ ***Boyle's law:*** *The volume of a fixed mass of a gas is inversely proportional to the pressure at constant temperature.* $PV = \text{aconstant i.e.} P_1V_1 = P_2V_2$ ❖ ***Charles's law:*** *The volume of a fixed mass of a gas is directly proportional to the absolute temperature at constant volume.* $\frac{V}{T} = \text{aconstant i.e.} \frac{V_1}{T_1} = \frac{V_2}{T_2}$ ❖ ***Pressure law:*** *The pressure of a fixed mass of a gas is at constant volume is directly proportional to its absolute temperature.* $\frac{P}{T} = \text{aconstant i.e.} \frac{P_1}{T_1} = \frac{P_2}{T_2}$ **Gas laws combined (Universal Gas Equation)** $\frac{PV}{T} = \text{aconstant}; \frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$
Absolute temperature	***Absolute zero*** *is the temperature at which the molecules of the gas have their possible lowest kinetic energy.* ***Or*** *Absolute zero is the lowest temperature attained before a gas liquefies and its volume reduces to zero.*

UNEB sample Questions:

Gas laws

2005 Qn4 1997 Qn3 1998 Qn16 2007 Qn4 2007 Qn43	1989 Qn13 1992 Qn6 2000 Qn33 2002 Qn12 2006 Qn15	Section B 1989 Qn7 1991 Qn10 1993 Qn3 2001 Qn3

Heat capacity	**Heat capacity** is the heat required to raise the temperature of any mass of a body by 1K. Heat energy given out (received) $= c\Delta\theta$ $= (\theta_2 - \theta_1)$
Specific heat capacity	**Specific Heat capacity** is the heat required to rise the temperature of 1Kg mass of a substance by 1K. Heat energy given out (received) $= mc\Delta\theta$ $= mc\ (\theta_2 - \theta_1)$
Latent Heat	**Latent heat**is the quantity of heat required to change the state of a substance at constant temperature.
	Specific latent heatis the quantity of heat required to change the state of a 1Kg mass of a substance without change of temperature. Heat energy given out or gained **= *ml*** (During change of state). <u>Specific Latent heat of fusion</u> is the quantity of heat required to change a 1Kg mass of a substance from solid state to liquid state without change of temperature. <u>Specific latent heat of vaporization</u> is the quantity of heat required to change a 1Kg mass of a substance from liquid sate to vapor state without change of temperature.

UNEB sample Questions:

Measurement of heat

1992 Qn4	2003 Qn39	1987 Qn14
2003 Qn13	2007 Qn28	1988 Qn19
2000 Qn4	Section B	1999 Qn15
1993 Qn3	1991 Qn3	2001 Qn34
1997 Qn15	2007 Qn2	2007 Qn8
2001 Qn34	2008 Qn2	<u>Section B</u>
1997 Qn4	**Latent heat**	1988 Qn5
2000 Qn3	1995 Qn11	1998 Qn2
2000 Qn38	2004 Qn3	1999 Qn3
2002 Qn26	1989 Qn33	2003 Qn3
2003 Qn33	2006 Qn8	1992 Qn8

Evaporation	Is the gradual change of state from liquid to gas that occurs at the liquid's surface.
Saturated Vapour	A saturated vapour is one which is in a dynamic equilibrium with its own liquid
Saturated Vapour Pressure	Saturated vapor pressure is the pressure exerted by a vapour is in a dynamic equilibrium with its own liquid
Boiling Point	Boiling point of a substance is the temperature at which its saturated vapour pressure becomes equal to the external atmospheric pressure.
Dew point	Dew point is the temperature at which the water vapour presents in the air is just sufficient to saturate it.

UNEB sample Questions:

Boiling, Evaporation and vapours

1987 Qn15	1991 Qn31	1988 Qn10
1989 Qn35	1997 Qn16	1997 Qn9
1990 Qn10	2001 Qn6	1995 Qn4
	2008 Qn4	2008 Qn41

❸ <u>GEOMETRIC OPTICS:-LIGHT</u>

REFLECTION

Reflection	Reflection is the change in the direction of a light ray or a beam of light after striking a surface. **A ray** is the direction of the path taken by light. **A beam** is a stream of light energy
Focal length	Focal length is the distance between the principal focus and the pole (for a mirror) or optical centre (for a lens).
Principal focus	Is a point on the principal axis at which all rays close and parallel to the principal axis converge after reflection at the mirror or refraction at the lens.
Centre of curvature	Is the centre of the sphere of which the mirror or lens forms part.
Radius of curvature	Is the radius of the sphere of which the mirror or lens forms part.
Magnification	Is the ratio of the height of the image to the height of the object. It is also defined as the ratio of the image distance to the object distance.
Real image	Is the image formed by actual intersection of reflected rays. It's the image which can be formed on a screen.
Virtual image	Is the image formed by apparent intersection of reflected rays. It's the image which **cannot** be formed on a screen.

UNEB sample Questions:

Rectilinear propagation of light	1997 Qn.4	**Reflection at curved surfaces**
1997 Qn.22	1998 Qn.7	2001 Qn.8
2000 Qn.34	**Reflection at plane surfaces**	2003 Qn.20
2002 Qn.27	1996 Qn.25	2005 Qn.29
2006 Qn.29	1999 Qn.28	2007 Qn.2
2006 Qn.27	1997 Qn.24	<u>Section B</u>
Section. B	2005 Qn.40	1995 Qn.5
1992 Qn.1	2007 Qn.16	1997 Qn.2 PP2
		2002 Qn.2 PP2

REFRACTION

Refraction	Is the change in the direction of light as it moves from one medium to another.
Refractive Index	Is the ratio of the sine of the angle of incidence to the sine of the angle of refraction.
Power of a Lens	Is the reciprocal of the lens's focal length in metres.
Total internal reflection	Is when light moving from a denser medium to a less dense medium is reflected when the critical angle is exceeded.
Critical angle, c	Is the angle of incidence in a denser medium when the angle of refraction in the less dense medium is 90^0.
Accommodation	Is the automatic adjustment of the eye to focus far and nearby objects by changing the focal length of the eye lens.
Minimum Deviation	Is the deviation that occurs when the angle of incidence is equal to the angle of emergency.
Dispersion	Is the separation of white light into its component colours by a glass prism.

UNEB sample Questions:

Refraction of light	**Lenses and optical instruments**	**Glass prisms**
1994 Qn40 1995 Qn24 1996 Qn1 1996 Qn35 1990 Qn4 1993 Qn9 1996Qn3PP2	1993 Qn7 2000 Qn21 2004 Qn14 2007 Qn10 1993 Qn.7 PP2 1994 Qn2 1998 Qn6 2000 Qn8	1996 Qn4 1987 Qn7 2001 Qn46 **Dispersion and colour** 1999 Qn29 1993 Qn 4 1996 Qn 16 2000 Qn 33 2001 Qn 37 2003 Qn 35 Section B 1994 Qn.4 PP2 2001 Qn.7 PP2

WAVES

Transverse Wave.	Is one in which the direction of vibration of the particles is perpendicular to the wave travel.
Longitudinal Wave	Is one in which the direction of vibration of a particle is in the same direction as the wave travel.
Wavelength	Is the distance between two successive particles which are in the same phase. *The wave length of a wave,* $\boldsymbol{\lambda}$ *in which the distance between* $\boldsymbol{n}$ *successive crests or troughs is* $\boldsymbol{x}$*, is given by;* $\boldsymbol{\lambda = \frac{x}{n-1}}$
Frequency	Is the number of complete oscillations made per second. $\text{Frequency} = \frac{\text{number of oscilations}}{\text{time taken}}$ $= \frac{1}{\text{Period time}}$ i.e $\mathbf{f = \frac{1}{T}}$
Amplitude	Is the maximum displacement of particles from its rest position.
Period	Is the time taken for a wave to make one complete oscillation.
Velocity of a wave	Is the distance moved by any point on a wave in one second. $\mathbf{V = f\lambda}$
Wave front	Is a line or section taken through by an advancing wave along which all particles are in phase.
Diffraction	Is the spreading of waves as they pass through a narrow opening.
Interference	Is a combination of waves to give a larger or smaller wave.
An echo	Is a reflected sound from a hard surface.
Reverberation	Is when the original sound and its echo merge so that they cannot de distinguished. This makes the original sound appear prolonged.
Resonance	Is when a body is set into vibrations of maximum amplitude with its own natural frequency by another nearby body vibrating with the same frequency.
Stationary wave	Is a wave formed when two progressive waves of equal frequency and amplitude travelling in opposite directions are superposed on each other.

UNEB sample Questions:		
Wave motion 1992 Qn7 1989 Qn30 1990 Qn21 1992 Qn1 1994 Qn23 1998 Qn23 1998 Qn26 2001 Qn18 2006 Qn22 2007 Qn35 2007 Qn39 2008 Qn31 1989 Qn6 1993 Qn4 2006 Qn5	**Electromagnetic waves** 1987 Qn30 1989 Qn16 2001 Qn21 2006 Qn31 2007 Qn13 **Sound waves** 2001 Qn19 1990 Qn40 1995 Qn22 1989 Qn27 1997 Qn23 1994 Qn10 2006 Qn42 2008 Qn26 1997 Qn26 1989 Qn2 1991 Qn14 1991 Qn40 1992 Qn32 1997 Qn33	1998 Qn25 1999 Qn27 2002 Qn17 2002 Qn25 **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

❺ MAGNETISM

Ferromagnetic Materials	Are materials which are strongly attracted by magnets. (i) **Paramagnetic** materials are materials that are slightly attracted by a strong magnetic field e.g Wood, Aluminium, brass, copper, platinum etc. (i)**Diamagnetic** materials are materials that are slightly repelled by a strong magnetic field e.g Zinc, Bismuth, sodium chloride, gold, mercury, e.t.c. Diamagnetic materials become weakly magnetized in a direction opposite to the magnetizing field.
Magnetic poles	Poles are places in the magnet where the resultant attractive forces appear to be concentrated. **1st law of magnetism:** *Like pole repel unlike pole attract.*
Magnetic field	Is the region surrounding a magnet in which the magnetic force is exerted.
Magnetic Meridian	Is a vertical plane containing the magnetic axis of a freely suspended magnet at rest under the action of the earth's field.
Geographical Meridian	Is a vertical plane containing the earth's axis of rotation.
Magnetic declination	Is the angle between the magnetic and Geographical meridians
Angle of dip (angle of Inclination)	Is the angle between the direction of the earth's resultant magnetic flux and the horizontal.
A neutral Point	Is a point at which the resultant magnetic field is zero.
Magnetic saturation	Is the limit beyond which the strength of a magnet cannot be increased.
Right–hand grip rule.	If the fingers of the right hand grip the solenoid in the direction of current, the thumb points to the North Pole.
Maxwell's screw rule (Right – hand screw rule)	If a right – handed screw moves forward in the direction of the current, the direction of rotation of the screw gives the direction of the field.
Electromagnetic induction	Electromagnetic induction is the production of an e.m.f in a conductor when the conductor cuts magnetic field lines.
Fleming's left hand rule (motor rule)	If the first finger, second finger and the thumb of the left hand are held at right angles, then the **F**irst finger points in the direction of the **F**ield, the se**C**ond finger in the direction of **C**urrent and the thu**M**b in the direction of the **M**otion.
Back e.m.f:	Is the e.m.f set up in opposition to the e.m.f applied to drive an electric motor.
Faradays laws	**Law 1:** Whenever a conductor cuts a magnetic field lines (or Whenever there is a change in magnetic flux linking a circuit), an e.m.f is induced. **Law 2:**The size of an induced e.m.f is directly proportional to the rate at which the conductor cuts the magnetic field lines.
Lenz's law:	The direction of induced current is such as to oppose the change causing it.
Fleming's right hand rule (Dynamo rule):	If the first finger, second finger and the thumb of the right hand are held at right angles to each other, then the **F**irst finger points in the direction of the induced **F**ield, the se**C**ond finger in the direction of induced **C**urrent and the thu**M**b in the direction of the **M**otion.
Self induction:	Is the process where an e.m.f is induced in a coil due to a changing current in the same coil.

Mutual induction:	Is the process where an e.m.f is induced in a coil due to a changing current in a near by coil not connected to the first one. **Transformer equation:** $\frac{\text{Seconary voltage}}{\text{Primary voltage}}$ $= \frac{\text{Number of turns in secondary}}{\text{Number of turns in primary}}$ $\frac{\mathbf{V_s}}{\mathbf{V_p}} = \frac{\mathbf{N_S}}{\mathbf{N_p}}$
Rectification	Is the process of changing alternating current to direct current. **A rectifier** is a device which converts a.c to d.c. **OR** It is a device which allows current to pass in one direction only.

UNEB sample Questions:

Magnetism Magnets and materials 1991 Qn23 1994 Qn1 1993 Qn37 1997 Qn29 1998 Qn32 2000 Qn36 2002 Qn20 2004 Qn8 2006 Qn14 2008 Qn18 2004 Qn41 1995 Qn7 2002 Qn6 2004 Qn4 2006 Qn3 2008 Qn3 **Magnetic effect of electric current** 1994 Qn2 1999 Qn10 1990 Qn19 1988 Q24 1990 Qn4 1991 Qn13	1994 Qn38 1995 Qn40 1997 Qn31 1998 Qn31 2001 Qn23 2003 Qn22 2005 Qn2 Section B 1992 Qn10 1997 Qn9 2000 Qn10 2007 Qn7 1987 Qn8 1993 Qn8 1997 Qn7 2001 Qn6 **Electromagnetic Induction** 2000 Qn6 2000 Qn22 2002 Qn5 2002 Qn40 2004 Qn9 Section B 2004 Qn42 2001 Qn47	**Transformers** 1999 Qn37 1995 Qn31 1997 Qn10 2003 Qn25 1989 Qn6 1989 Qn37 1992 Qn29 1993 Qn30 1994 Qn19 1994 Qn35 1995 Qn32 2002 Qn32 2005 Qn25 2007 Qn31 Section B 1987 Qn8 1993 Qn8 1997 Qn7 2001 Qn6 **Rectification** 1987 Qn32 1993 Qn17 1994 Qn30 2000 Qn39 Section B 1992 Qn8 1995 Qn9

❻ <u>ELECTRICITY</u>

1st Law of electricity:	Like charges repel, unlike charge attract.
A **coulomb**	Is the charge passing any point in a circuit when a current of 1 ampere flows for 1 second.
Cell	Is a devise which produces electricity from a chemical reaction.
Primary cells	Cells that produce electricity from an irreversible chemical reaction. Or are cells which cannot be restored to their original condition once their components are used up.
Secondary cells	Cells that produce electricity from a reversible chemical reaction. They are cells which can be recharged after they run down by passing a current through them.
Polarization	Is a defect in a simple cell which results from formation of a layer of hydrogen bubbles on the copper plate.
Local action	Is a defect in a simple cell due to impurities in zinc which results in the zinc being used up even when current is not supplied.
Resistance	Is the opposition of a conductor to the flow of current. Effective resistance for resistors in series: $R = R_1 + R_2 + R_3 + \ldots\ldots$ Effective resistance for resistors in parallel: $\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots\ldots$
	An Ohm is the resistance of a conductor in which a current of **1A** flows when a p.d of **1V** is applied across it.
	Ohm's Law: *The current passing through a metallic conductor is directly proportional to the potential difference between its ends at constant temperature.* $\text{Voltage(P.d)} = \text{Current} \times \text{Resistance}$
Potential different(p.d)	**P.d b**etween two points is the work down when 1C of electricity moves from one point to the other. $\mathbf{V = IR}$
Electromotive force(e.m.f)	E.m.f of a cell is its terminal p.d on an open circuit. OR: Is the terminal p.d of the cell when it is not supplying current. $\left(\text{Electromotive force}\right) = (\text{external P.d}) + (\text{internal P.d})$ $E = (IR) + (Ir)$ $\mathbf{E = I(R + r)}$
A volt	Is the p.d between two points such that **1J** of electrical energy is changed into other forms of energy when **1C** of charge passes from one point to the other.

Kilowatt hour (kWh)	Is the energy supplied by a device which does work at a rate of 1000J in one hour.
	$\begin{bmatrix}\text{Electricity}\\ \text{(or electrical}\\ \text{energy)}\end{bmatrix} = \text{Current} \times \text{Voltage} \times \text{time}$ $\mathbf{E = IVt = I^2Rt = \frac{V^2t}{R}}$ $\text{Ectrical Power} = \text{Current} \times \text{Voltage}$ $\mathbf{P = IV = I^2R = \frac{V^2}{R}}$
A fuse	Is short length of wire of material with a low melting point which melts and breaks the circuit when the current through it exceed a certain value.
Electrolysis	Is the process by which a substance is decomposed by passing an electric current. **1st Law of electrolysis** *The mass of substance liberated in electrolysis is proportional to the charge passed.*

UNEB sample Questions:

Current Electricity 2008 Qn32 2007 Qn48 1991 Qn35 1997 Qn35 1993 Qn15 2007 Qn3 1987 Qn29 2001 Qn31 1989 Qn32 1990 Qn32 1992 Qn8 1994 Qn21 1997 Qn30 1998 Qn34 1999 Qn35 2000 Qn37 2003 Qn23 2006 Qn38 Section B 2002 Qn50 1994 Qn5 1997 Qn8 1998 Qn8 2000 Qn9 2002 Qn7 2000 Qn9 2002 Qn7 1992 Qn15	1989 Qn11 1991 Qn28 1994 Qn24 1995 Qn29 1998 Qn37 2004 Qn6 2007 Qn12 1994 Qn32 Section B 1989 Qn7 1998 Qn6 **Electrical energy and power** 1997 Qn37 1989 Qn8 2007 Qn4 2003 Qn38 1992 Qn6 1990 Qn3 **Commercial electricity** 1995 Qn33 2002 Qn36 1988 Qn10 1990 Qn37 1991 Qn15 1998 Qn35 1999 Qn36 1999 Qn40 2003 Qn37 2006 Qn28	2006 Qn36 2007 Qn14 Section B 1992 Qn2 1997 Qn8 2008 Qn4 **Electric lighting** 1990 Qn39 1991 Qn7 1991 Qn20 1992 Qn2 1993 Qn33 1999 Qn39 2000 Qn31 2002 Qn18 1989 Qn17 2008 Qn17 Section B 1991 Qn3 2000 Qn8 **Electric cells** 19995 Qn28 1998 Qn33 1998 Qn39 2002 Qn15 Section B 1993 Qn6 1994 Qn4 1995 Qn6 1996 Qn10

❼ MODERN PHYSICS

Atomic number:	Is the number of protons in the nucleus of an atom.
Mass number:	Is the total number of protons and neutrons in the nucleus of an atom.
Isotopes:	Are atoms of the same element having the same atomic number but different mass numbers. **OR** Are atoms of the same element having the same number of Protons but different number of neutrons.
Cathode rays:	Are streams of fast-moving electrons.
Thermionic emission:	Is the process by which electrons are released from a heated metal surface.
Photo electric effect:	Is the process by which electrons are released from a metal surface when radiation of the right (sufficient) frequency falls on it.
X-Rays:	Are radiations of electromagnetic waves that are produced when fast moving electrons are stopped by matter.
Radioactivity	Is the spontaneous disintegration of unstable element with emission of radiations.
Radioisotope	Is an isotope which undergoes spontaneous disintegration with emission of radiations.
An alpha Particle	Is a helium nucleus which has lost two electrons. α–decay: $\boldsymbol{{}^{A}_{z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He}$
Bata particles	are streams of high – energy electrons. β – decay: $\boldsymbol{{}^{A}_{z}X \rightarrow {}_{Z+1}^{A}Y + {}^{0}_{-1}e}$
Gamma rays	are electromagnetic radiation of short wavelength. γ – decay: $\boldsymbol{{}^{A}_{z}X \rightarrow {}^{A}_{Z}Y + \gamma - rays}$
Half – life	Is the time taken for a radioactive substance to decay to a half its original amount. The mass remaining after a time t, $\mathbf{M_t}$, when an original sample of mass $\mathbf{M_o}$decays with a half- life of $\mathbf{t_{\frac{1}{2}}}$ is given by; $\mathbf{M_t = M_o\left(\frac{1}{2}\right)^n}$**:** Where, $\mathbf{n = \frac{t}{t_{\frac{1}{2}}}}$ Then the mass decayed after a time T is given by; $\mathbf{M_{Decayed} = M_o - M_t}$

	OR: Using the table <table><tr><th>Time taken T</th><th>Mass remaining M_t</th><th>Mass Decayed $M_D = M_o - M_t$</th></tr><tr><td>0</td><td>M_0</td><td>0</td></tr><tr><td>$t_{\frac{1}{2}}$</td><td>$\frac{1}{2^1}M_o$</td><td></td></tr><tr><td>$2t_{\frac{1}{2}}$</td><td>$\frac{1}{2^2}M_o$</td><td></td></tr><tr><td>$3t_{\frac{1}{2}}$</td><td>$\frac{1}{2^3}M_o$</td><td></td></tr><tr><td>-</td><td>-</td><td></td></tr><tr><td>-</td><td>-</td><td></td></tr><tr><td>$nt_{\frac{1}{2}}$</td><td>$\frac{1}{2^n}M_o$</td><td></td></tr></table> Where: $\mathbf{nt_{\frac{1}{2}} = t}$
	OR: Using the crude method: $M_0 \xrightarrow{t_{\frac{1}{2}}} \frac{1}{2}M_o \xrightarrow{t_{\frac{1}{2}}} \frac{1}{4}M_o \xrightarrow{t_{\frac{1}{2}}} \frac{1}{8}M_o$.
Nuclear fission	Is a process whereby a heavy nucleus splits into lighter nuclei with release of energy.
Nuclear fusion	Is a process whereby light nuclei combine to form a heavy nucleus with release of energy
Background radiation	Is the radiation which originates from radioactive compounds in the earth's crust and from particles and rays from outer space.

UNEB sample Questions

Atomic physics 1991 Qn18 1990 Qn7 1990 Qn11 1991 Qn8 1994 Qn9 1995 Qn18 2004 Qn22 2004 Qn32 2006 Qn21 2007 Qn20 2008 Qn2 <u>Section B</u> 1987 Qn3 2004 Qn. **Thermionic emission** 1987 Qn28 1988 Qn3 1997 Qn18 1999 Qn20 2002 Qn19 2004 Qn23	2007 Qn38 2008 Qn25 Section B 1991 Qn8 2002 Qn8 2005 Qn48 **X-rays** 1987 Qn16 1987 Qn22 1989 Qn36 1990 Qn16 1991 Qn38 1992 Qn22 1994 Qn39 1995 Qn25 1999 Qn30 2002 Qn10 Section B 1988 Qn5 2000 Qn4 2000 Qn6 2007 Qn8 **Radioactivity**	Section B 1990 Qn2 1994 Qn6 1997 Qn6 1999 Qn6 2001 Qn50 **Half - life** 1994 Qn15 1987 Qn6 2005 Qn36 1994 Qn6 2001 Qn4 2002 Qn23 2008 Qn8 1992 Qn18 1993 Qn28 1995 Qn19 1995 Qn20 1997 Qn40 1999 Qn23 2000 Qn4 2004 Qn30

2004 Qn34 2005 Qn33 2007 Qn5 2008 Qn27 Section B 1995 Qn1 2000 Qn6 2003 Qn8 2004 Qn8 **Cathode ray oscilloscope** 1988 Qn40 1994 Qn34 1998 Qn11 1999 Qn21 1999 Qn22 2001 Qn16 2002 Qn7 2002 Qn21	1997 Qn8 1989 Qn6 1988 Qn9 1998 Qn8 1989 Qn7 1990 Qn3 1992 Qn7 1993 Qn31 1997 Qn20 1997 Qn38 1998 Qn27 2000 Qn2 2000 Qn28 2002 Qn3 2003 Qn17 2004 Qn20 2005 Qn18 2008 Qn16	2005 Qn36 2006 Qn23 Section B 1988 Qn3 1990 Qn2 1996 Qn6 2000 Qn4 **Nuclear reactions** 2008 Qn44 1991 Qn1 1993 Qn22 1994 Qn18 2000 Qn7 2001 Qn17 Section B 1993 Qn2 2006 Qn6 1999 Qn5