INTRODUCTION

Physics is the study of the properties of matter with respect to energy changes. These energy changes occur with respect to space and time. In order to understand physics, measurements of the changes in the observed physical quantities are carried out.

Physical quantity is any quantity that can be measured using a specific instrument or calculated and has specific units e.g. time, length, speed, force e.t.c.

CLASSIFICATION OF PHYSICAL QUANTITIES

Physical quantities can be classified in to
(a) **Vectors quantities or scalar quantities**
(i) Vector quantities are physical quantities with both magnitude (size) and direction e.g. velocity, acceleration, force, weight, displacement e.t.c
(ii) Scalar quantities are physical quantities with magnitude only e.g. mass, time, distance, volume e.t.c
(a) **Basic quantities or Derived quantities**
(i) Basic physical quantities are the fundamental quantities where other quantities are derived from e.g. mass, time, length e.t.c
(ii)Derived physical quantities are got combining two or more basic physical quantities e.g. area, speed, density e.t.c

UNITS

A unit is a chosen standard size to which the measurements of a physical quantity is compared. The international accepted units in which physical quantities are measured are to be referred to as S.I units (International system of units)

There are 7 basic physical quantities tabulated below and their corresponding S.I units.

Basic physical quantity	S.I unit	Symbol
Mass	Kilogram	Kg
Time	Second	s
Length	Meter	m
Temperature	Kelvin	K
Luminous intensity	Candela	Cd
Electric current	Ampere	A
Amount of substance	Mole	mol

Some of the examples of derived physical quantities are given below

Derived physical quantity	**S.I unit**	**Symbol**
Area	Square meter	m^2
Volume	Cubic meter	m^3
Speed	Meter per second	m/s
Density	Kilogram per cubic meter	Kg/m^3

Some derived S.I units have been given special names e.g. units of

(i) Force

$F = ma[Kg][m/s^2]$

The unit Kgm/s^2 is called a Newton [N]

(ii) Pressure

$P = \frac{F}{A} \quad \frac{[Kg][m/s^2]}{[m^2]}$ This unit is called a Pascal [Pa]

PREFIXES

In order to avoid writing very big or small values some prefixes are used in conjunction with the S.I unit for are given dimension. Some of the prefixes used with S.I units of all kinds are listed in the table below.

Prefix	**Value**	**Abbreviation**
Pico -	10^{-12}	P
Nano -	10^{-9}	N
micro -	10^{-6}	μ
Milli -	10^{-3}	M
cent -	10^{-2}	C
kilo -	10^{3}	K
mega -	10^{6}	M
Giga -	10^{9}	G
tera -	10^{12}	T

e.g. $10km = 1 \times 10^3m = 1000m$

$15MA = 15 \times 10^6A = 15\ 000\ 000A$

MECHANICS

MEASUREMENTS

(A) MEASUREMENT OF LENGTH

Length is the one dimensional space between two fixed points. The S.I unit of length is meter (m). Other units in which length or distance can be measured conveniently can be expressed with the prefixes given above.

The instruments commonly used for measuring different dimensions of length are

(i) Measuring tape
(ii) Meter rule
(iii) Vernier caliper
(iv) Micrometer screw gauge
(v) Engineer's caliper

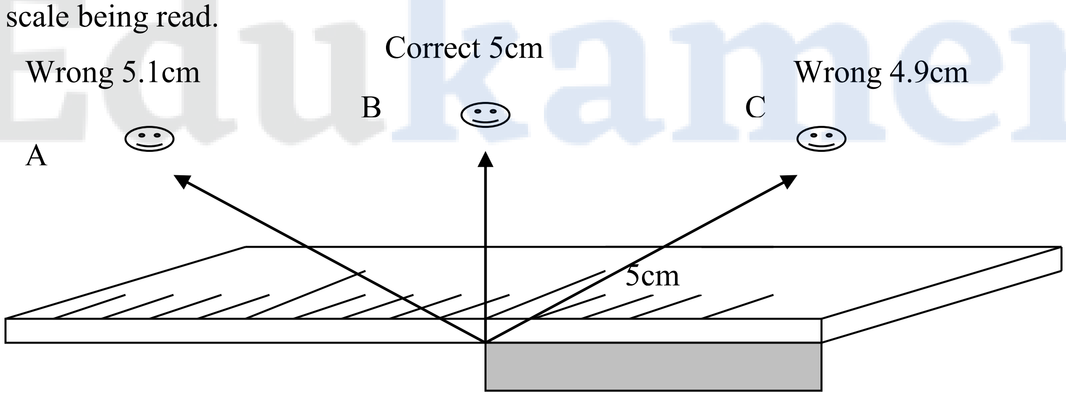
(a) MEASURING TAPE

This is used to measure large distances e.g. length of a football field.

(b) METER RULE

The meter rule is used to measure relatively larger dimensions of length such as the length of a table. It is not very accurate for measuring very small dimensions of length such the thickness of a piece of paper. In order to attain accurate measurements when using a meter rule the following precautions must be taken.

(i) Avoid the zero error.
Always make correction for zero error if the measurement did not start at the zero mark.
(ii) Avoid the error due to parallax by positioning your eye directly above the mark of the scale being read.



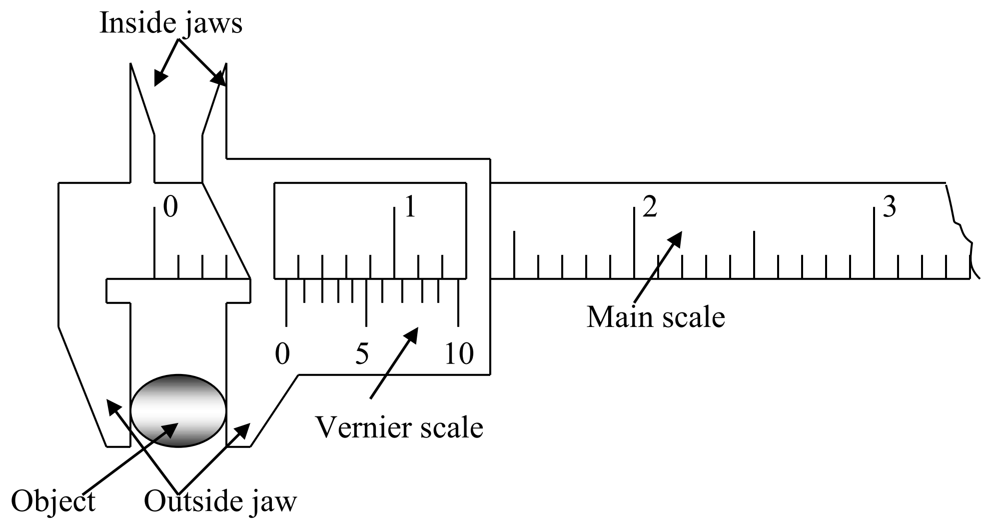
The correct reading is got when the eye is positioned at B. Position A and B are wrong because of the error due to parallax.

The smallest dimension which an instrument can measure is called its accuracy. The accuracy of a meter rule is 1mm or 0.1cm

(c) VERNIER CALIPER

The vernier caliper is an instrument used to measure the internal and external diameter of cylindrical object such as a water pipe. The vernier caliper is more accurate than a meter rule and it is used to measure small dimensions of length.

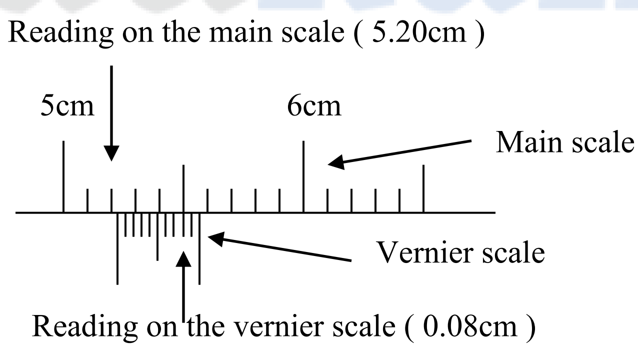
The vernier caliper has two linear scales i.e. fixed (main) scale and moving (vernier) scale which has 10 subdivisions.



The object whose diameter is to be measured is clamped between jaws of the vernier caliper as shown above.

HOW TO READ A VERNIER CALIPER

Consider the vernier caliper reading below



(i) Get the reading from the main scale just before the start of the vernier scale. This gives the first decimal number reading.

(ii) Get the reading on the vernier scale which coincide with the one from the main scale. This gives the second decimal number reading.

(iii) Add the two readings.

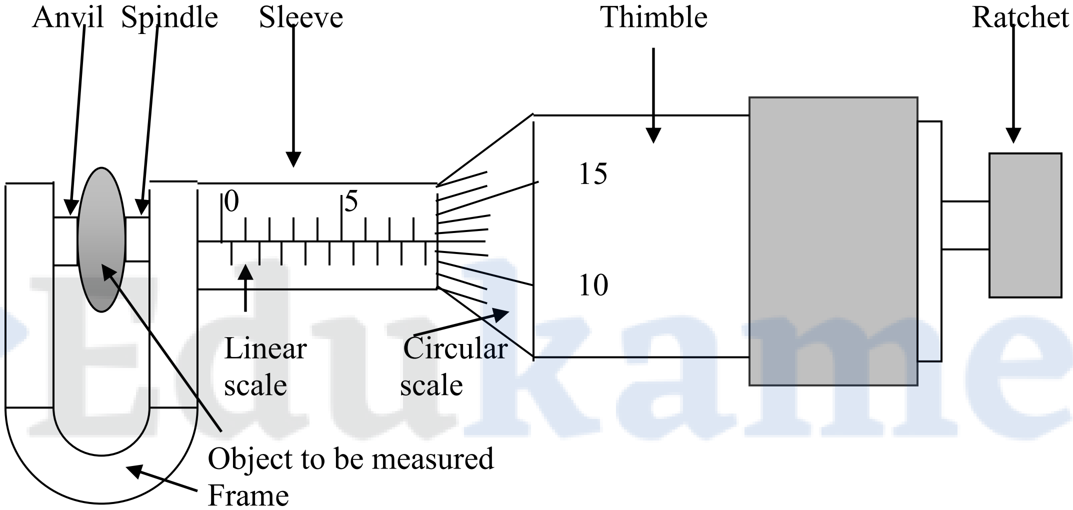
Main scale = 5.20cm
Vernier scale = + 0.08cm
Final reading = 5.28cm

It can be seen that the accuracy of a vernier caliper is 0.01cm or 0.1mm.

(d) MICROMETER SCREW GAUGE

The micrometer screw gauge is a very sensitive instrument for measuring very small dimensions of length such as the thickness of a metal wire, hair or paper. The micrometer screw gauge is more accurate than the vernier caliper. The main parts of a micrometer screw gauge are anvil and spindle where you clamp the object to be measured, the sleeve where there is the linear or fixed scale, the thimble where there is the circular or rotating scale and the ratchet.

The linear scale is graduated in half mm graduations and the circular scale represents 0.01mm of the movement of the spindle. The spindle is driven forward and backwards by the screw which is inside the thimble.



The reading shown above is

Reading from the linear scale	=	8.50mm
Reading from the circular scale	= +	0.12mm
Final reading	=	8.62mm

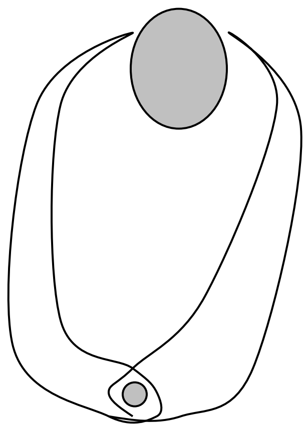
PRECAUTIONS TAKEN WHEN USING A MICROMETER SCREW GAUGE

(i) Wipe dust from the anvil and spindle
(ii) Wipe the object to be measured
(iii) Use the ratchet for tightening the instrument as you clamp the object until you hear a click sound to avoid over tightening of the screw which may cause damage to the screw or deformation of the object.
(iv) Make correction for the zero error if it exists as a result of the zero mark on the circular scale not being able to coincide with the middle line of the fixed scale when the instrument is in the closed position.

The accuracy of a micrometer screw gauge is 0.01mm.

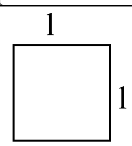
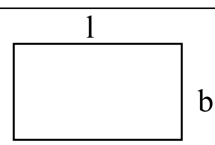
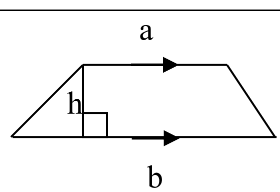
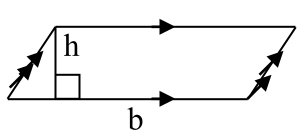
(e) <u>ENGINEER'S CALIPER</u>

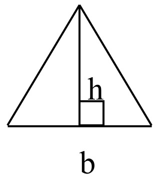
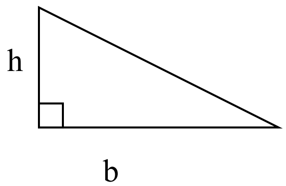
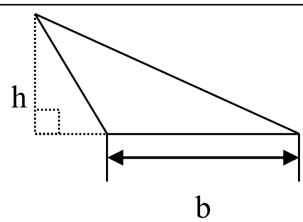
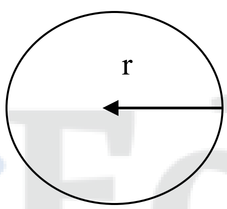
The engineer's caliper is used to measure the internal and external diameters of hollow objects such as pipes. The object to be measured is clapped in the in the jaws of the calipers. The instrument has no scale attached to it. The calipers are locked in position once they have been used to mark the dimension and the measurements are red off by laying the caliper points onto a scale ruler.



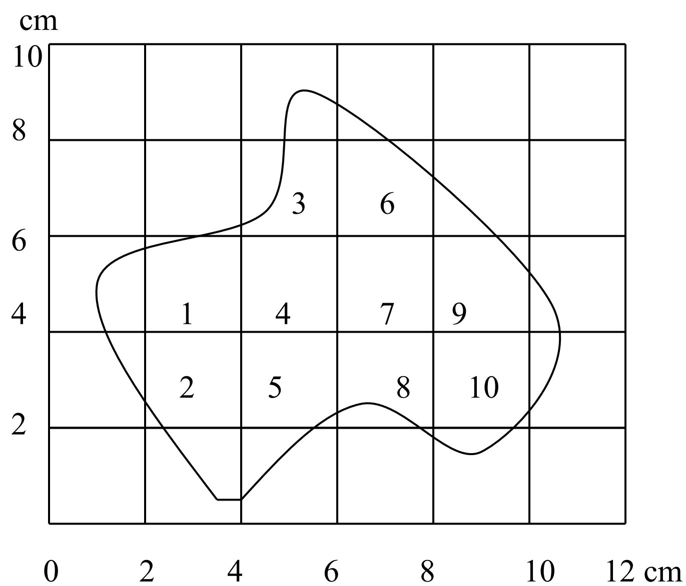
(B) MEASUREMENT OF AREA

Area is a two dimensional space in a given plane. S.I unit of area is meter squared [m^2]. The area of regular figures whose dimensions are known can be calculated. Some selected figures are given in the table below.

Shape	**Name**	**Formula of area**
	Square	A = l x l = l^2
	Rectangle	A = l x b = lb
	Trapezium	$A = \frac{1}{2}(a+b)h$
	Parallelogram	A = bh

	Acute triangle	$A=\frac{1}{2}bh$
	Right angled triangle	$A=\frac{1}{2}bh$
	Obtuse triangle	$A=\frac{1}{2}bh$
	Circle	$A = \pi r^2$

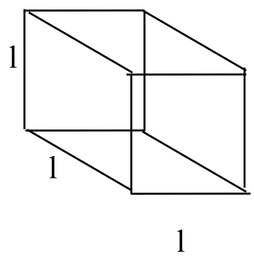
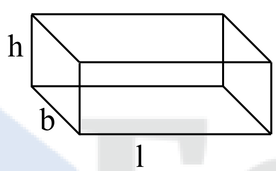
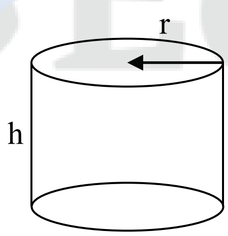
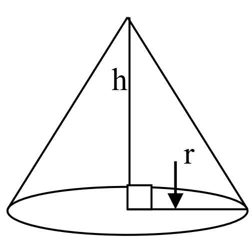
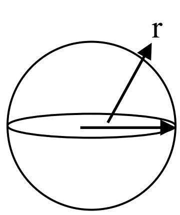
For **irregular** objects the area is found using the approximate method. Subdivide the area in small squares. Count the number of half or more than half complete squares inside the area. Multiply the number of counted squares with the are of one square.



Area of one square = 2 x 2 = 4cm^2
Area of the figure = 4 x 10 = 40cm^2

(C) MEASUREMENT OF VOLUME

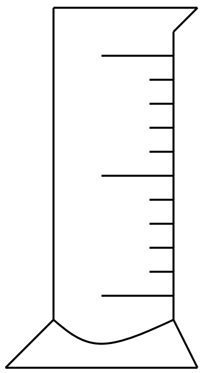
Volume is a three dimensional space occupied by an object. S.I unit is cubic meter (m^3). For regular shaped objects with known dimensions, volume can be calculated.

Shape	Name	Formula for volume
	Cube	V = l x l x l = l^3
	Cuboid	V = l x b x h = lbh
	Cylinder	$V = \frac{1}{3}\pi r^2 h$
	Cone	$V = \frac{1}{3}\pi r^2 h$
	Sphere	$V = \frac{4}{3}\pi r^3$

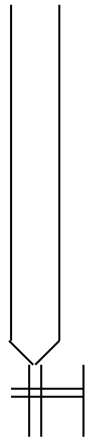
VOLUME OF LIQUIDS

The volume of liquids can be measured using the following apparatus.

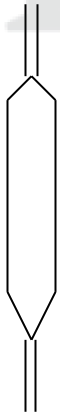
(a) Measuring cylinder



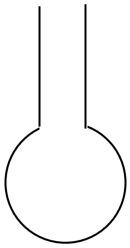
(b) Burette



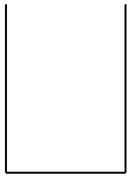
(c) Pipette



(d) Volumetric flask



(e) Beaker



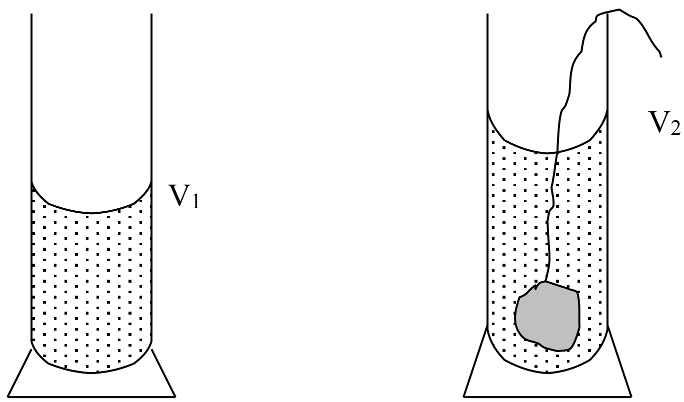
The measuring cylinder is the one which is mostly used to measure the volume of a liquid. Pour the liquid in a measuring cylinder to a given mark and get the reading.

VOLUME OF IRREGULAR SHAPED OBJECTS

Volume of irregular shaped objects is measured using the **displacement method**. The volume of the displaced liquid is equal to the volume of the immersed object.

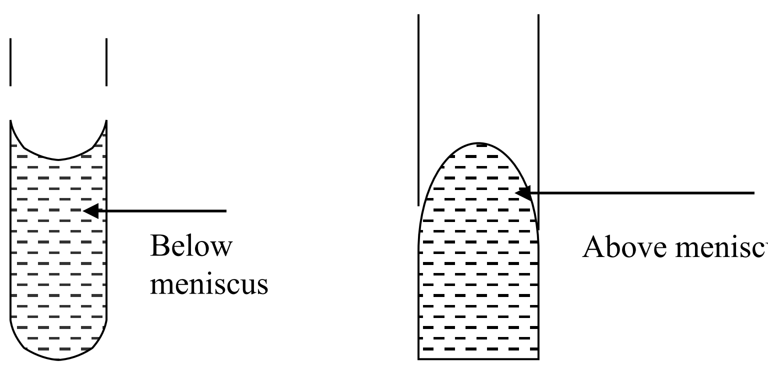
(i) USING A MEASURING CYLINDER

- Pour a liquid in a measuring cylinder and record the volume as V_1.
- Tie the irregular shaped object to very thin string and lower in the measuring cylinder. The volume rises to V_2.
- The volume of the object is given by $V = V_2 - V_1$.



PRECAUTIONS

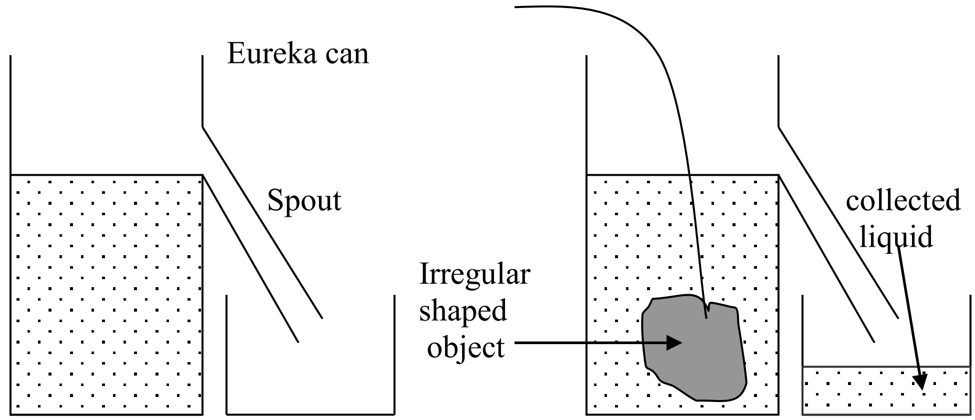
- Lower the object gently to avoid splashing of the liquid
- Make sure the solid is insoluble.
- Use a light thin string to tie the object.
- Avoid parallax error by taking the reading directly below the meniscus for less denser liquids and above the meniscus above the meniscus for denser liquids



- Put the measuring cylinder on a flat horizontal surface.
- Make sure the liquid has stopped shaking before taking the reading.
- Scale must face your direction.

(ii) USING A EUREKA OR OVERFLOW OR DISPLACEMENT CAN

Pour the liquid in the Eureka can until it overflows from the spout.



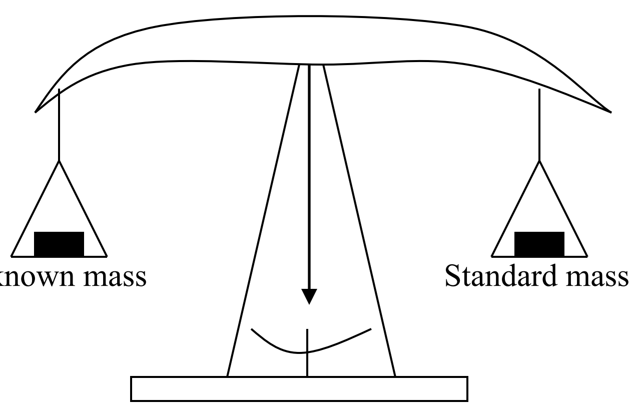
Wait until the water has stopped overflowing then lower the stone tied to a very thin string gently in the can. The water displaced by the stone will be collected in the beaker as shown. The volume of the stone is equal to the volume of the displaced water.

PRECAUTIONS

- Before lowering the stone fill the can to the spout until the water overflows.
- Wait until the water stops to dropping from the spout before lowering the stone.
- Lower the stone gently to avoid splashing.
- Use a very thin string.
- Make sure that the stone is completely immersed in the water.
- Make sure the stone is insoluble
- Put the can on the horizontal surface.

(D) MEASUREMENT OF MASS

Mass is the amount of matter contained in an object. It is measured using a **Beam balance**. The beam balance measures mass of the object by comparing the mass of an object to the mass of the standard mass using the principle of moments.



Mass is measured in kilograms [kg] and because it is the amount of matter in a substance it is always constant. Mass is a scalar quantity.

(E) MEASUREMENT OF WEIGHT

Weight is defined as the gravitational force acting on an object. Different planets have different magnitudes of gravitational force. Therefore the weight of an object changes depending on the gravitational field strength e.g. 1kg object has weight of 10N on the surface of the earth and the same object has weight of about 2N on the surface of the moon.

Weight = Mass x Gravitational field strength.

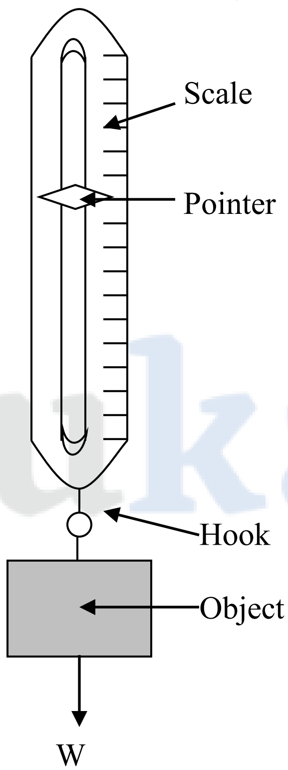
$$w = mg$$

where w = weight

m = mass and

g = gravitational field strength or acceleration due to gravity

The S.I. unit of weight is a Newton [N]. Weight is a vector quantity, since it is always directed towards the centre of the planet. Weight is measured using a spring balances.



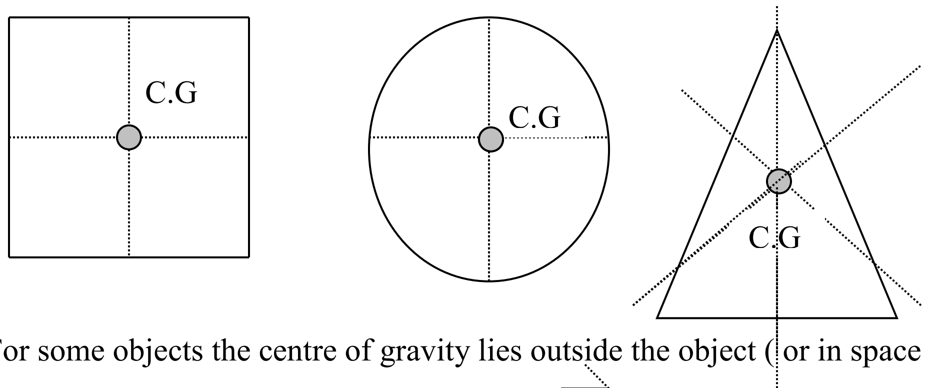
DIFFERENCES BETWEEN MASS AND WEIGHT

No	MASS	WEIGHT
1	Mass is constant	Weight varies
2	Mass is a scalar quantity	Weight is a vector quantity
3	Mass is measured using a beam balance	Weight is measured using a spring balance
4	Mass is measured in kilograms [kg]	Weight is measured in Newtons [N]
5	Mass is the amount of matter contained in an object	Weight is the gravitational force acting on an object
6	Mass is a basic physical quantity	Weight is a derived physical quantity

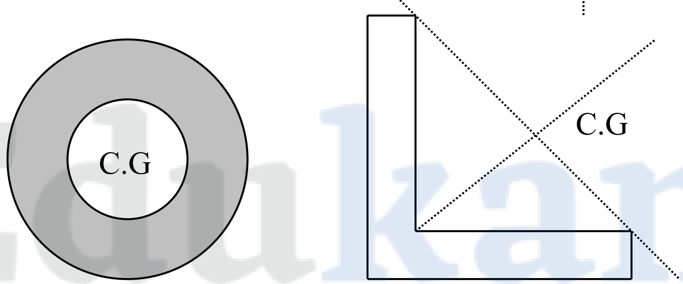
CENTRE OF MASS AND CENTRE OF GRAVITY

- The centre of mass of a body is the point on a body where the mass seems to be concentrated.
- The centre of gravity of a body is a point where the weight of the body acts.

For most rigid bodies the centre of mass and centre of gravity lie on the same point. The centre of mass and gravity of regularly shaped bodies is located at the point where the lines of symmetry meet. This is the geometric centre of the object.



For some objects the centre of gravity lies outside the object (or in space)

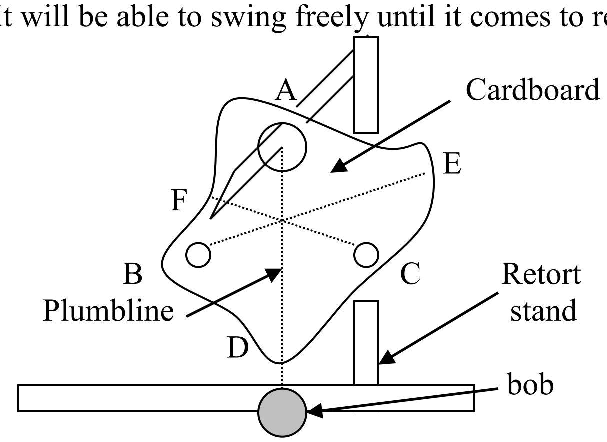


<u>HOW TO FIND THE CENTRE OF GRAVITY FOR AN IRREGULLAR SHAPED OBJECT OR LAMINA</u>

To find centre of gravity of an irregular shaped lamina (like a card board). The following methods can be used.

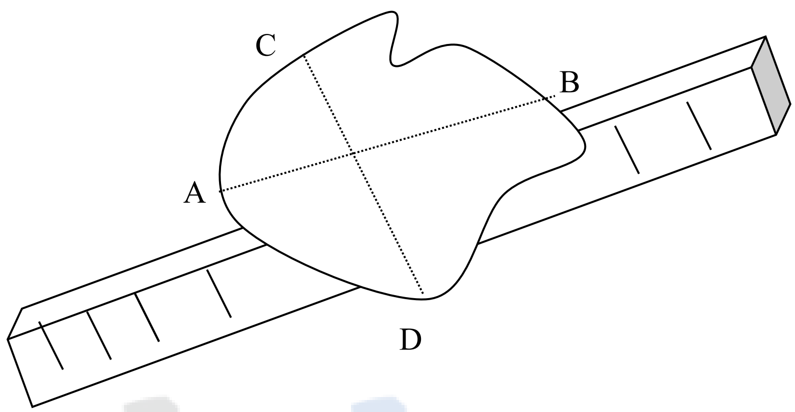
(a) <u>PLUMBLINE METHOD</u>

Make three holes at well spaced intervals around the edge of the lamina mark them A, B and C. Suspend the lamina through the hole marked A on the nail (pin) hold on the clamp stand so that it will be able to swing freely until it comes to rest.



Now suspend the plumbline (string with a bob) on the nail on which the lamina is suspended as shown above. Mark straight line AD on the lamina were the plumbline passes because this is the line where the centre of gravity lies. Repeat the procedure by suspending the lamina through B and draw the line BE using the plumbline. Where the lines AD and BE intersects is the position of the centre of gravity. For proof if the position of the centre of gravity is correctly located suspend the lamina through the hole marked C and check if the plumbline will pass through the centre of gravity.

(b) <u>BALANCING METHODE</u>



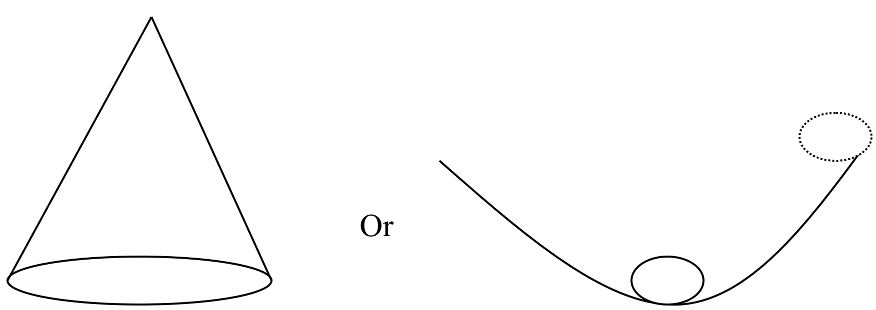
Balance the lamina on the metre rule as shown above and mark the line AB along the edge of the metre rule where the lamina balances. Then turn the lamina so that it can also balance in a different direction. Mark the new balancing line CD. Where AB and CD meet is the centre of gravity.

EQUILIBRIUM OF BODIES

A body is said to be in equilibrium when it's resultant force and resultant moment (torque) are both zero. There are three types of equilibria

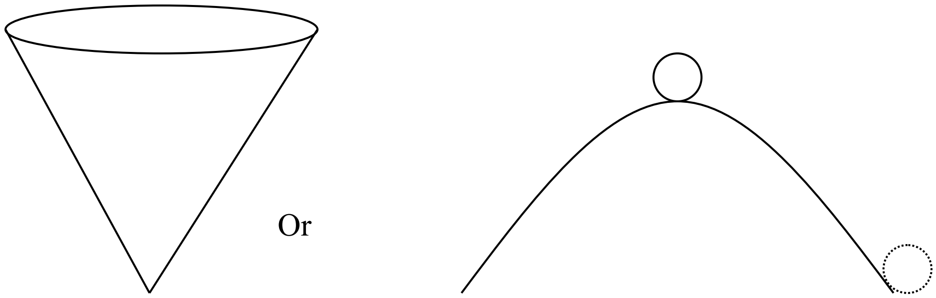
(a) <u>STABLE EQUILIBRIUM</u>

A body is in stable equilibrium if it always returns to it's original resting position whenever it is tilted and then released

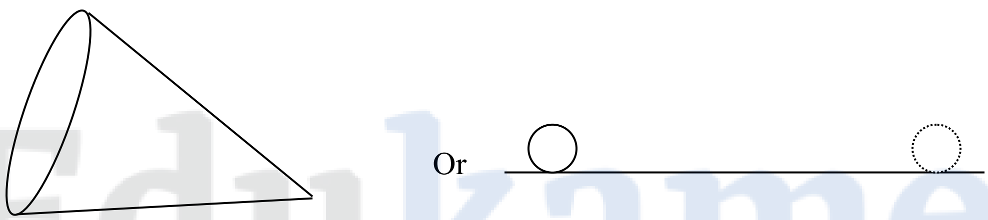


(b) UNSTABLE EQUILIBRIUM

The body is in unstable equilibrium if it topples or over turns whenever it is slightly disturbed.



(c) NEUTRAL EQUILIBRIUM
The body is in neutral equilibrium if it remains at rest on the new position when disturbed.



HOW TO INCREASE THE STABILITY OF A BODY

Stability is the tendency of a body to remain in stable equilibrium. Stability can be increased by
(a) Lowering the centre of mass (or gravity)
(b) Widening the base area.

(F) MEASUREMENT OF DENSITY

Density is the mass per unit volume. It is the amount of matter contained in a unit volume of a substance it's symbol is rho - ρ

$$Density = \frac{mass}{volume} \qquad \rho = \frac{m}{v}\left[\frac{kg}{m^3}\right]$$

The S.I unit for density is therefore kg/m^3 but sometimes g/cm^3 is used for convenience.

$$1kg/m^3 = \frac{1kg}{1m^3} = \frac{1x1000g}{1x1000000cm^3} = \frac{1}{1000} g/cm^3$$

$$1000kg/m^3 = 1g/cm^3$$

The density of pure substances is always constant. Some selected examples are given.

Substance	Density kg/m³	Density g/cm³	Relative density
Aluminium	2700	2.7	2.7
Brass	8500	8.5	8.5
Copper	8900	8.9	8.9
Gold	19300	19.3	19.3
Iron	7860	7.86	7.86
Alcohol	790	0.79	0.76
Mercury	13600	13.6	13.6
Water	1000	1	1

DENSITY OF REGULAR SOLIDS

Measure the mass 'm' using a beam balance and calculate the volume 'v' if the dimensions are given.

e.g. (a) Find the density of an object of mass 800g and dimensions 6cm x 2cm x 5cm
(b) Express the density in kg/m^3

Solution

(a) $v = 6 \times 2 \times 5$
$= 60cm^3$

$$\rho = \frac{m}{v}$$
$$= \frac{800}{60}$$
$$= 13.33 g/cm^3$$

(b) $\rho = 1000 x 13.33$
$= 1333 kg/m^3$

DENSITY OF IRREGULAR SOLID

First measure the mass 'm' using a beam balance. Then find the volume 'v' using the displacement method. Then calculate the density using the formula for density

$$\rho = \frac{m}{v}$$

DENSITY OF A LIQUID

Measure the mass 'm_1' of an empty measuring cylinder. Pour the liquid in the measuring cylinder and find the new mass 'm_2' of the measuring cylinder and the liquid.

Mass of the liquid 'm' = $m_2 - m_1$
Read the volume 'v' of the liquid from the measuring cylinder and calculate the density from the formula

$$\rho = \frac{m}{v} = \frac{m_2 - m_1}{v}$$

NOTE: To find the density of a very large object e.g. moon
- Get a small piece from the object and find it's density
- The density of the small piece = density of the large object.

DENSITY OF MIXTURES

To find the density of the mixture of substances which do not react chemically (physical mixing). Find the mass and volume of the mixture and use the formula

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

The density of the mixture lies between the densities of the components of the mixture depending on which one is more the mixture.

Examples
(i) Alcohol of density 790kg/m^3 and mass 15.8kg is mixed with water of density 1000kg/m^3 and mass 2.5kg. Find the density of the mixture.

Substance	**Volume in m^3**	**Mass in kg**	**Density in kg/m^3**
Alcohol	0.02	15.8	790
Water	*0.0025*	2.5	1000
Mixture	*0.0225*	*18.3*	822.22

Calculations

From $\rho = \frac{m}{v}$ $\quad v = \frac{m}{\rho}$

Volume of water = $\frac{2.5}{1000} = 0.0025m^3$

Volume of alcohol = $\frac{15.8}{790} = 0.02m^3$

Volume of mixture = $0.02 + 0.0025 = 0.0225m^3$

Mass of mixture = mass of water + mass of alcohol
= $2.5kg + 15.8kg = 18.5kg$

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

$$= \frac{18.5}{0.0225} = \underline{822.22kg/m^3}$$

(ii) Iron of density $7860kg/m^3$ is mixed with brass of density $8500kg/m^3$ to make steel of density $8000kg/m^3$ and volume $80m^3$. Find

(a) the masses of iron and brass

(b) the volumes of iron and brass in the alloy.

Substance	**Volume in m^3**	**Mass in kg**	**Density in kg/m^3**
Iron	V_{Iron}	M_{Iron}	7860
Brass	V_{Brass}	M_{Brass}	8500
Steel	80	640000	8000

<u>Calculation</u>

From $\rho = \frac{m}{v}$ $\quad m = \rho x v$

Mass of steel = $8000x80 = 640000kg$

$V_{Iron} + V_{Brass} = 80$……………………….(1)

$M_{Iron} + M_{Brass} = 640000$…………………..(2)

But M_{Iron} = density of iron x volume of iron

$= 7860V_{Iron}$ ……………………(3)

and M_{Brass} = density of brass x volume of brass

$8500V_{Brass}$…………………..(4)

Replacing equations (3) and (4) into equation (2)

$7860V_{Iron} + 8500V_{Brass} = 640000$…………..(5)

From equation (1) $V_{Iron} = 80 - V_{Brass}$ replace into (5)

$7860 (80 - V_{Brass}) + 8500V_{Brass} = 640000$

$628800 - 7860V_{Brass} + 8500V_{Brass} = 640000$

$628800 + 640V_{Brass} = 640000$

$640V_{Brass} = 640000 - 628800 = 11200$

$V_{Brass} = \frac{11200}{640}$

$\underline{V_{Brass} = 17.5m^3}$

From $V_{Iron} = 80m^3 - V_{Brass}$

$V_{Iron} = 80m^3 - 17.5m^3$
$\underline{V_{Iron} = 62.5m^3}$

From $M_{Iron} = 7860V_{Iron}$
$= 7860 \times 62.5$
$\underline{= 491250kg}$

and $M_{Brass} = 8500V_{Brass}$
$= 8500 \times 17.5$
$\underline{= 148750kg}$

RELATIVE DENSITY

Relative density is defined as the ratio of the density of a substance to that of water. It has no units because it is a ratio.

$$Relative\ density = \frac{density of\ a\ subsatnce}{density of\ water}$$

e.g. Density of mercury is $13600kg/m^3$ and that of water is $1000kg/m^3$

$$Relative density of\ mercury = \frac{13600kg/m^3}{1000kg/m^3}$$

$$= 13.6$$

From the formula for relative density

$$\text{Relative density}\,(R.D) = \frac{\text{density of a subsatnce}}{\text{density of water}}$$

$$\text{but } \rho = \frac{m}{v} \qquad \text{where}$$

$$RD = \frac{\rho_s}{\rho_w}$$

$$R.D = \frac{m_s / v_s}{m_w / v_w} \qquad m_s = \text{mass of substance}$$

$$R.D = \frac{m_s}{v_s} \div \frac{m_w}{v_w} \qquad m_w = \text{mass of water}$$

$$= \frac{m_s}{v_s} \times \frac{v_w}{m_w} \qquad v_s = \text{volume of substance}$$

$$v_w = \text{volume of water}$$

If the volume of substance is equal to the volume of water ($v_s = v_w$)

$$\therefore R.D = \frac{m_s}{m_w} \quad \text{If } v_s = v_w$$

$$\text{Relative density} = \frac{\text{mass of the subsatnce}}{\text{mass of an equal volume of water}}$$

$$\text{again } w = mg$$

$$\therefore \text{Relative density} = \frac{m_s \times g}{m_w \times g} = \frac{w_s}{w_w} \text{ if } v_s = v_w$$

$$\text{Relative density} = \frac{\text{weight of a substance}}{\text{weight of an equal volume of water}}$$

again from the equation of relative density

$$R.D = \frac{\text{density of substance in } kg/m^3}{\text{density of water in } kg/m^3}$$

$$R.D = \frac{\text{density of a substance } kg/m^3}{1000 kg/m^3}$$

$$R,D = \text{density of a substance in } g/cm^3$$

e.g.

$$\rho_{Hg} = 13.6 g/cm^3$$

$$R.D_{Hg} = 13.6$$

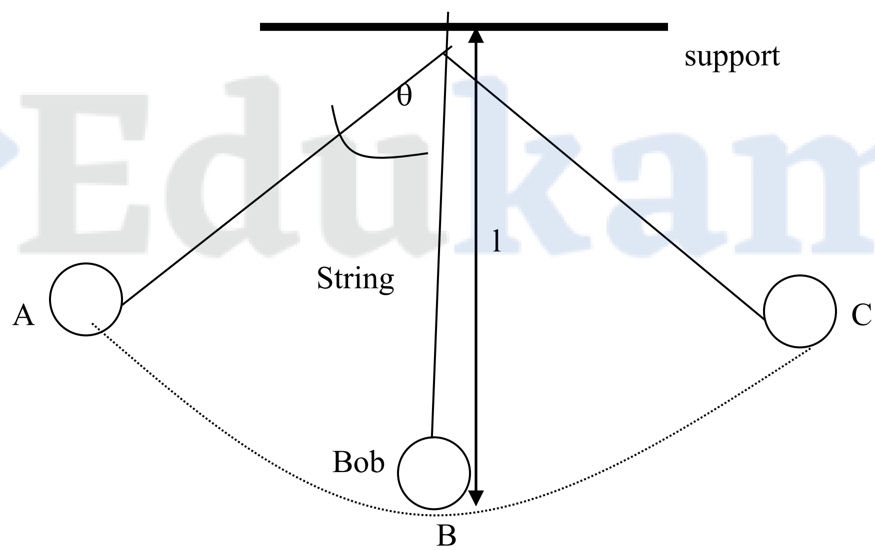
(G) MEASUREMENT OF TIME

Time is defined as the interval of occurrence between two fixed events. It is measured in seconds but other units are used for convenience.

60 seconds = 1minute
60 minutes = 1hour
24 hours = 1day
1 hour = 60sec x 60 sec = 3600secounds

Any event which repeats itself regularly in equal intervals of time can be used to measure time e.g.
(a) The oscillations of a simple pendulum when air resistance is neglected.
(b)The oscillations of a spring balance in the mechanical watches
(c)The oscillations of current in the electronic circuits in digital watches

SIMPLE PENDULUM



The simple pendulum is made by suspending a small heavy mass (bob) at the end of a weightless string such that it is free to swing whenever it is given a displacement and released.

(i) AMPLITUDE

The maximum displacement of the bob from the rest position. It is represented by the angle θ (θ - theta)

(ii) COMPLETE OSCILLATION

The swing of a pendulum from the maximum displacement 'A' to the maximum displacement 'C' and back to 'A'.

(iii) PERIODIC TIME (T)

Time taken to complete one oscillation. It is measured in seconds.

(iv) FREQUENCY (f)

The total number of oscillations made in one second. It is measured in $\frac{1}{s}$ which is given a special name called a Hertz [Hz]. It is related to the periodic time T by the formulae

$$f = \frac{1}{T} \quad \text{or} \quad T = \frac{1}{f}$$

(v) LENGTH (l)

The distance from the support to the centre of the bob

FACTORS WHICH AFFECT THE PERIOD AND FREQUENCY OF A SIMPLE PENDULUM

The period and frequency of a simple pendulum are affected by:
(a) the length of the pendulum
(b) the gravitational field strength (g) or the acceleration due to gravity.
The period is connected to the length (l) and acceleration due to gravity by a formula

$$T = 2\pi\sqrt{\frac{l}{g}}$$

The period is therefore directly proportional to the length and inversely proportional to acceleration due to gravity.

HOW TO MEASURE THE PERIOD OF A SIMPLE PENDULUM

Measure the time (t) of several oscillations e.g. 20. The time for 1 oscillation

$$Periodic\ Time\ (T) = \frac{Time\ for\ 20\ oscillations\ (t)}{Number\ of\ oscillations}$$

$$T = \frac{t}{20}$$

VECTORS AND VECTOR QUANTITIES

Physical quantities can be classified into scalars or vector quantities.

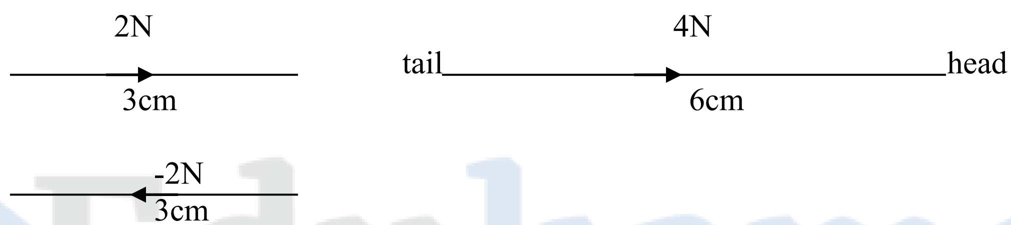
(a) SCALAR QUANTITY

A physical quantity with magnitude only. They do not have direction e.g. mass, volume, density, speed, area, current, temperature e.t.c

(b) VECTOR QUANTITY

A physical quantity which has both magnitude and direction e.g. velocity, acceleration, force, weight, displacement, moment of a force (or torque), momentum. e.t.c.

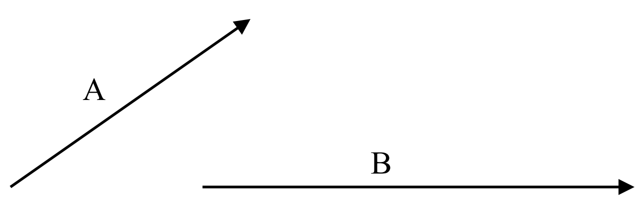
A vector quantity can be represented by a directed line segment whose length is proportional to the magnitude and the arrow head on the line shows the direction.



COMPOSITION OR ADDITION OF VECTORS

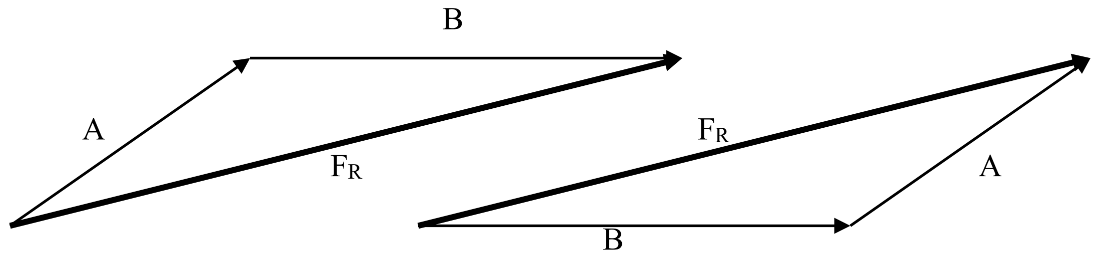
Several vectors can be added to get one **resultant vector.** The vectors which are added are called **components** of the resultant vector.

When adding vectors, the magnitude and direction of the components has to be taken into consideration. There are two methods used when adding vectors. Suppose we are given vectors A and B shown below find their resultant.



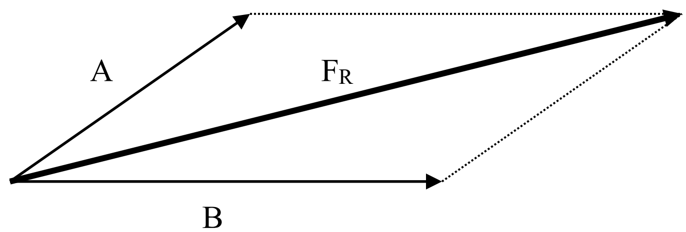
(a) HEAD TO TAIL METHOD

Join the head of the first vector to the tail of the second vector. The resultant is from the tail of the first vector to the head of the second vector



(b) PARALLELOGRAM

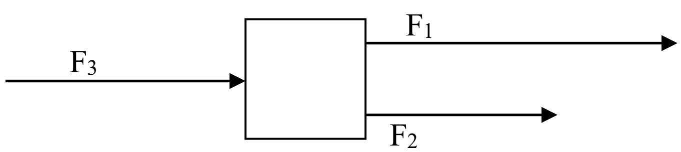
Join the tails of the two vectors and complete the parallelogram



The resultant is the diagonal from the tails of the component vectors

ADDING VECTORS IN SAME DIRECTION

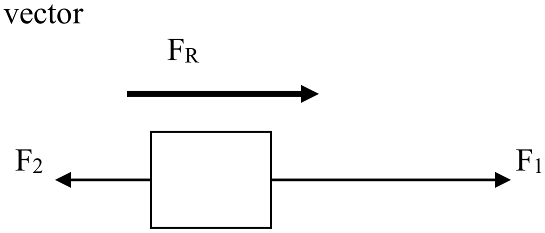
If the vectors are acting in the same direction find algebraic sum of the vectors



$F_R = F_1 + F_2 + F_3$

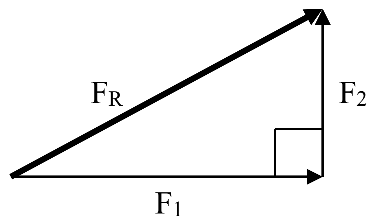
VECTORS IN THE OPPOSITE DIRECTION

If the vectors are in the opposite direction find the difference and the resultant is in the direction of the larger vector



$F_R = F_1 – F_2$

VECTORS ACTING PERPENDICULAR TO EACH OTHER

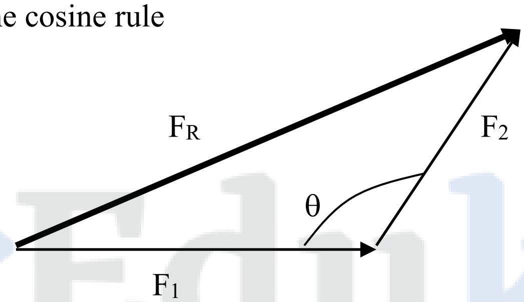


Use the Pythagoras theorem

$$F_R^2 = F_1^2 + F_2^2$$

VECTORS WHICH ARE NOT PERPENDICULAR

Use the cosine rule



$$F_R^2 = F_1^2 + F_2^2 - 2F_1F_2\cos\theta$$

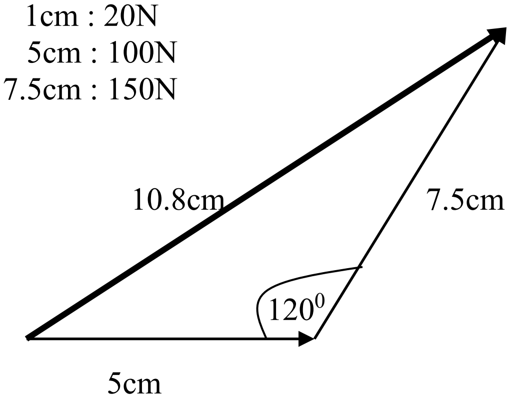
EXAMPLES

Find the resultant of 100N and 150N force acting at an angle of 120^0 to each other.
(a) Graphical method
(b) Calculation

Solution

(a) Graphical

Scale 1cm : 20N
5cm : 100N
7.5cm : 150N



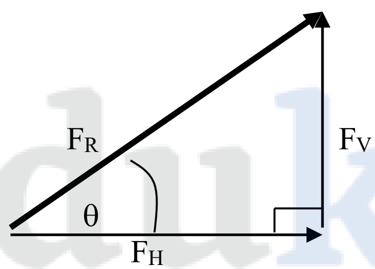
F_R = 10.8 x 20
F_R = 218N

(b) Calculation

$$F_R^2 = 100^2 + 150^2 - 2(100)(150)Cos120^0$$
$$F_R^2 = 10000 + 22500 - 30000(-0.5)$$
$$F_R^2 = 32500 + 15000$$
$$F_R^2 = 47500$$
$$F_R = \sqrt{47500}$$
$$F_R = 217.94N \approx 218N$$

RESOLUTION OF VECTORS

The process of finding the components when the resultant vector is given. The angle which the resultant makes with one of the components must be given. For any given resultant vector there are infinity pairs of components but the one which is more important is perpendicular to each other.



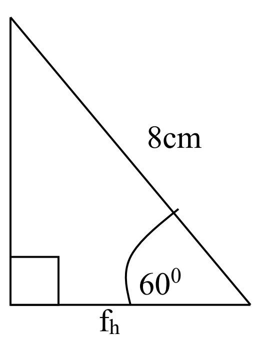
$F_V = F_R \sin\theta$
$F_H = F_R \cos\theta$

EXAMPLE

A man pushes a lawn mower on a horizontal ground with a force of 80N at an angle of $60^0$to the horizontal. Find the effective force causing the motion by
(a) Graphical method
(b) Calculation

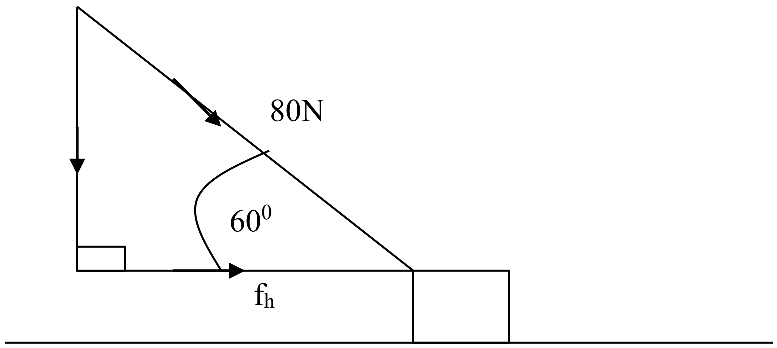
Solution

(a) Graphical
Scale 1cm :10N
8cm : 80N



f_h = 4cm
Effective horizontal force
f_h = 4 x 10N
f_h = 40N

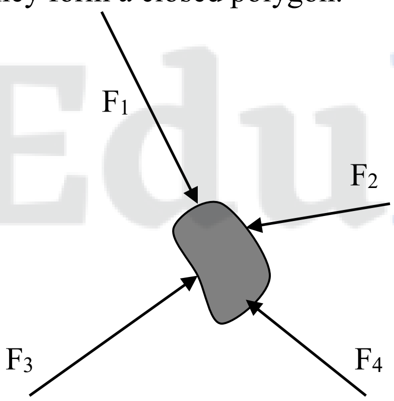
(b) Calculation

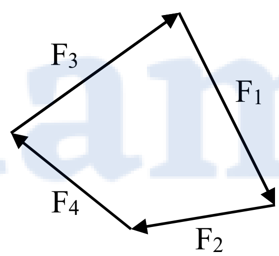


$f_h = 80N \sin\theta$
$f_h = 80\sin60^0$
$= 80 \times 0.5$
$= \underline{40N}$

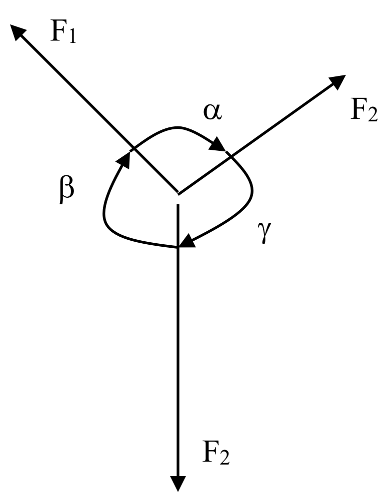
POLYGON OF FORCES

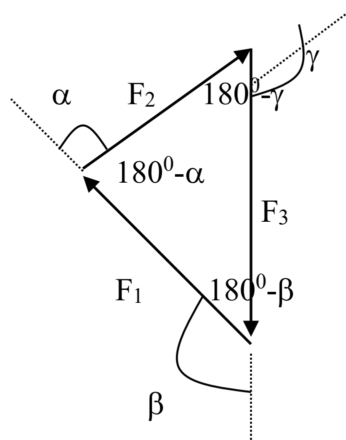
When several forces act on a body and it remains at rest, the forces added head to tail (vector addition) they form a closed polygon.





A special case is when a body is acted by three forces.





$$\frac{F_1}{\sin(180^0-\gamma)}=\frac{F_2}{\sin(180^0-\beta)}=\frac{F_3}{\sin(180^0-\alpha)}$$
$$\frac{F_1}{\sin\gamma}=\frac{F_2}{\sin\beta}=\frac{F_3}{\sin\alpha}$$

This is called **Lami's** theorem

SPEED, VELOCITY, AND ACCELERATION

SPEED

This is the rate of change of distance with time.

$$Speed=\frac{distance[m]}{time[s]}$$

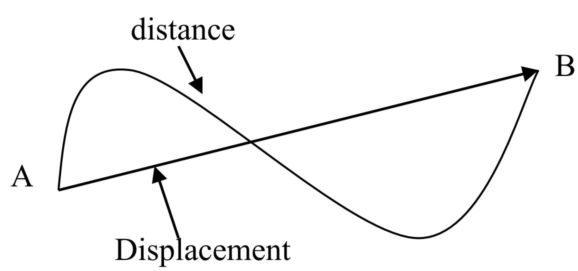
Speed is measured in m/s and it is a scalar quantity

$$Average\ \ speed=\frac{total\ \ distance}{time\ \ \ taken}$$

The actual speed of a body at a given instant in time is called the **Instantaneous speed.**

DISPLACEMENT

The distance moved in a specified direction. The S.I. unit for displacement is meters [m] and is a vector quantity.



VELOCITY

The rate of change of distance in a specified direction with time or
The rate of change of displacement with time or
Speed in specified direction.

$$Velocity=\frac{displacement[m]}{time[s]}$$

The S.I unit of velocity is m/s and it is a vector quantity.

ACCELERATION

The rate of change of velocity with time.

$$Acceleration = \frac{change \ \ of \ \ velocity\,[m/s]}{time \qquad\qquad [s]}$$

The S.I unit of acceleration is m/s^2 and it is a vector quantity.
The increase in velocity is called **acceleration** and the decrease in velocity is called **deceleration** or **retardation.**

A body can be moving with constant speed in a circle but it will be said to accelerate because of the continuous can in direction. So the velocity can change either in magnitude or direction.

<u>FORMULAE FOR LINEAR MOTION</u>

Symbols used are
u - initial velocity
v - final velocity
t - time
a - acceleration
s - displacement (or distance)
g - acceleration due to gravity.
h - height.

Consider a body which is accelerated uniformly from initial velocity 'u' to final velocity 'v' in time 't'.
Change of velocity = v - u
From the definition of acceleration

$$Acceleration = \frac{chnge \ \ of \ \ velocity}{time}$$

$$a = \frac{v-u}{t}$$

$$at = v - u$$

$$v = u + at..........\,.....(1)$$

From $average velocity = \frac{total \ \ distance}{time \ \ taken}$

$$total \ distance = average velocity \ x \ time taken$$

$$s = \left(\frac{v+u}{2}\right)t..........\,..(2)$$

substitute (1) into (2)

$$s = \left(\frac{u + at + u}{2}\right)t$$

$$s = \frac{2ut + at^2}{2}$$

$$s = ut + \frac{1}{2}at^2 \ldots\ldots\ldots.\ldots.(3)$$

From (1)

$$v = u + at$$

$$t = \frac{v - u}{a}$$

substitute into (2)

$$s = \left(\frac{v + u}{2}\right)\left(\frac{v - u}{a}\right)$$

$$s = \frac{(v + u)(v - u)}{2a}$$

$$s = \frac{v^2 - u^2}{2a}$$

$$2as = v^2 - u^2$$

$$v^2 = u^2 + 2as \ldots\ldots\ldots.\ldots\ldots(4)$$

Examples

1. Suppose a car starts from rest and accelerates uniformly to a speed of 5m/s in 10s. Find
(a) acceleration
(b) distance moved in this time

Solution

u = 0m/s   v = 5m/s   t = 10s   a = ?   t = ?

(a)

$$v = u + at$$

$$5 = 0 + a(10)$$

$$\frac{5}{10} = \frac{10a}{10}$$

$$\underline{a = 0.5m/s^2}$$

(b)

$$s = \left(\frac{v + u}{2}\right)t$$

$$s = \left(\frac{5 + 0}{2}\right)10$$

$$\underline{s = 25m}$$

2. Suppose a car traveling at 5m/s is brought to rest in a distance of 20m. Find it's deceleration and the time taken to stop.

solution

s = 20m   v = 0m/s   u = 5m/s   a = ?   t = ?

(a)

$$v^2 = u^2 + 2as$$
$$0 = 5^2 + 2(a)(20)$$
$$0 = 25 + 40a$$
$$40a = -25$$
$$a = \frac{-25}{40}$$
$$\underline{a = -0.625 m/s^2}$$

(b)

$$v = u + at$$
$$0 = 5 + (-0.625)t$$
$$0.625t = 5$$
$$t = \frac{5}{0.625}$$
$$\underline{t = 8 \sec}$$

3. A car starts from rest and accelerates at $4 m/s^2$ through a distance of 20m. How fast is it then going . How long did it take?

Solution
$a = 4m/s^2$ s = 20m u = 0m/s v = ? t = ?

(a)

$$v^2 = u^2 + 2as$$
$$v^2 = 0 + 2(4)(20)$$
$$v^2 = 160$$
$$v = \sqrt{160}$$
$$\underline{v = 12.65 m/s}$$

(b)

$$v = u + at$$
$$12.65 = 0 + 4(t)$$
$$4t = 12.65$$
$$t = \frac{12.65}{4}$$
$$\underline{t = 3.16 \sec}$$

4. Find the time taken for a car to travel 98m if it starts from rest and accelerates at $4m/s^2$.

Solution
s = 98m $a = 4m/s^2$ u = 0m/s t = ?

$$s = ut + \frac{1}{2}at^2$$
$$98 = 0 + \frac{1}{2}(4)t^2$$
$$98 = 2t^2$$
$$t^2 = \frac{98}{2}$$
$$t = \sqrt{49}$$
$$\underline{t = 7 \sec}$$

5. A car is moving at 72km/h when it begins to slow down from point '**A**' with a deceleration of $1.5m/s^2$. How long does it take to travel 70m to point **'B'** as it slows down?

Solution

$$u = 72km/h = \frac{72km}{1h} = \frac{72x1000m}{1x60x60s} = \frac{72000m}{3600s} = 20m/s$$

$a = -1.5m/s^2$

$s = 70m$

$t = ?$

$$s = ut + \frac{1}{2}at^2$$

$$70 = 20t + \frac{1}{2}(-1.5)t^2$$

$$140 = 40t - 1.5t^2$$

$$1.5t^2 - 40t + 140 = 0$$

$$t = \frac{-b \pm \sqrt{b^2 + 4ac}}{2a}$$

$$t = \frac{40 \pm \sqrt{(-40)^2 - 4(1.5)(140)}}{2(1.5)}$$

$$t = \frac{40 \pm \sqrt{760}}{3}$$

$$t = \frac{40 \pm 27.57}{3}$$

$$t = \frac{40 + 27.57}{3} \text{ or } \frac{40 - 27.57}{3}$$

$$t = \frac{67.57}{3} \text{ or } \frac{12.43}{3}$$

$\underline{t = 22.52\text{sec}}$

or

$\underline{t = 4.14\text{sec}}$

Alternatively to avoid the quadratic equation use the following method which require two formulae of linear motion

$$v^2 = u^2 + 2as$$

$$v^2 = 20^2 + 2(-1.5)(70)$$

$$v^2 = 400 - 210$$

$$v^2 = 190$$

$$v = \sqrt{190}$$

$\underline{v = 13.78m/s}$

$$s = \left(\frac{v+u}{2}\right)t$$

$$70 = \left(\frac{13.78 + 20}{2}\right)t$$

$$70 = 16.89t$$

$$t = \frac{70}{16.89}$$

$\underline{t = 4.14\text{sec}}$

The first answer 22.52sec in the first method is the time taken for the car to decelerate from '**A**' to rest and then accelerate at 1.5m/s in the opposite direction to a point '**B**' which is 70m from '**A**'**.** Therefore the appropriate answer is 4.14sec.

6. A car covers 8m in the first second and 12m in the second second. Find
   (a) initial velocity
   (b) acceleration
   (c) distance covered in the third second

Solution

In the first second

s = 8m t = 1sec u = ? a = ?

$$s = ut + \frac{1}{2}at^2$$

$$8 = u(1) + \frac{1}{2}(a)(1)^2$$

$$8 = u + \frac{1}{2}a$$

$$16 = 2u + a \text{.......... ....(1)}$$

<u>After 2 seconds</u>
The total distance covered s = 8 + 12 = 20m
Total time t = 2sec
u = ? a = ?

$$s = ut + \frac{1}{2}at^2$$

$$20 = u(2) + \frac{1}{2}a(2)^2$$

$$20 = 2u + 2a$$

$$10 = u + a \text{.......... ....(2)}$$

Solving (1) and (2) simultaneously
From (2) $a = 10 - u$ .and substitute in (1)

$$16 = 2u + (10 - u)$$

$$16 = 2u + 10 - u$$

$$16 - 10 = u$$

$$\underline{u = 6m/s}$$

$$a = 10 - u$$

$$a = 10 - 6$$

$$\underline{a = 4m/s^2}$$

<u>Therefore (a) u = 6m/s and (b) a = 4m/s²</u>

(c) <u>After 3 seconds</u>
u = 6m/s a = 4m/s^2 t = 3sec s = ?

$$s = ut + \frac{1}{2}at^2$$

$$s = 6(3) + \frac{1}{2}(4)(3)^2$$

$$s = 18 + 18$$

$$\underline{s = 36m}$$

36m is the total distance covered in 3 seconds therefore the distance covered in the third second only is $= 36 - 20 = \underline{16m}$

EXERCISE

1 A bus traveling in a straight line with uniform acceleration has an instant speed of 6m/s. 5seconds later, has reached speed of 36m/s. Find
   (a) the magnitude of its acceleration
   (b) the distance traveled in 5seconds?

2 A car traveling at 72km/h accelerates to 108km/h in 3seconds and immediately begins to retard uniformly until it stops in 10seconds later. Calculate
   (a) the acceleration
   (b) the retardation
   (c) the total distance traveled

3 An aero plane starting from rest is uniformly accelerated for 20seconds so that it can leave the runway with the velocity of 80m/s. Estimate the shortest possible length of the runway.

4 A bullet moving with the speed of 5m/s strikes a tree and penetrates 3.5cm before stopping. Find
   (a) the magnitude of the acceleration and
   (b) time taken to stop?

5 A rough value of deceleration of a skidding automobile is about 7.0m/s^2. Using this how long does it take for a car going at 30m/s to stop after the skid starts. How far does the car go in this time?

6 A truck initially traveling at 20m/s decelerated at 1.50m/s^2. Find
   (a) how long it takes to stop
   (b) how far it moves in that time and
   (c) how far the truck moves in the third second after the brakes are applied.

7 The driver of a car that is going at 25m/s suddenly notices a train blocking the road. At the instant, the brakes are applied the train is 60m away. The car decelerates uniformly and strikes the train 3seconds later.
   (a) how fast was the car moving on impact?
   (b) what was the magnitude of its acceleration during the 3seconds?

MOTOIN UNDER GRAVITY

Bodies which are falling freely in the earth's gravitational field move with constant acceleration called the acceleration due to gravity 'g' which is called the gravitational field strength. On earth the gravitational field strength or acceleration due to gravity is

$$g = 9.81 m/s^2 \approx 10 m/s^2 \text{ or}$$
$$g = 9.81 N/kg \approx 10 N/kg$$

The air resistance has been neglected in this case. Therefore equations of linear motion apply with a few changes on the symbols.

$$v = u + gt \text{..............................}(1)$$
$$h = \left(\frac{v+u}{2}\right)t \text{..............................}(2)$$
$$h = ut + \frac{1}{2}gt^2 \text{..............................}(3)$$
$$v^2 = u^2 + 2gh \text{..............................}(4)$$

When a body is moving vertically upwards it's velocity decreases therefore it is decelerating and $g \approx -10 m/s^2$, and at the maximum height the final velocity $v = 0 m/s$. When the body is moving downwards it's velocity is increasing and therefore accelerating and $g \approx +10 m/s^2$, and the initial velocity at the maximum height is $u = 0 m/s$

EXAMPLES

(1) A boy drops a stone from a bridge. If it takes 3sec for stone to hit the water beneath the bridge, how high above the water is the bridge?

Solution

Downward motion

u = 0m/s g = 10m/s^2 t = 3sec h = ?

$$h = ut + \frac{1}{2}gt^2$$
$$h = 0 + \frac{1}{2}(10)(3)^2$$
$$h = 0 + 5(9)$$
$$\underline{h = 45m}$$

(2)A boy throws a ball upwards with a speed of $15 m/s$

(a) how high does it go?
(b) what is it's speed just before the boy catches it again?
(c) how long was it in the air (neglect air friction)?

Solution

(a) Considering upward motion

$g = -10m/s \quad v = 0m/s \quad u = 15m/s \quad h = ?$

$v^2 = u^2 + 2gh$

$0 = 15^2 + 2(-10)h$

$0 = 225 - 20h$

$20h = 225$

$h = \frac{225}{20}$

$\underline{h = 11.25m}$

(b) Considering the downward motion

$g = 10m/s^2 \quad u = 0m/s \quad h = 11.25m \quad v = ?$

$v^2 = u^2 + 2gh$

$v^2 = 0 + 2(10)(11.25)$

$v^2 = 225$

$v = \sqrt{225}$

$\underline{v = 15m/s}$

(c) Considering the upward motion

$v = 0m/s \quad u = 15m/s \quad g = -10m/s^2$

$v = u + gt$

$0 = 15 - 10t$

$10t = 15$

$\underline{t = 1.5\sec}$

If it takes 1.5sec for the ball to reach the maximum height it will take another 1.5sec for it to move from the maximum height to the boy

$\therefore$ Total time of flight = 1.5 + 1.5 = 3.0sec

Alternatively when the boy catches the ball it's displacement from him is zero. Therefore

$h = 0m \quad g = -10m/s^2$ and $u = 15m/s$

$$h = ut + \frac{1}{2}gt^2$$

$$0 = 15t + \frac{1}{2}(-10)t^2$$

$$0 = 30t - 10t^2$$

$$0 = 10t(3 - t)$$

$10t = 0$ or $3 - t = 0$

$\underline{t = 0\sec}$ or $\underline{t = 3\sec}$

t = 0sec is when the boy was throwing the ball and t = 3sec is when the boy was catching the ball again.

(3)A girl throws a ball straight upwards with a speed of 40m/s. How long will it take to reach 20m on its way down again.

Solution

Considering upward motion

$g = -10m/s^2 \quad v = 0m/s \quad u = 40m/s \quad h = ? \quad t = ?$

$v^2 = u^2 + 2gh$	$v = u + gt$
$0 = 40^2 + 2(-10)h$	$0 = 40 - 10t$
$20h = 1600$	$10t = 40$
$\underline{h = 80m}$	$\underline{t = 4\sec}$

The maximum height reached is 80m and time to reach the maximum height is 4sec.

Considering downward motion, calculate the time to fall 60m which will be 20m above the ground.

$u = 0m/s \quad g = 10m/s^2 \quad h = 60m \quad t = ?$

$$h = ut + \frac{1}{2}gt^2$$

$$60 = 0 + \frac{1}{2}(10)t^2$$

$$5t^2 = 60$$

$$t^2 = 12$$

$$\underline{t = 3\sec}$$

Total time = 4 + 3.46

= <u>7.46sec</u>

Alternatively considering the displacement of the ball from the girl to be 20m.

$g = -10m/s^2 \quad u = 40m/s \quad h = 20m \quad t = ?$

$$h = ut + \frac{1}{2}gt^2$$

$$20 = 40t + \frac{1}{2}(-10)t^2$$

$$20 = 40t - 5t^2$$

$$t^2 - 8t + 4 = 0$$

$$t = \frac{-b \pm \sqrt{b^2 - 4ac}}{2a}$$

$$t = \frac{8 \pm \sqrt{(-8)^2 - 4(1)(4)}}{2(1)}$$

$$t = \frac{8 \pm \sqrt{48}}{2}$$

$$t = \frac{8 \pm 6.92}{2}$$

$$t = \frac{8 + 6.92}{2} \qquad t = \frac{8 - 6.92}{2}$$

$$t = \frac{14.92}{2} \quad \text{0r} \quad t = \frac{1.02}{2}$$

$$\underline{t = 7.46\text{sec}} \qquad \underline{t = 0.51\text{sec}}$$

t = 0.51sec is the time taken for ball to reach 20m above the ground on the way up and t = 7.46sec is the time to reach 20m above the ground on the way down.

(4)How fast must the ball be thrown straight upwards if it has to return to thrower in 3sec.

Solution

Considering upward motion

If it takes 3sec to for the whole flight the it will take 1.5sec to reach the maximum height.

$g = -10m/s^2 \quad v = 0m/s \quad t = 1.5m/s \quad u = ?$

$v = u + gt$

$0 = u - 10(1.5)$

$\underline{u = 15m/s}$

EXERCISE

1. A frightened diver hangs by his fingers from a diving board with his feet 50m above the water.
(a)how long after his fingers give out will he strike the water?
(b)How fast will he be going then?

(2) A stone is thrown straight upwards from the ground with the velocity of 15m/s and goes as high as a nearby building. The stone returns to the ground 3.0s after it was thrown. How high (in meters) is the building?

(3) A girl throws a ball straight down from the top of a 50m building with a speed of 20m/s.

   (a) How long does it take for ball to reach the ground?
   (b) How fast is it then going before it hits the ground?

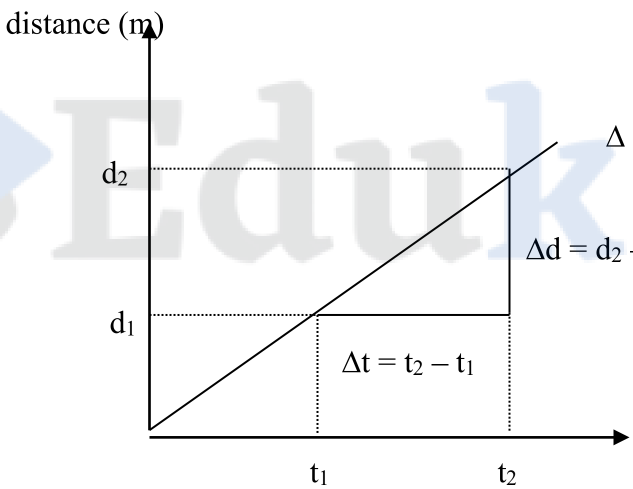
(4) A girl is standing on the top edge of an 18m high building. She tosses a coin upwards with a speed of 7.0m/s. How long does it take for the coin to hit the ground 18m below? How fast is the coin going just before it strikes the ground?

GRAPHICAL REPRESENTATION OF LINEAR MOTION

Problems in linear motion can be solved using graphs.

DISTANCE – TIME GRAPH

The plot of distance on the vertical axis against time on the horizontal axis.

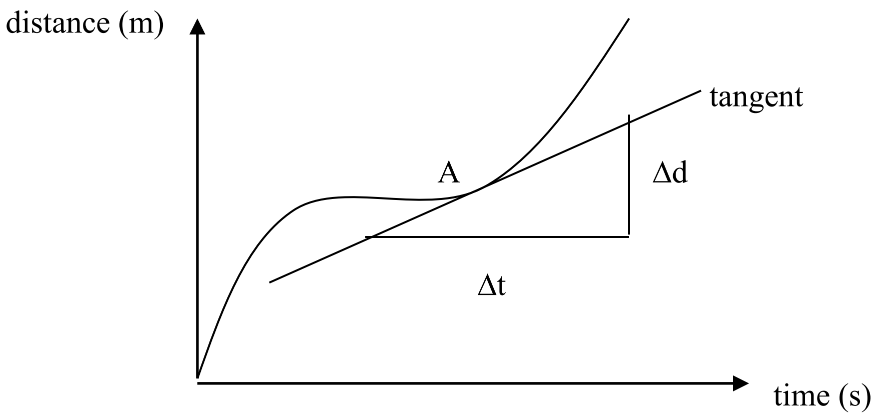


$$Gradient = \frac{vertical\ change}{horizontal\ change}$$

$$= \frac{\Delta d}{\Delta t}$$

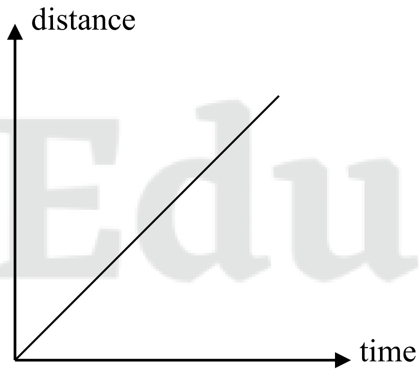
$$= \frac{d_2 - d_1}{t_2 - t_1}$$

The gradient from the distance time graph gives **speed**
If the speed is varying the graph is going to be a curve and the instantaneous speed at a given point e.g. A is found by calculating the gradient of the tangent at that point.

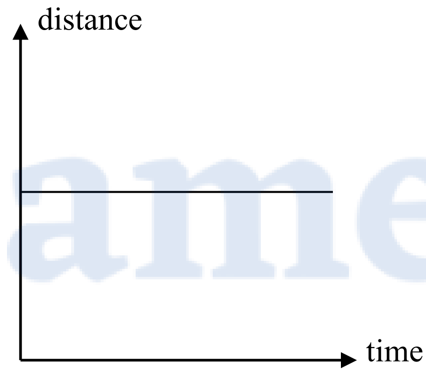


Instantaneous speed at point A = gradient = $\frac{\Delta d}{\Delta t}$

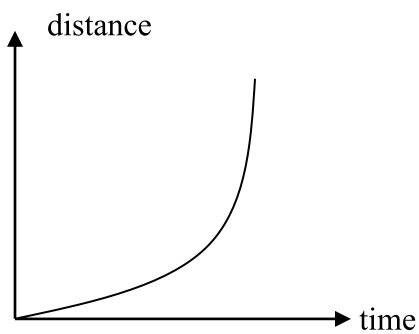
(a) DIFFERENT TYPES OF DISTANCE TIME GRAPH



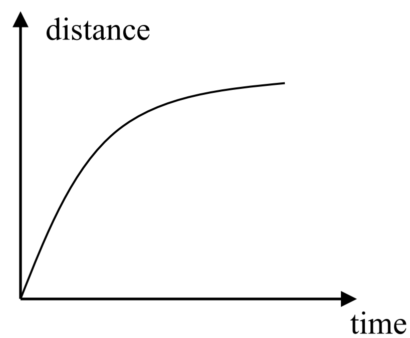
Constant speed



stationary or at rest



increasing speed or accelerating



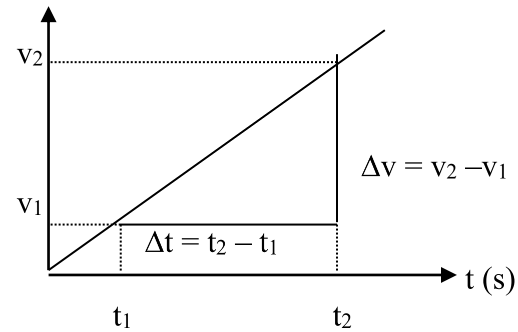
decreasing speed or decelerating

(b) DISPLACEMENT – TIME GRAPH

Refer to the distance – graph but note that where there is speed change to velocity.

(c) VELOCITY – TIME GRAPH

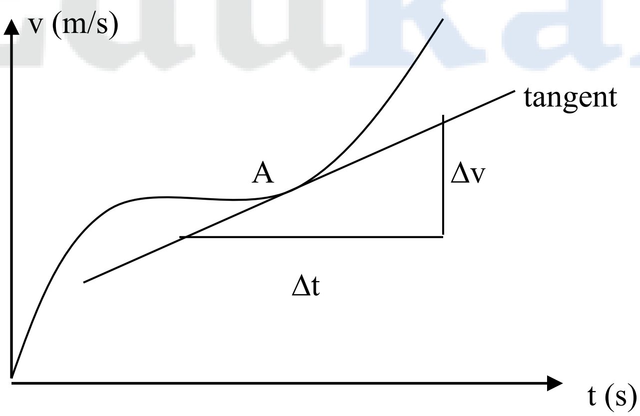
The plot of velocity on the vertical axis against time on the horizontal axis.



$$gradient(slope) = \frac{vertical\ change}{horizontal change}$$

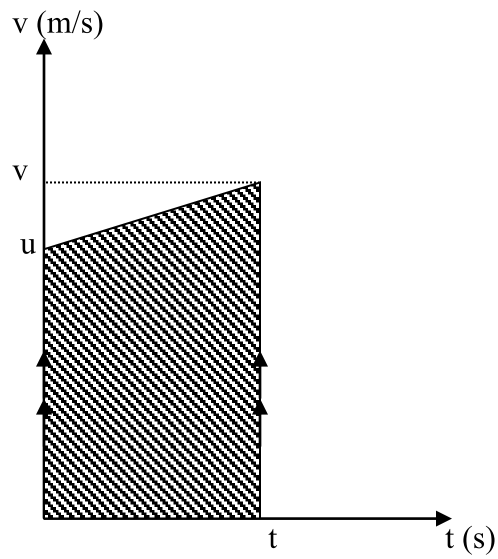
$$= \frac{\Delta v}{\Delta t} = \frac{v_2 - v_1}{t_2 - t_1}$$

The gradient from the velocity from the velocity time graph gives **acceleration.** If the acceleration is varying the graph is going to be a curve be a curve. The instantaneous acceleration at a given point e.g. A is equal to the gradient of the tangent at that point.



Instantaneous acceleration at A = gradient at A $= \frac{\Delta v}{\Delta t}$

Suppose a body is accelerated uniformly from initial velocity 'u' to final velocity 'v' in time 't'. Its velocity time graph will look like.



The shape under the graph is a trapezium.

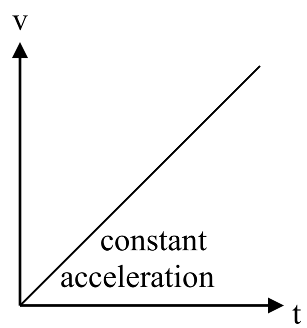
$\therefore The\ area\ of\ the\ graph = \frac{1}{2}(a+b)h$

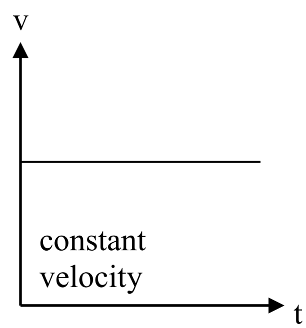
$$A = \frac{1}{2}(v+u)t$$

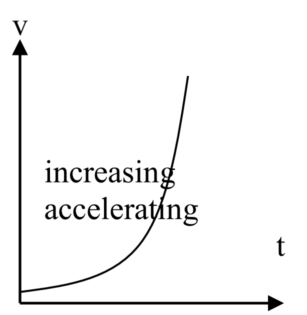
$$A = \frac{(v+u)t}{2}\ but\ this\ is\ the\ formula\ of\ distance\ 's'$$

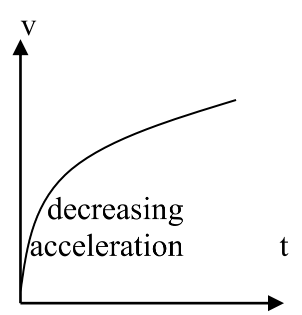
$$s = \frac{(v+u)t}{t}$$

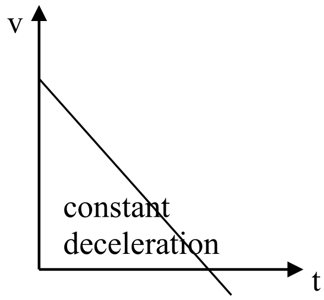
There fore the area under the velocity time graph gives **distance** covered.

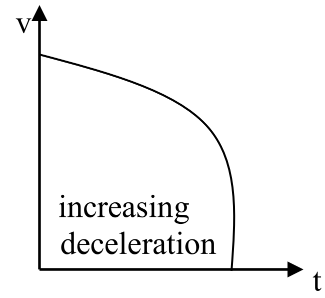


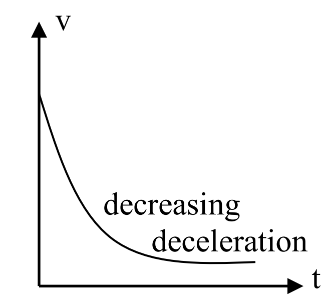












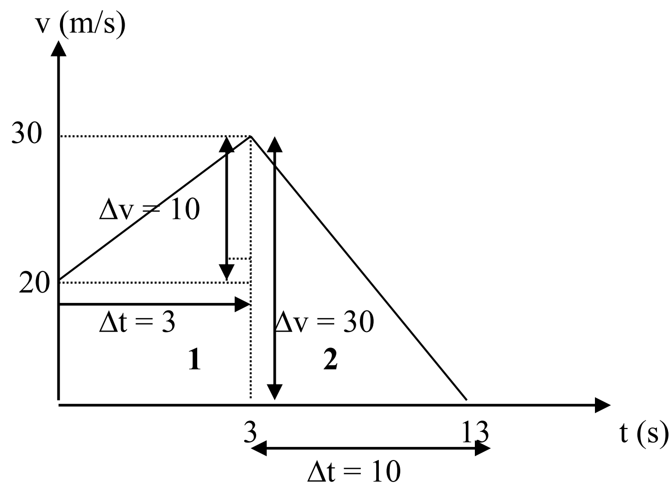
<u>EXAMPLE</u>

(5) A car traveling at 72km/m accelerates to 108km/h in 3 sec and immediately decelerates uniformly to rest in 10 sec. Find the

(a) acceleration
(b) deceleration
(c) total distance traveled

<u>solution</u>

72km/h = 20m/s
108km/h = 30m/s



$(a)\ a = \frac{\Delta v}{\Delta t} = \frac{10}{3} = \underline{3.33 m/s^2}$

$(b)\ a = \frac{\Delta v}{\Delta t} = \frac{-30}{10} = \underline{-3 m/s^2}$

$(c)\ distance = area\ \mathbf{1} + area\ \mathbf{2}$

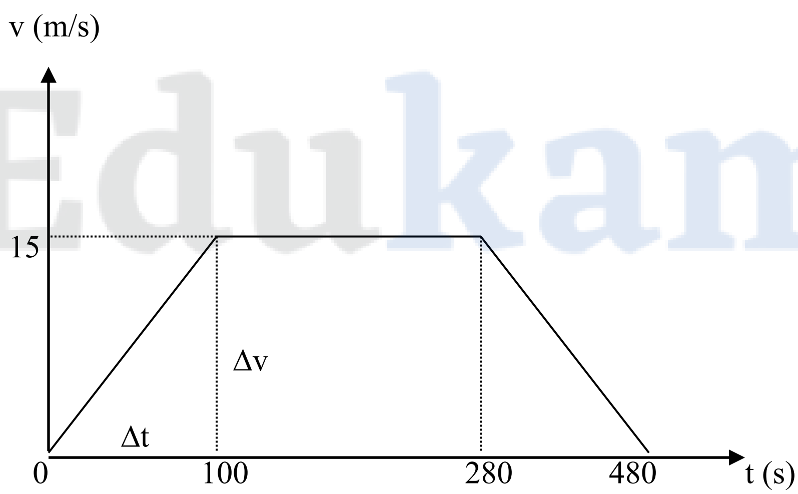
$$= \frac{1}{2}(a+b)h + \frac{1}{2}bh$$

$$= \frac{1}{2}(20+30)3 + \frac{1}{2}(10)(30)$$

$$= 75 + 150$$

$$= \underline{225 m}$$

(6) A car is accelerated uniformly at 0.15m/^{2} to a speed of 15m/s. The speed is maintained for 3 min. and it is retarded uniformly to come to rest in 8 min. after starting. Draw the velocity time graph and use it to find the average velocity.



$a = \frac{\Delta v}{\Delta t}$

$0.15 m/s^2 = \frac{15}{\Delta t}$ $\qquad Average\ velocity = \frac{total\ distance}{total\ time}$

$\Delta t = 100\sec$

$distance = area$

$A = \frac{1}{2}(a+b)h$

$= \frac{1}{2}(480+180)15$

$= \frac{1}{2} \times 660 \times 15$

$= \underline{4950m}$

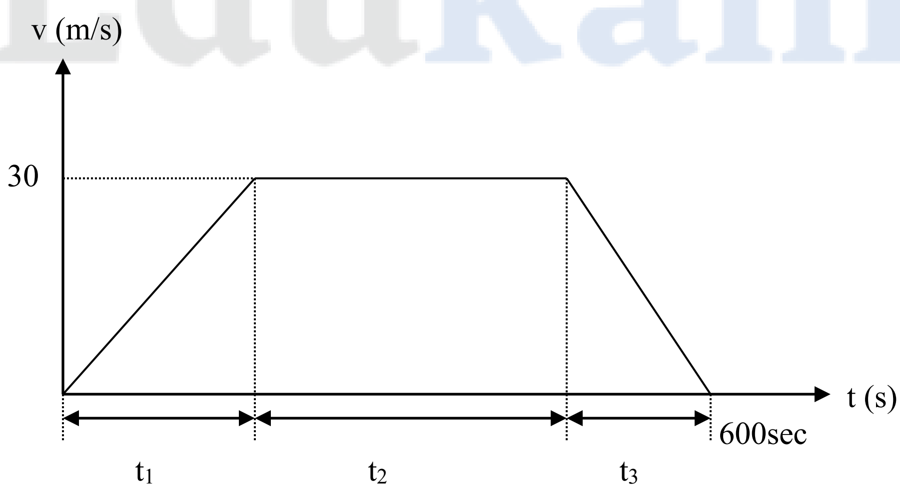
$Average\ speed = \frac{4950}{480}$

$= \underline{10.3m/s}$

(7) A train moves from station [A] to station [B] which is 10km apart. If it starts by accelerating uniformly to a speed of 30m/s then the speed is maintained for sometime before it is brought to rest with uniform retardation. Given that the acceleration is twice the retardation and the total time for the whole journey is 10 min. Find

(a) the time when the speed was constant
(b) the acceleration

<u>solution</u>



(a) $distance = 10 \times 1000 = \underline{10\ 000m}$

$time = 10 \times 60 = \underline{600\sec}$

$distance = area\ under\ the\ graph$

$$A = \frac{1}{2}(a+b)h$$

$$10\ 000 = \frac{1}{2}(600 + t_2)30$$

$$10\ 000 = 9\ 000 + 15t_2$$

$$15t_2 = 10\ 000 - 9\ 000$$

$$15t_2 = 1\ 000$$

$$t_2 = \frac{1\ 000}{15}$$

$$\underline{t_2 = 66.67\sec}$$

(b) $acceleration = 2 \times deceleration$

$a = gradient$

$$a = \frac{\Delta v}{\Delta t}$$

$$\frac{30}{t_1} = 2 \times \frac{30}{t_3}$$

$$\underline{t_3 = 2t_1} \text{ .... (1)}$$

$$t_1 + t_2 + t_3 = 600$$

$$t_1 + 66.67 + t_3 = 600$$

$$t_1 + t_3 = 600 - 66.69$$

$$\underline{t_1 + t_3 = 533.33} \text{ .... (2)}$$

$Substitute\ (1)\ into\ (2)$

$$t_1 + 2t_1 = 533.33$$

$$3t_1 = 533.33$$

$$t_1 = \frac{533.33}{3}$$

$$\underline{t_1 = 177.78\sec}$$

$$\therefore a = \frac{30}{t_1}$$

$$a = \frac{30}{177.78}$$

$$\underline{a = 0.168m/s^2}$$

<u>EXERCISE</u>

1. A train starting from rest accelerated uniformly at $2m/s^2$ for 15s. It then travels for 30s at the velocity reached and is then brought to rest with uniform retardation after 10s more.
   (a) Draw a velocity time graph of the motion and from the graph find
   (b) The total distance traveled
   (c) Its retardation and
   (d) Verify your results from formulae

2. A body starts from rest and accelerates at $3m/s^2$ for 4s. Its velocity remains constant at the maximum value so reached for 7s and it finally comes to rest with uniform retardation after 5s. Find by graphical method
   (a) The distance moved during each stage of the motion
   (b) The average velocity over the whole period.
3. A train starts from station **A** with an acceleration of $0.2m/s^2$ and attains its maximum speed in 1.5min. After maintaining at speed for 4min. it is uniformly retarded for 4s before coming to rest in station **B**. Find by drawing a suitable graph
   (a) The distance between **A** and **B** in kilometers
   (b) The maximum speed in km/h
   (c) The average speed in m/s
4. A train starts from station **A** and accelerates uniformly to a speed of 20m/s. This speed reached is maintained for some time before it is brought to rest with uniform retardation to station **B** . Given that total distance covered is 2km, time for the whole journey is 1min and that the acceleration is twice the deceleration find
   (a) the time when it was moving with constant speed
   (b) the acceleration
5. When a certain ball is dropped to the ground from a height of 2.0m, it bounces back up to its original height.
   (a) Plot a graph of the height of the ball versus time for the first 3.0 s of its motion.
   (b) Plot the graph of the ball's velocity during the same period.

FORCES

Force is the influence that changes or tends to change the body's state of rest or uniform motion in a straight line. The S.I unit of force is kgm/s^2 which is given a special name a Newton [N]. A Newton is a force such that when acting on a body of mass 1kg produces an acceleration of $1m/s^2$.

$1[N] = 1[kg].1[m/s^2]$

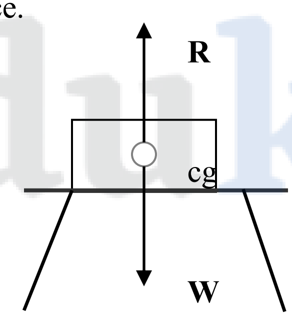
TYPES OF FORCES

(i) WEIGHT (W)

The gravitational force acting on an object. It acts vertically downward through the center of gravity.

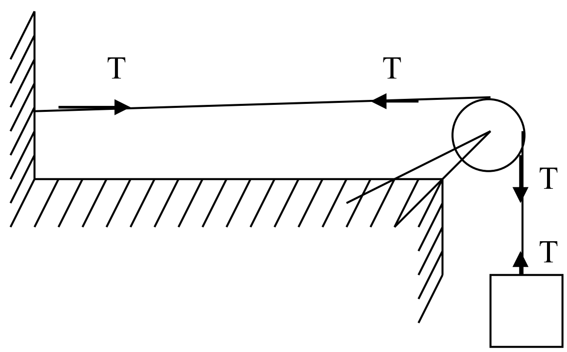
(ii) REACTION FORCE (R)

When a force is exerted on a body there will be exert an equal and opposite reaction force.



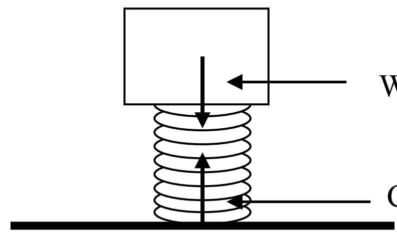
(iii) TENSION (T)

The inward force exerted by bodies under stretch.



(iv) COMPRESSION (C)

The outward force exerted by bodies under compression.

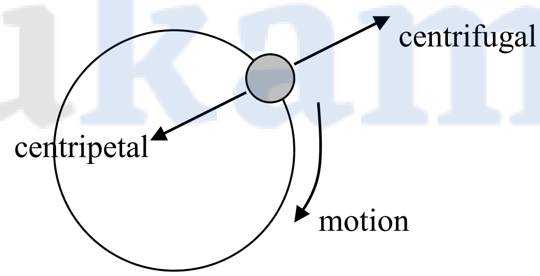


(v) THRUST

The force exerted by displaced fluids e.g. **upthrust** which is equal to the weight of the displaced fluid.

(vi) CENTRIPETAL AND CENTRIFUGAL FORCE

This is the force acting on a body in circular motion. The inward force is the centripetal and outward force is the centrifugal.



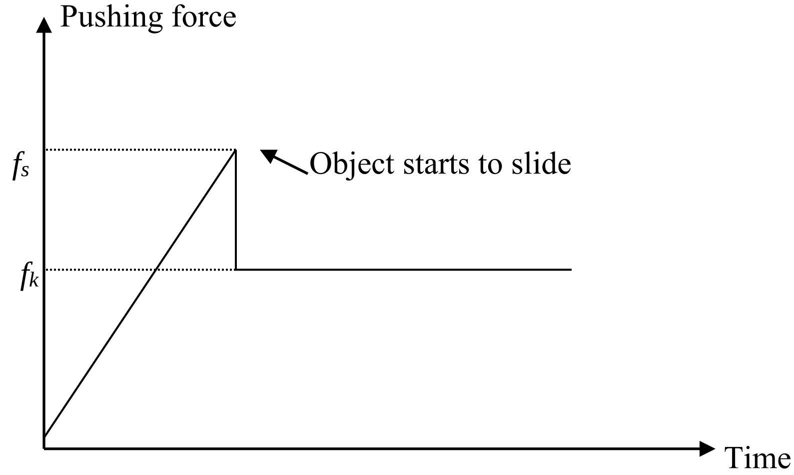
(vii) GRAVITATIONAL FORCE

The force of attraction between two bodies which is directly proportional to the product of their masses and inversely proportional to the square of their distance of separation.

(viii) FRICTION FORCE

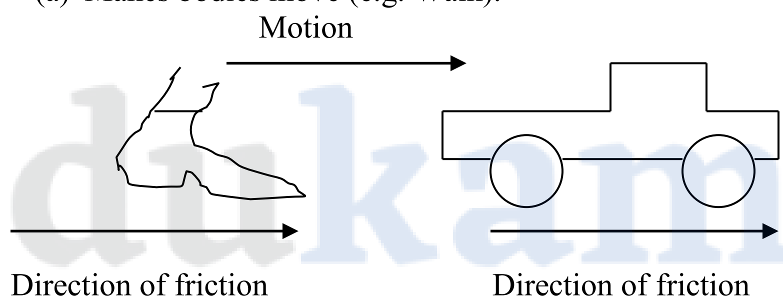
The force which opposes the sliding motion between two surfaces. There are two types of friction forces.

(i) Static Friction (f_s) - The friction before motion
(ii) Sliding or Kinetic or dynamic friction (f_k)- Friction force, for bodies which are in motion. The maximum static friction is greater than the sliding friction.



<u>Uses of Friction</u>

(a) Makes bodies move (e.g. Walk).



(b) In braking system of Vehicles.

<u>Disadvantages of Friction</u>

Causes wear and tear of materials

<u>Reduction of Friction</u>

(i) Use of lubricant e.g. Grease
(ii) Use of rollers

To study the effects of forces on bodies the following must be known.

(a) the magnitude of the force
(b) the direction of the force
(c) the point of application
(d) the body exerted by the force
(e) the body producing the force

Effects of forces

(a) change in motion (causes acceleration or deceleration).
(b) causes deformation (change in shape).
(c) causes the turning effect

EFFECTS OF FORCES ON MOTION (DYNAMICS)

This is the study of motion and also what is producing it. We look at Newton's laws of motion.

Newton's first law

The body remains in it's state of rest or uniform motion in a straight line unless acted by a resultant external force.
It is sometimes referred to as the law of **inertia**. Which is a tendency of a body to resist changes in motion. Inertia is proportional to the mass of a body. The larger the mass the more is the inertia.
If there is an external force acting on the body, the motion of the body will change (i.e. It will accelerate or decelerate). This is stated in Newton's Second Law of motion.

Newton's second law

The rate of change of **momentum** is directly proportional to the applied force and takes place in the direction of motion.
Where momentum (P) is the product of mass and velocity:

$$P = mv$$

Suppose we are given a body of mass 'm' which is accelerated uniformly from initial velocity 'u' to final velocity 'v' in time 't'.

Initial momentum = mu
Final momentum = mv.
Change in momentum = mv – mu

$$\Delta P = mv - mu$$

Rate of change of momentum = $\frac{\Delta P}{t} = \frac{mv - mu}{t}$

from the Newton's second law

$$\therefore f \propto \frac{mv - mu}{t}$$

$$f \propto m\left(\frac{v - u}{t}\right) \quad \text{but} \quad \left[a = \frac{v - u}{t}\right]$$

f α ma if m is constant f α ma turns to f α a Therefore the second law be restated as 'The acceleration produced on the body is directly proportional to the applied force.'

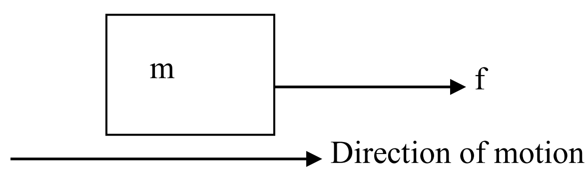
from f α ma
f = Kma

where K is a constant of proportionality and K = 1.

$$f = ma$$

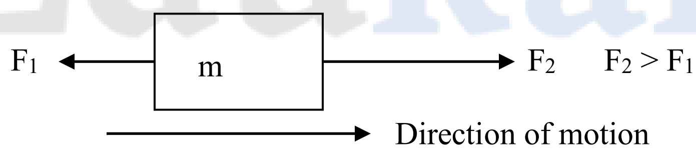
f is the resultant force in the direction of motion.

(a) **A body of mass 'm' acted by one force 'f'**.



$$f = ma$$

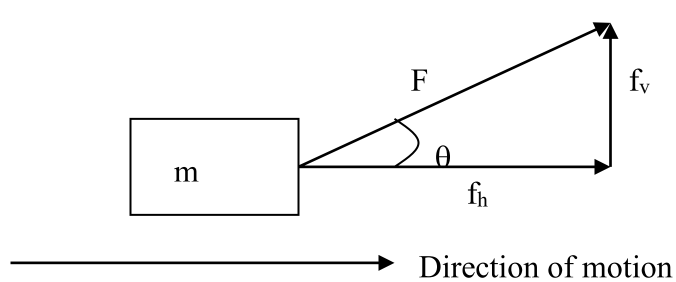
(b) A body acted by several forces get the resultant in the direction of motion.



The resultant force in the direction of motion is $f_r = F_2 - F_1$

$$f_r = F_2 - F_1 = ma$$

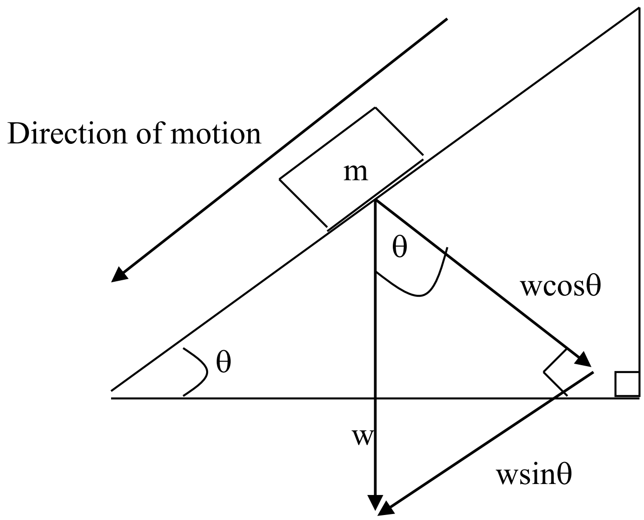
(c) The applied force 'F' is not in the direction of motion.



Find the component of F which is in the direction of motion, (f_h).

$f_h = ma$
but $f_h = F\cos\theta$ therefore
$F\cos\theta = ma$

(d) A body sliding on an inclined plain.



The component of weight which is parallel to the inclined plane (i.e. wsinθ) is the one which is causing the motion.

$\therefore f = ma$
$w\sin\theta = ma$
If there was fiction force f_f on the plane it will be acting up the incline to oppose the motion. Therefore the resultant force in the direction of motion would be

Resultant force (f) = $w\sin\theta - f_f$ and the equation now becomes

$f = ma$
$w\sin\theta - f_f = ma$

<u>Examples</u>

1. What force will produce a velocity of 1.2 m/s in 6 sec on a body of mass 0.5 kg starting from rest?

<u>Solution</u>

$u = 0$
$v = 1.2m/s$
$t = 6\sec$
$m = 0.5kg$
$f = ?$

From the first equation of motion

$v = u + at$

$a = \dfrac{v-u}{t}$

$a = \dfrac{1.2-0}{6}$

$a = 0.2m/s^2$

Therefore the force will be

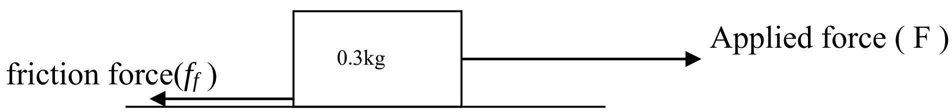
$f = ma$

$f = 0.5 \times 0.2$

$f = 0.1N$

2. A horizontal force of 0.6 N acts on a body of 0.3 kg. The friction resistance force of 0.15 N opposes the first force. What acceleration will be produced?

Solution



The resultant force $(f_r) = F - f_f$

$= 0.6N - 0.15$

$= 0.45N$

$F = 0.6N$
$f_f = 0.15N$
$m = 0.3kg$
$a = ?$

$f = ma$

$a = \dfrac{f_r}{m} = \dfrac{0.45}{0.3}$

$a = 15m/s^2$

3. A car of mass 1000kg is accelerated at 2m/s^2.
   (a) What resultant force acts on the car?
   (b) If the resistance to the motion is 1000N, What is the force due to the engine?

Solution

$m = 1000kg$
$a = 2m/s^2$
$f_f = 1000N$
$f_r = ?$

(a) $f = ma$

$f = 1000 \times 2$

$f = 2000N$

$\therefore f_r = 2000N$

(b) $f_r = \text{force due to engine}(f_e) - f_f$

$\therefore \text{force due to engine}(f_e) = f_r + f_f$

$f_e = 2000N + 1000N$

$f_e = 3000N$

4. A body of mass 2 kg moves with constant velocity of 13 m/s when a force of 10 N acts on it.

a) find the friction force
b) when the force is increased to 18 N. Find the acceleration produced?

Solution

(a) When a force of 10N acts on the body it moves with constant velocity meaning that the acceleration and the resultant force on the body is zero.

Applied force must be equal to the friction force

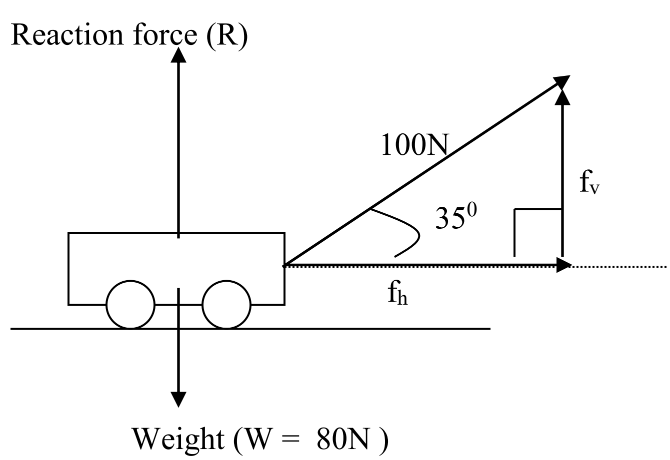
$f_r = 10\text{N}$

(b) When the applied force is increased there will be a resultant force

$$f = 18 - 10$$
$$f = 8N$$

$$a = \frac{f}{m} = \frac{8}{2}$$
$$a = 4m/s^2$$

5. A child pulls with a force of 100N on a wagon of mass 8kg at an angle of 35^0 to the horizontal.
(a) At what rate will the wagon accelerate?
(b) With how large a force is the ground pushing up on the wagon?



Solution

$f = 100N$

$m = 8kg$

$angle\ (\vartheta) = 35^0$

$a = ?$

($a)$ The component of the applied force which is causing the motion is f_h

$f_h = f\cos\vartheta$

$f_h = 100 x \cos 35^0$

$f_h = 81.92N$

$\therefore f_h = ma$

$a = \frac{f_h}{m}$

$a = \frac{81.92}{8}$

$a = 10.24$

(b) The force with which the ground is pushing the wagon is the reaction force (R).
Because there is no motion in the vertical direction the resultant in that direction is zero

$R + f_v = 80N$

$R + f\sin\theta = 80N$

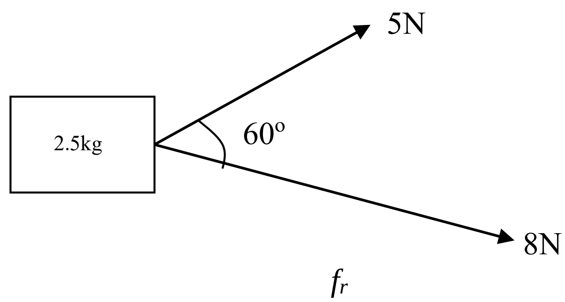
$R + 100\sin 35^0 = 80N$

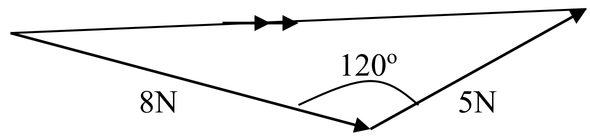
$R + 57.4N = 80N$

$R = 80N - 57.4N$

$R = 22.6N$

6. The horizontal forces f_1 and f_2 acts on a body of mass 2.5 kg. f_2 has magnitude of 5 N and 8 N and the angle between them is 60º. Find the acceleration of the body?





$f_r^2 = 8^2 + 5^2 - 2(8)(5)\cos 120^0$

$f_r^2 = 64 + 25 - 80(-0.5)$

$f_r^2 = 64 + 25 + 40$

$f_r^2 = 129$

$f_r = 11.36N$

But $f_r = ma$

$\therefore a = \frac{f_r}{m}$

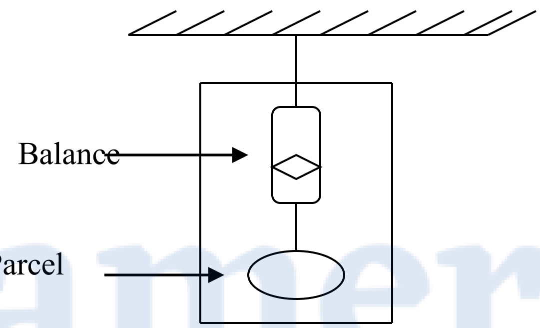
$a = \frac{11.36}{2.5}$

$a = 4.54 m/s^2$

7. Lift problem

A parcel of mass 4.5kg is suspended from a spring balance in a lift. What does the balance read if the lift is

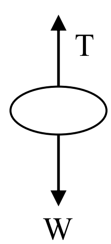
(a) Moving with uniform speed
(b) Accelerating upwards at $1.5 m/s^2$
(c) Accelerating downwards at $0.5 m/s^2$.



Solution

Drawing a free body diagram of the parcel and the reading on the spreading balance is equal to the tension (T)

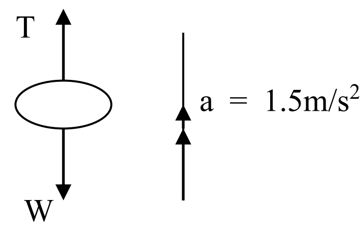
(a)



Because the lift is moving with constant speed the resultant force is zero

Therefore T = W
T = mg
T = 4.5 x 10
T = 45N

(b) The resultant force (F_r) is acting upwards meaning that the tension (T) is greater than the weight (W)



F_r = T - W

and F_r = ma

∴ T – W = ma

T – mg = ma

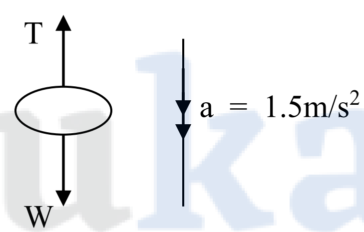
T – 4.5 x 10 = 4.5 x 1.5

T – 45 = 6.25

T = 45 + 6.25

T = 51.75N

(c) The resultant force (F_r) is acting downwards meaning that the weight is greater than the tension



F_r = W - T

but F_r = ma

W- T = ma

T = W - ma

T = mg – ma

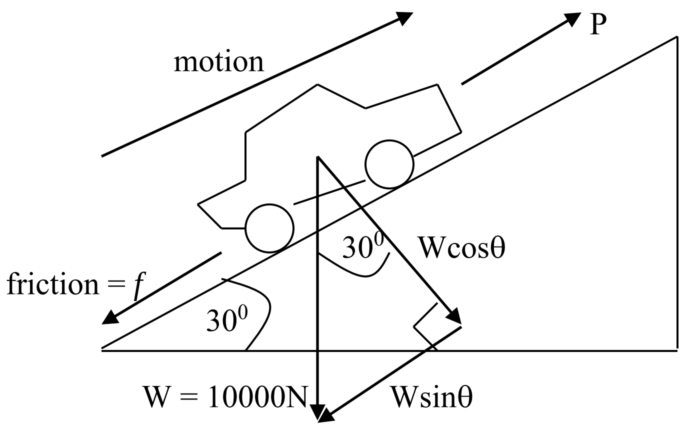
T = 4.5 x 10 – 4.5 x 0.5

T = 45 - 2.25

T = 42.75N

8. A car of mass 1000kg is moving up a hill inclined at 30^0 to the horizontal. Given that the total frictional force on the car is 1000N, calculate the force (P) of the engine when the car is

   (a) Accelerating upwards at $4m/s^2$?
   (b) Moving with a steady speed of 15m/s?



Solution

(a) The weight of the car is

$W = mg$

$W = 1000x10$

$W = 10000N$

The resultant force in the direction of motion is

$F_r = ma$

$F_r = 1000x4$

$F_r = 4000N$

But $F_r = P - (W\sin\theta + f)$

$4000 = P - (10000\sin 30^0 + 1000)$

$4000 = P - (5000 + 1000)$

$P = 10\,000N$

(c) If it is moving with constant speed the resultant force in the direction of motion is zero.

$F_r = 0 = P - (W\sin\theta + + f)$

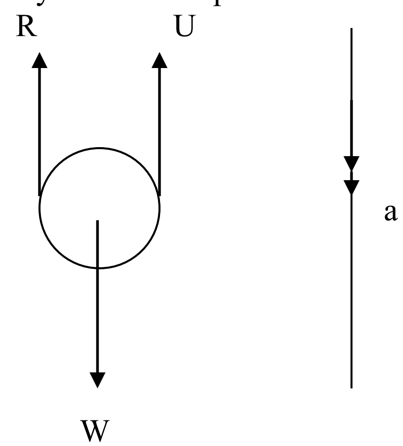
$0 = P - (10000\sin 30^0 + 1000)$

$P = 5000 + 1000$

$P = 6000N$

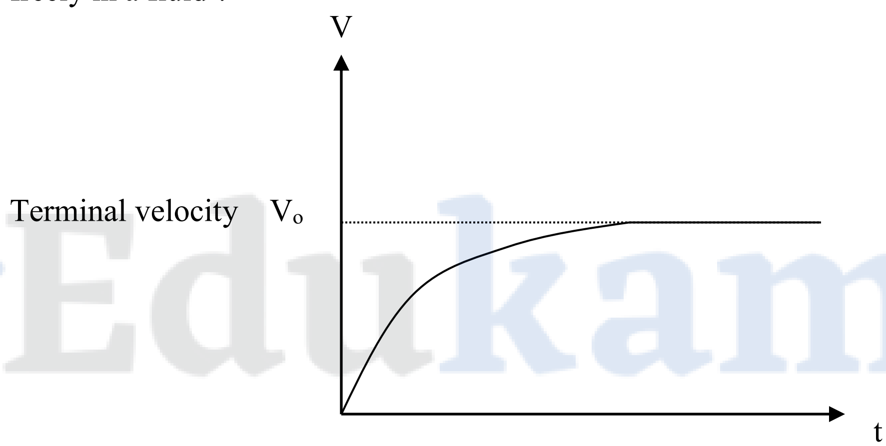
FLUID RESISTANCE AND TERMINAL VELOCITY

Bodies which are falling freely in a fluid experiences three forces which are



(a) The upthrust (U) - This acts vertically upwards and it is equal to the weight of the displaced fluid. Because the volume of the object is constant it follows that the volume and the weight of the displaced fluid will be constant. Therefore the upthrust is also constant.
(b) Weight (W) – Acts vertically downwards and if the gravitational field strength is constant it follows that weight is also constant.
(c) Fluid resistance (R) – Acts vertically upwards it is also called viscosity. This is directly proportional to the velocity of the body. For a body accelerating downwards the weight (W) is greater than the total upward force (R + U). But because the velocity is increasing the value of R also increases until the sum R + U will be equal to W (W = R + U). When this condition is reached the resultant force acting on the body will be zero. Therefore it will stop accelerating and move with a constant velocity called **terminal velocity**.

'Terminal velocity is the final constant velocity reached by bodies which are falling freely in a fluid'.



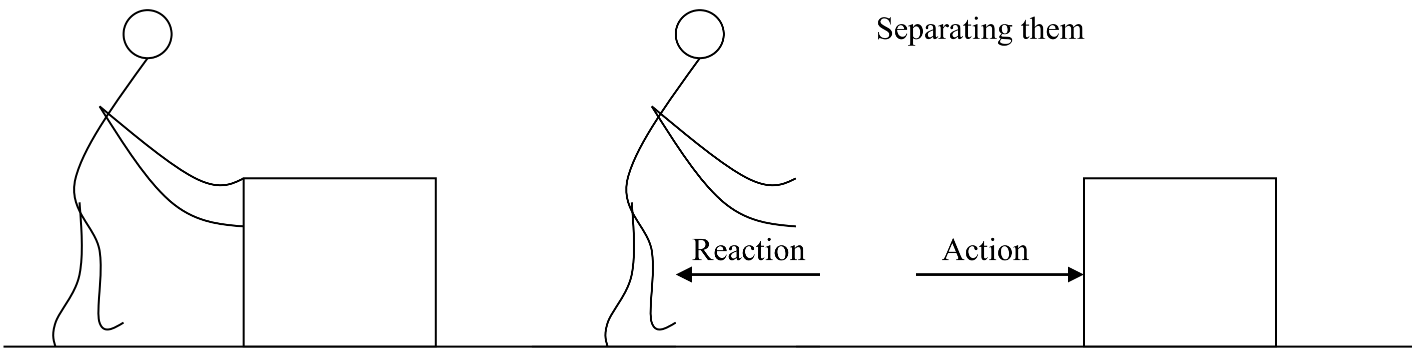
When the body is falling freely in a fluid
(a) Acceleration (a) – decreases until it reaches zero
(b) Resultant force [F_r = W- (U +R)] – decreases until it reaches zero
(c) Velocity (v) – increases until it reaches the constant terminal velocity.

Newton's third law of motion

When two bodies A and B are in contact and A exerts a force on B. B will exert an equal and opposite reaction force on A in the same line of action. This stated in Newton's third law of motion which states that

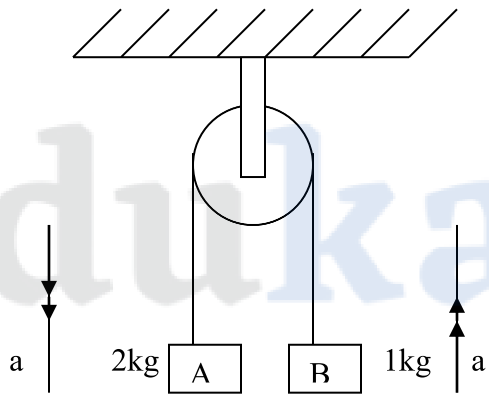
'To every action there is an equal and opposite reaction force'.

Note that the action and reaction force do not act on the same body otherwise they will cancel and you cannot have an acceleration. Consider a boy pushing an object on the floor. The action force acts on the object and the reaction force acts on the boy.



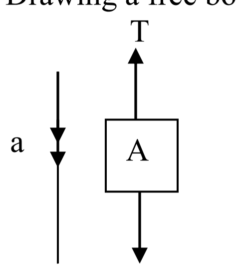
Examples

(1) A string (assuming to have no weight and not stretch) is placed over a smooth pulley. To the ends of the string are attached masses of 2kg (A) and 1kg (B) and both parts of the string are vertical.
(a) With what acceleration does the system move?
(b) What is the reaction at the axle of the pulley



Solution

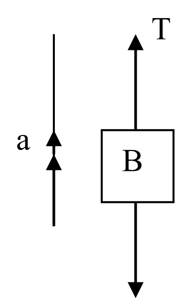
(a) Drawing a free body diagram of each mass



W = mg
= 2(10)
= 20N

The resultant force (F_r) is acting downwards

$$F_r = W - T$$
$$F_r = ma$$
$$\therefore W - T = ma$$
$$20 - T = 2(a)$$
$$20 - T = 2a \text{........}(1)$$

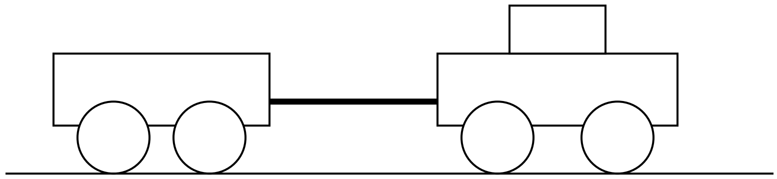


W = mg
= 1(10)
= 10N

The resultant force is acting

(8) A car of mass 1000kg is towing a trailer of mass 400kg on a horizontal ground. The total frictional force resisting the motion is 10N per kg. If the car is moving with constant speed find

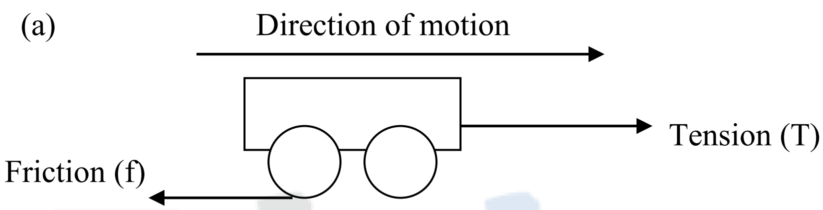
(a) The tension in the towing bar
(b) The driving force of the engine
(c) If the car starts to accelerate at $2m/s^2$ find the new driving force of the engine.



Solution

Separating the two bodies and drawing their free body diagrams

(a)

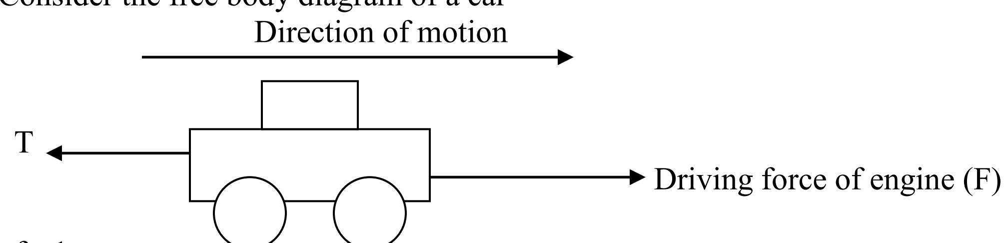


Friction on the trailer (f) = 10 x 400
f = 4 000N

The trailer is moving at constant speed, so the resultant force is equal to zero. Therefore the tension is equal to the friction force.

$$f = T$$
$$f = 4000N$$
$$\therefore T = 4000N$$

(c) Consider the free body diagram of a car



friction force on the car (f) = 10 x 1000
f = 10 000N

The car is moving with constant speed, so the resultant force is equal to zero.
Therefore total forward force = Total backward force

Driving force of engine $(F) = T + f$

$$F = 4\,000 + 10\,000$$

$$\underline{F = 14\,000N}$$

(c) Now that the car starts to accelerate there is a resultant force (F_r) in the direction of motion meaning that the driving force has increased.

$$F_r = F - (T + f)$$

Also $F_r = ma$

$$\therefore F - (T + f) = ma$$

$$F - (4\,000 + 10\,000) = 1000 \times 2$$

$$F - 14\,000 = 2000$$

$$F = 14\,000 + 2\,000$$

$$\underline{F = 16\,000N}$$

EXERCISE

(1) A car of mass 1000kg is accelerating at $2m/s^2$.
   (a) What resultant force acts on the car?
   (b) If the resistance to the motion is 1000N, what is the force due to the engine?

(2) A mass of 2kg is at rest on a rough horizontal table. A force of 20N is applied to the mass at an angle of 30^0 to the horizontal (table). The frictional resistance force is equal to 5N. What is the acceleration of the mass?

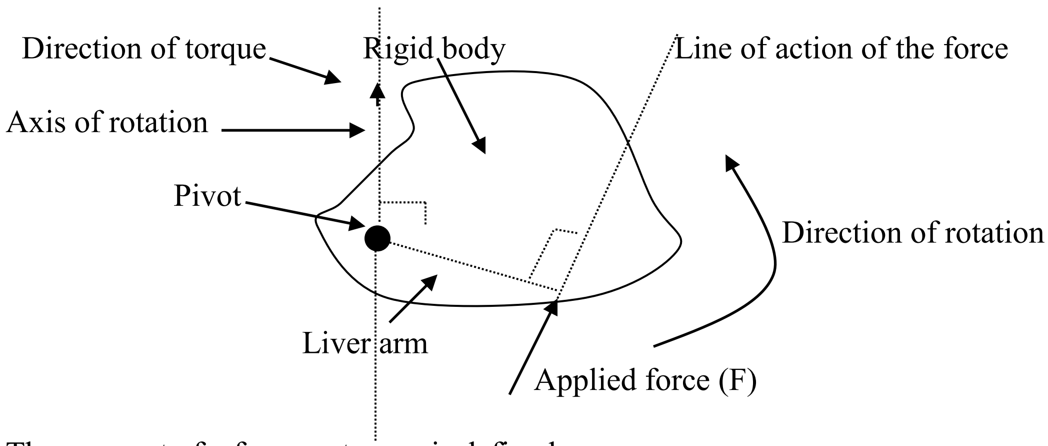
(3) Two forces of 20N and 10N act on a body of mass 0.5kg at right angle to each other. What is acceleration of the mass in magnitude and direction?

(4) A man of mass 80kg stands in a lift. What is the reaction from the floor of the lift if the lift
   (a) Moves upwards with steady speed?
   (b) Moves upwards with acceleration of $0.5m/s^2$
   (c) Moves downwards with acceleration of $0.4m/s^2$

(5) A truck of mass 1000kg pulling a trailer of mass 450kg accelerates at $0.6m/s^2$. Resistance to the motion on either vehicle is 4N per kg of mass.
   (a) What is the tension in the towing bar?
   (b) What is the traction (driving) force of the engine?

THE TURNING EFFECT OT FORCES (MOMENTS)

When the line of action of the resultant force acting on the rigid body is not passing through the center of gravity or the pivot the turning effect called the moment of the force or torque (τ) is produced.



The moment of a force or torque is defined as
'The product of the force and perpendicular distance of the line of action of the force from the turning point (pivot)'

Moment of a force = force x perpendicular distance of the line of action of the force from the turning point.

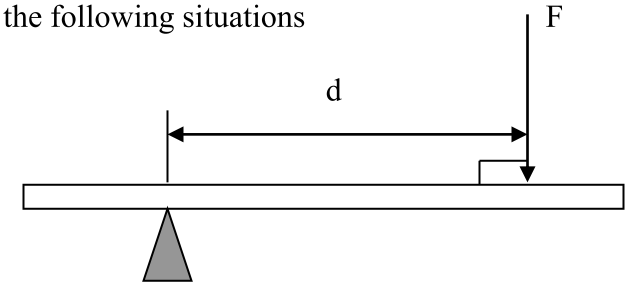
$$\tau = F \ x \ d$$
$$[N][m]$$

The S.I unit of the torque is therefore Nm . The **lever arm** of a force is the length of the perpendicular dropped from the axis of rotation (pivot) to the line of action of the force.

The moment of the force is a vector quantity and its direction is found using the right hand rule 'Grasp the axis of rotation in the right hand with the fingers circling th axis in the same sense of rotation either clockwise or anticlockwise. The thumb of the hand points along the axis in the direction of the torque.'

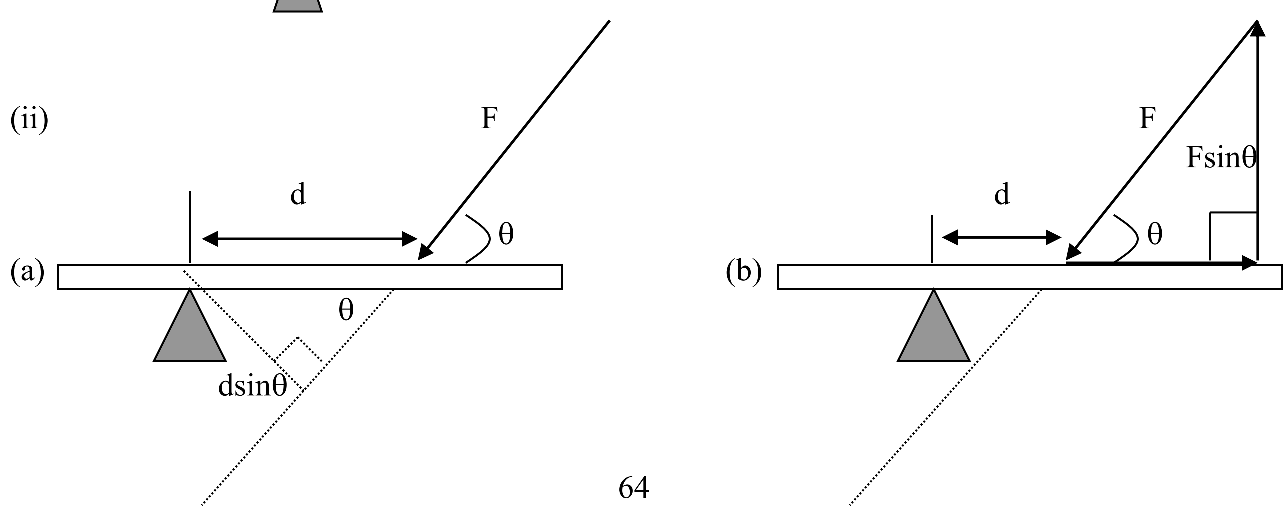
Consider the following situations

(i)



$\tau = F \ x \ d$

(ii)

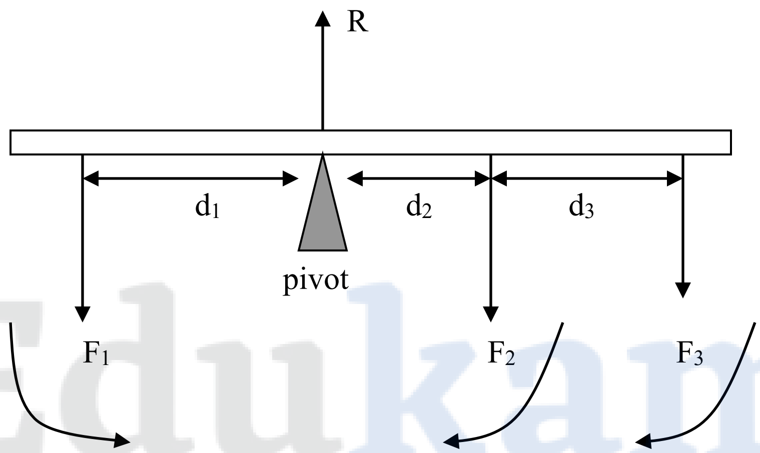


$\tau = F\,x\,d\sin\theta$ $\qquad\qquad$ $\tau = F\sin\theta\ x\ d$

$\tau = Fd\sin\theta$ $\qquad\qquad$ $\tau = Fd\sin\theta$

The principal of moments

The principal of moments states that
'When a body is acted by several forces and remains in equilibrium the sum of the clockwise moments about any point is equal to the sum of the anticlockwise moments about that point'



Taking moments about the pivot the reaction force R has no torque because it's lever arm is zero. The force F_1 produces a anticlockwise moment and the forces F_2 and F_3 produces clockwise moments. Using the principal of moments

Sum of clockwise moments = sum of anticlockwise moments.

$$F_2\,x\,d_2 + F_3\,x\,d_3 = F_1\,x\,d_1$$

$$F_2 d_2 + F_3 d_3 = F_1 d_1$$

Conditions of equilibrium

If the body is acted on by a number of coplanar forces (i.e. forces in the same plane) and is in static equilibrium (i.e. there is rest or un accelerated motion) the following two conditions must apply.

(a) The sum of the forces in one direction must equal the sum of forces in the opposite direction.

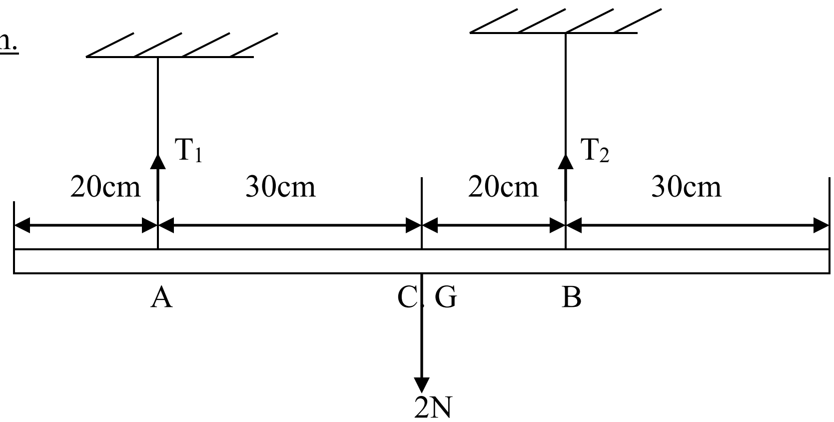
(b) The principle of moments must apply
'The sum of the clockwise moments about any point equals the sum of the anticlockwise moments about the same point'.

The first statement is a consequence of there being no translational motion in any direction and the second follows since there is no rotation of the body. In brief if a body is in static equilibrium the forces and the moments must both balance.

Examples

(1)Two thin strings support a 2N meter rule 20cm and 30cm respectively from the ends. Calculate the tension in each string.

Solution.



The moments can be taken about any point

(i) Taking moments about the center of gravity (C.G), T_1 produces the clockwise moment and T_2 produces the anticlockwise moment.. Using the principle of moments

Sum of clockwise moment = sum of anticlockwise moment

$T_1 \times 30 = T_2 \times 20$

$3T_1 = 2T_2$

$T_1 = \frac{2}{3} T_2$ ....(1)

(ii) Total upward forces = Total downward forces

$T_1 + T_2 = 2N$ ....(2)

Solving (1) and (2) simultaneously

Replace (1) into (2)

$$\frac{2}{3}T_2 + T_2 = 2N$$

$$\frac{5}{3}T_2 = 2$$

$$T_2 = \frac{2x3}{5}$$

$$\underline{\underline{T_2 = 1.2N}}$$

$$T_1 = \frac{5}{2}T_2$$

$$T_1 = \frac{5}{2}(1.2)$$

$$\underline{\underline{T_1 = 0.8N}}$$

Alternatively
Taking moments about one of the points where the unknown acts will eliminate the simultaneous equation. Take moments about A

$$2x30 = T_2 x50$$

$$60 = 50T_2$$

$$T_2 = \frac{60}{50}$$

$$\underline{\underline{T_2 = 1.2N}}$$

$$But\, T_1 + T_2 = 2N$$

$$T_1 + 1.2 = 2$$

$$T_1 = 2 - 1.2$$

$$\underline{\underline{T_1 = 0.8N}}$$

<u>EXERCISE</u>

(1) A uniform half metre rule is freely pivoted at the 15cm mark and it balances horizontally when a body of mass 40g is hung from 2cm mark. Draw a clear force diagram of the arrangement and calculate the mass of the half metre rule.

(2) A pole AB of length 10m and weight 800N has its centre of gravity 4m from the end A, and lies on horizontal ground. The end B is to lifted by a vertical force applied at B. Calculate the least force required to do this?

(3) It is found that a uniform wooden lath 100cm long and of mass 95g can be balanced on a knife-edge when a 5g mass is hung 10cm from one end. How far is the knife – edge from the centre of the lath?

(4) A uniform metre rule of weight 0.9N is suspended horizontally by two vertical loops of threads A and B placed at 20cm and 30cm

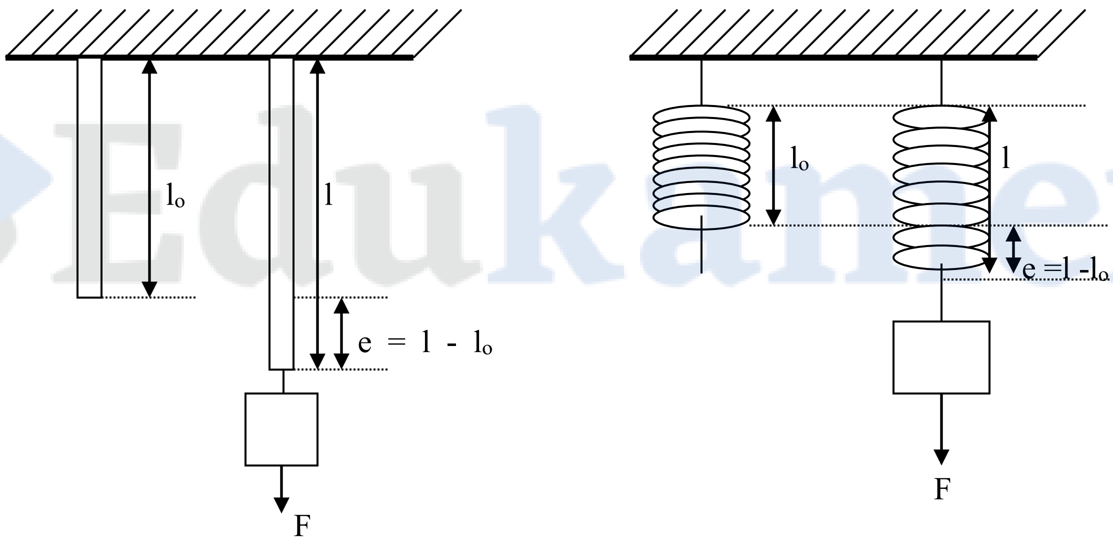
from its ends respectively. Find the distance from the centre of the rule at which a 2N weight must be suspended

(a) to make loop A become slack (zero tension)
(b) to make loop B slack

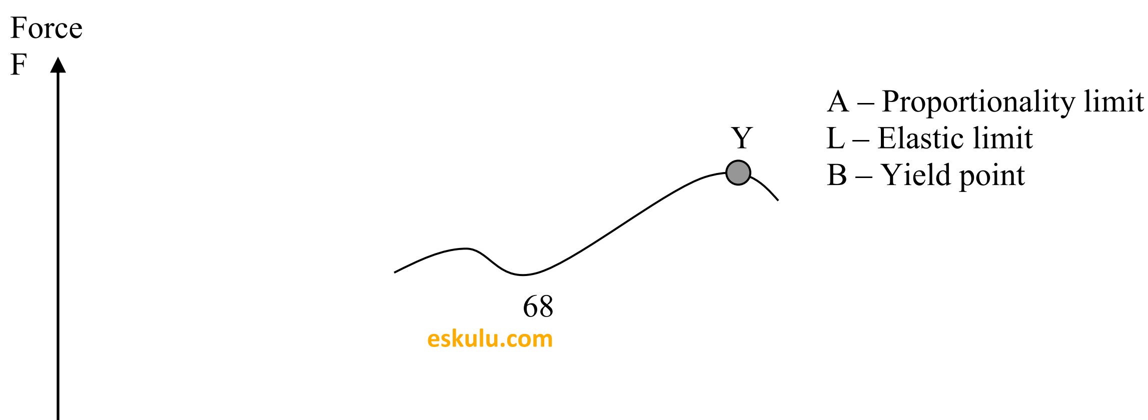
EFFECT OF FORCE ON THE SHAPE OF AN OBJECT

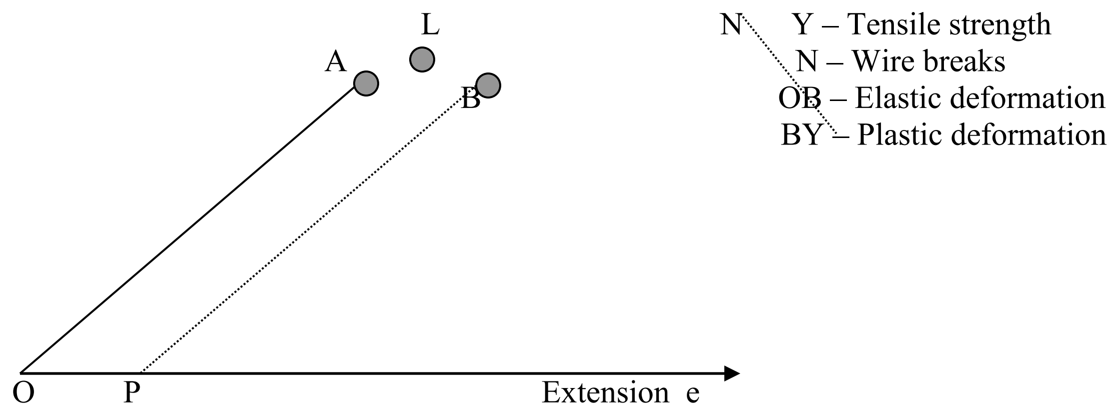
Materials can be characterized in terms of their deformability under the action of a force. Two major types of deformation occur. In one, the substance flows under the action of a force. This behavior is characteristic of fluids. The other type of deformation, which is only temporary, is elastic in nature, the stretching of a spring. When the deforming force is removed, the deformation returns to zero. Bodies which are able to regain their original length and shape after the application of a deforming force are said to be **elastic.**

If a rigid bar or spring is suspended to a stretching force by hanging a weight on it, the bar will stretch a distance **e**.



When the force **F** is plotted against the extension **e** a graph is obtained which is a straight line **OA**, followed by a curve **ABY**,





Along the line OA it can be seen that the force is proportional to the extension produced. Point A is called the limit of proportionality. Along OA and up to L, just beyond A, the returns to its original length when the load was removed. The force at L is called the elastic limit. Along OL the metal is said to under go changes called elastic deformation. The energy stored in the metal during elastic deformation is recovered when the load is removed.

Beyond the elastic limit L, however, the wire has a permanent extension such as OP when the force is removed at B. Beyond L, therefore, the wire is no longer elastic. The extension increases rapidly along the curve ABY as the force on the wire is further increased and at N the wire thins and breaks. When the elastic limit is passed, some of the energy stored in the metal is transformed to heat and is not recovered when the load is removed. The molecules of the wire begin to 'slide' across each other soon after the load exceeds the elastic limit. We say the material now becomes plastic This is indicated by the slight 'kink' at B beyond L and it is called the yield point of the wire. The change from an elastic to plastic stage is often shown by a sudden increase in the extension.

As the load is increased further the extension increases rapidly along the curve YN and the wire then becomes narrower and finally breaks.

<u>HOOKE'S LAW</u>

From the straight line OA, we deduce that

' the extension is proportional to the force or tension in a wire if the proportionality limit is not exceeded'

This is known as Hooke's law and expressed as an equation

$$F \,\alpha\, e$$

$$F = ke \quad \text{where } F - \text{force}$$

$$e - \text{extension}$$

$$k - \text{force constant (which is the measure of stiffness of the wire)}$$

The force constant k is the force needed to cause a unit extension

$$k = \frac{F}{e}\frac{[N]}{[m]}\ S.I\ unit\ k\ is \therefore N/m$$

Note the following points:

(i) After the limit of proportionality the wire no longer obeys Hooke's law, but still returns to its original form when the load is removed. It remains elastic.

(ii) After the elastic limit, the wire shows a permanent deformation and never regains its original shape and size.

(iii) At the yielding point there is a marked change in the internal structure brought about by the slipping of crystal planes.

(iv) In the plastic region (beyond the yielding point) small increases in load produce marked increases in the extension because of the flow processes.

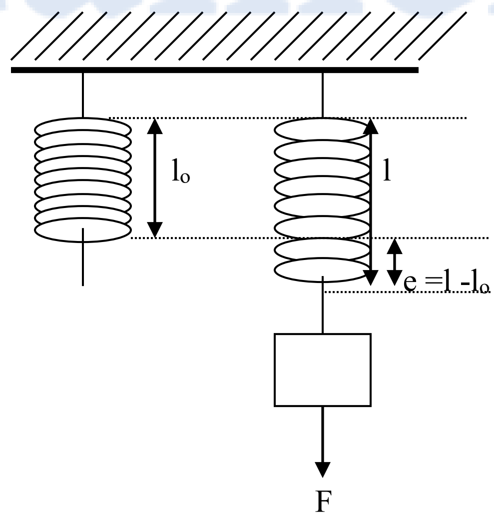
(v) Eventually a constriction or neck forms at weak point and the tensile force pull the rod apart.

(vi) Before the constriction forms, further re arrangement of the crystal imperfections allows the stress to increase and finally reach its maximum value (the breaking stress).

CONNECTED SPRINGS

A spring with, force constant **k** will extend by an extension **e** when the applied force is **F**

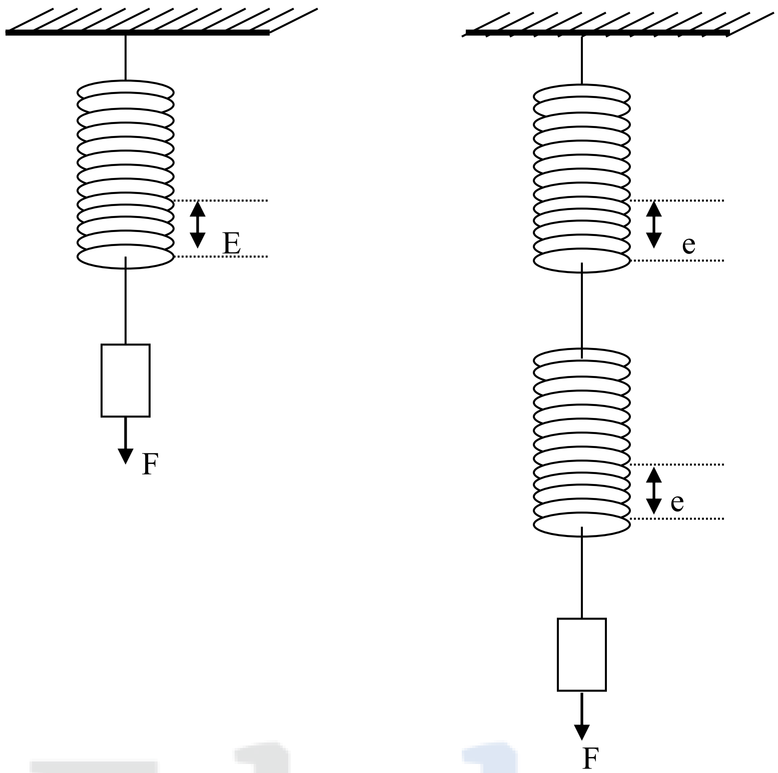
$$F = ke \qquad k = \frac{F}{e}$$



When two such identical springs are connected in

(c) SERIES

When the same force F is applied on the combination, the force F will act on each spring and each will be extended by 'e' giving the total extension of e + e = 2e



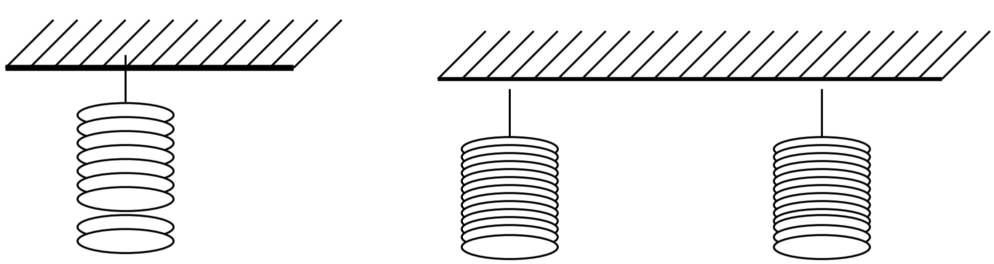
If the force constant for the combination is k_1 then

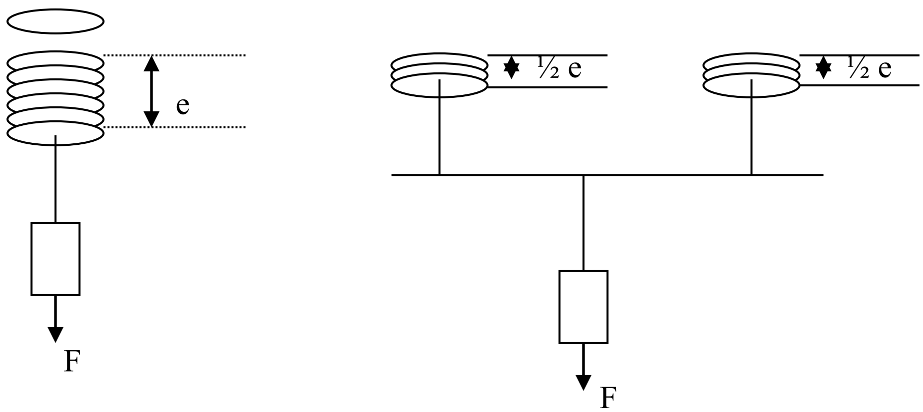
$$F = k_1(e + e)$$
$$F = k_1(2e)$$
$$k_1 = \frac{F}{2e} = \frac{1}{2}\left(\frac{F}{e}\right) = \frac{1}{2}k$$

The new force constant k_1 has reduced by a factor $\frac{1}{2}$ of the constant of a single spring meaning that the stiffness has reduced by the same factor.

(d) PARALLEL

When the same force F is applied to the combination the force will be distributed between the two springs and, therefore, $\frac{1}{2}$ F will act on each. The total extension therefore will be $\frac{1}{2}e$





If the force constant of the parallel combination is k_2 then

$$F = k_2\left(\frac{1}{2}e\right)$$

$$k_2 = \frac{2F}{e} = 2\left(\frac{F}{e}\right) = 2k$$

The force constant has increased by a factor of 2 and the stiffness has also doubled.

EXAMPLES

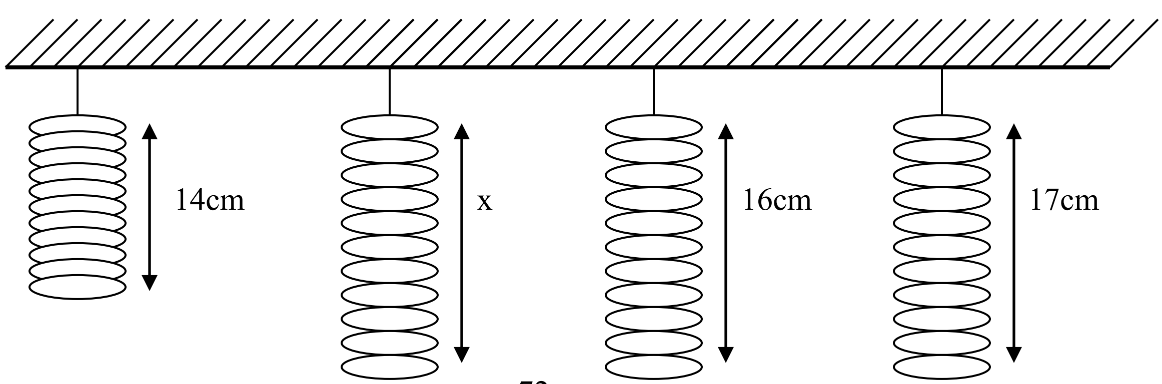
1. What is the force constant of a spring which is stretched
   (a) 2mm by a force of 4N
   (b) 4cm by a mass of 200g

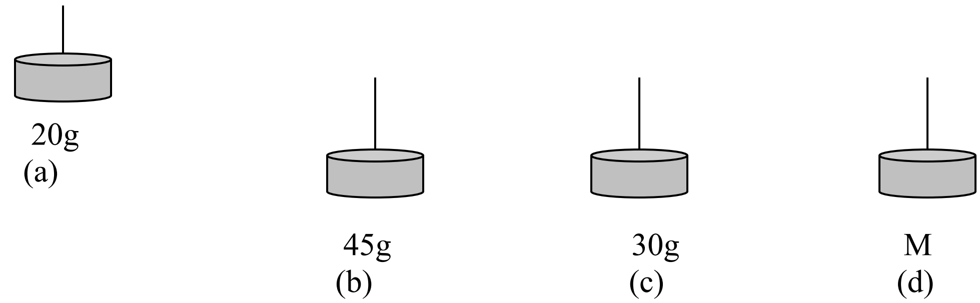
Solution

$$(a)\ e = 2mm = 0.002m$$
$$F = 4N$$
$$F = ke$$
$$k = \frac{F}{e} = \frac{4}{0.002}$$
$$\underline{k = 2000N/m}$$

$$(b)\ e = 4cm = 0.04m$$
$$F = \left(\frac{200}{1000}\right)\times 10 = 2N$$
$$k = \frac{F}{e} = \frac{2}{0.04}$$
$$\underline{k = 50N/m}$$

2. The figure shows 4 diagrams, not to scale, of the same spring which obeys Hooke's law





What is the length x and mass M

<u>Solution</u>

Let the original length of the spring before being loaded be l_o. From (a) and (c) the extension is therefore $14 - l_o$ and $16 - l_o$ respectively

$$From\ F = ke$$

$$k = \frac{F}{e} = \frac{20}{14 - l_o} = \frac{30}{16 - l_o} \qquad \therefore The\ spring\ constant\ k = \frac{20}{14 - l_o}$$

$$2(16 - l_o) = 3(14 - l_o) \qquad k = \frac{20}{14 - 10}$$

$$32 - 2l_o = 42 - 3l_o \qquad \underline{k = 5g/cm}$$

$$\underline{l_o = 10cm}$$

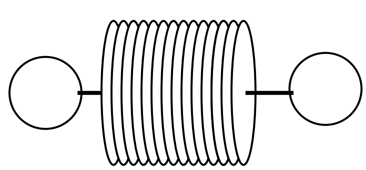
$$From(b)\ F = ke$$

$$e = \frac{F}{k} = \frac{45}{5} = 9cm \qquad and\ from(c)\ K = \frac{F}{e} \quad but\ e = 17 - 10 = 7cm$$

$$But\ x = l_o + e \qquad 5 = \frac{M}{7}$$

$$\therefore \underline{x = 10 + 9 = 19cm} \qquad \therefore \underline{M = 35g}$$

3. The figure below shows a type of spring used in physics experiments



When some students hang one of the springs vertically from the arm of a retort stand and measure *l*, the length of the spring, when different loads W are attached to the lower loop, they obtain the values shown in the below

W/N	0	0.50	1.00	1.50	2.00
l/mm	20	26	46	61	80

(a) (i) Copy the table and add to the table values of e, the extension of the spring.
(ii) Plot a graph of W/N (y-axis) against e/mm (x-axis). Draw the best straight line through your points

(b)
(c)

WORK ENRGY AND POWER

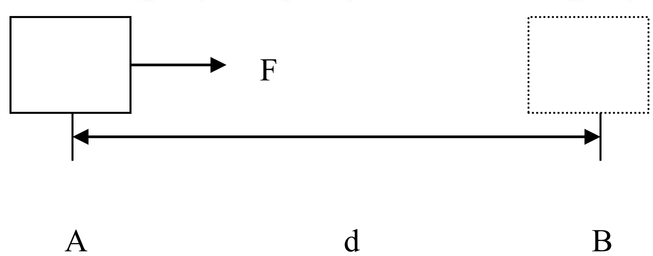
(A) WORK

This is defined as the product of force and the distance moved in the direction of the force.

W = F x d
[N][m]

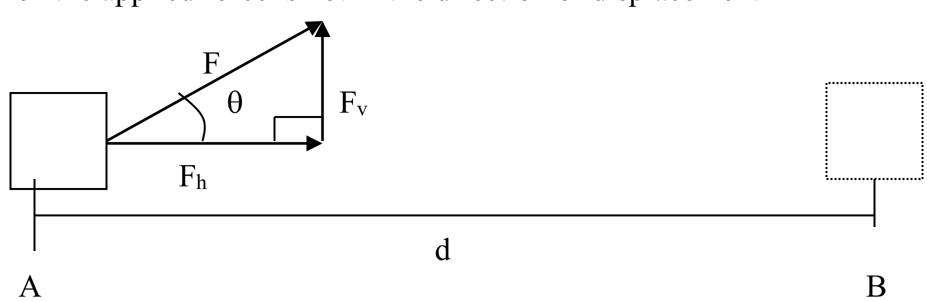
The S.I unit of the distance is Nm. This is given a special name called a joule [J].

(i) When the applied force is in the direction of the displacement



W = F x d

(ii) When the applied force is not in the direction of displacement

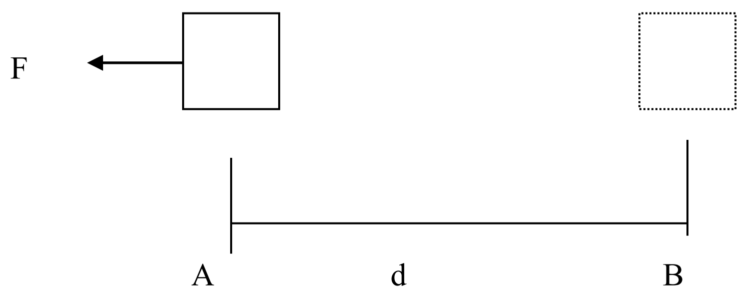


Find the components of the force F i.e. $F_h = F\cos\theta$ and $F_v = F\sin\theta$.

The component of the force in the direction of displacement is F_h

$$W = F \times d$$
$$W = F_h \times d$$
$$W = F\cos\theta \times d$$

(iii)



$$W = F \times d\cos 180^0$$
$$W = -Fd$$

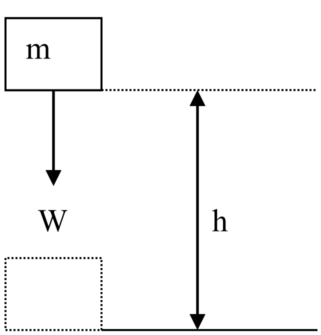
This is the work done against the force e.g. friction force.

(B) ENERGY

This is defined as the ability to do work.
There are different forms of energy but at the moment we consider the mechanical energy which is the combination of Potential and Kinetic energy.

(i) GRAVITATIONAL POTENTIAL ENERGY (Pe)

Gravitational potential energy is energy possessed by a body due its position in the gravitational field.
Consider a body of mass 'm' lifted through a height 'h'



Work done = F x d
Work done = Weight x height
Work done = (mg) x (h)
W= mgh

The work done in the gravitational potential field is called the potential energy

$$\therefore P_e = mgh$$

(iii) KINETIC ENERGY (K_e)

This is defined as the energy possessed by a body in motion.
Consider a body of mass (m) which is accelerated uniformly from rest an initial velocity (u) to final velocity (v)

W = F x d

But F_R = ma from Newton's second law of motion ....(i)
From the third equation of linear motion

$$v^2 = u^2 + 2as$$

$$2as = v^2 - u^2 \quad \text{...(ii)}$$

$$s = \frac{v^2 - u^2}{2a}$$

the equation above for 's' gives the distance 'd'

Replacing (i) and (ii) in the equation for work

$$W = F \ x \ d$$

$$W = ma \ x \left(\frac{v^2 - u^2}{2a} \right)$$

$$W = \frac{mv^2 - mu^2}{2}$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

The product of $\frac{1}{2}$ by the m by the v^2 is called the kinetic energy (K_e)

$$K_e = \frac{1}{2}mv^2$$

Therefore work done = final K_e - initial K_e
Work done = Change in kinetic energy
Work done = Change in energy
This is called the work energy theorem

LAW OF CONSERVATION OF ENERGY

It states that in a closed system the total amount of energy will remain constant.

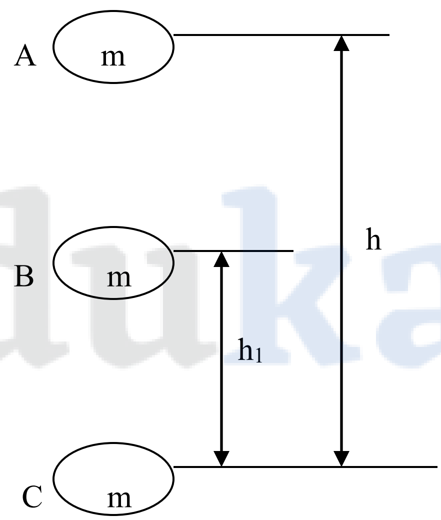
The closed system is where there is no energy leaving or entering it. But within the system there is energy transformation from one form to another. Therefore the total amount of energy in that system will be constant.

The law can be restated as
' Energy is neither created nor destroyed but can be transformed from one form to another'

ENERGY CONVERSION

(A) **Bodies falling in the gravitational field**

Given a body of mass 'm' which is dropped from the height 'h' in the gravitational field.



At point A

P_e = mgh and K_e = 0
Total energy (E) = $K_e + P_e$
E = mgh + 0
E =mgh

At point B

$P_e = mgh_1$ and $K_e = \frac{1}{2}mv^2$ from the equation of linear motion

$v^2 = u^2 + 2as$

$v^2 = 0 + 2g(h-h_1)$

$v^2 = 2gh-2gh_1$

$$K_e = \frac{1}{2}mv^2$$

Substitute in the equation for $K_e = \frac{1}{2}m(2gh - 2gh_1)$

$$K_e = mgh - mgh_1$$

Total energy (E) = $P_e + K_e$

$E = mgh_1 + mgh - mgh_1$

$\underline{E = mgh}$

<u>At point C</u>

$P_e = 0$ and $K_e = \frac{1}{2}mv^2$ from the equation of linear motion

$v^2 = u^2 + 2as$

$v^2 = 0 + 2gh$

$v^2 = 2gh$

$$K_e = \frac{1}{2}mv^2$$

Substitute in the equation for $K_e = \frac{1}{2}m(2gh)$

$$K_e = mgh$$

Total energy (E) = $K_e + P_e$

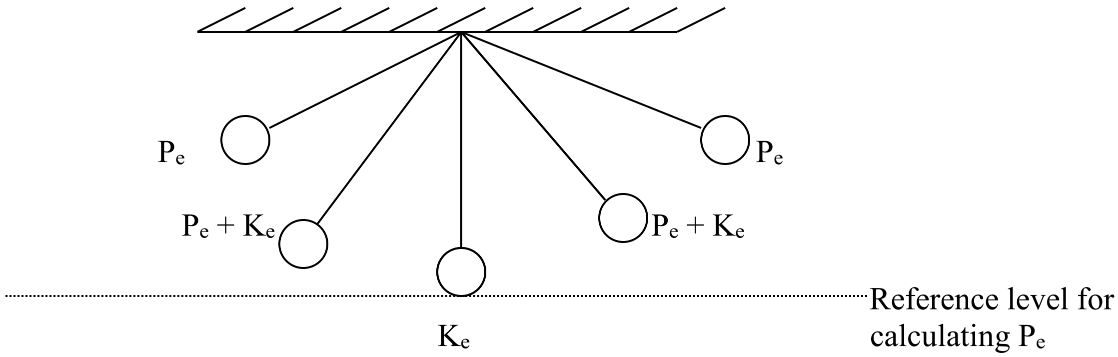
$E = mgh + 0$

$\underline{E = mgh}$

It can be seen that the total energy at point A, B, and C is the same and equal to mgh. When a body is falling freely in the gravitational field neglecting air resistance, there is energy transformation from potential energy to kinetic energy.

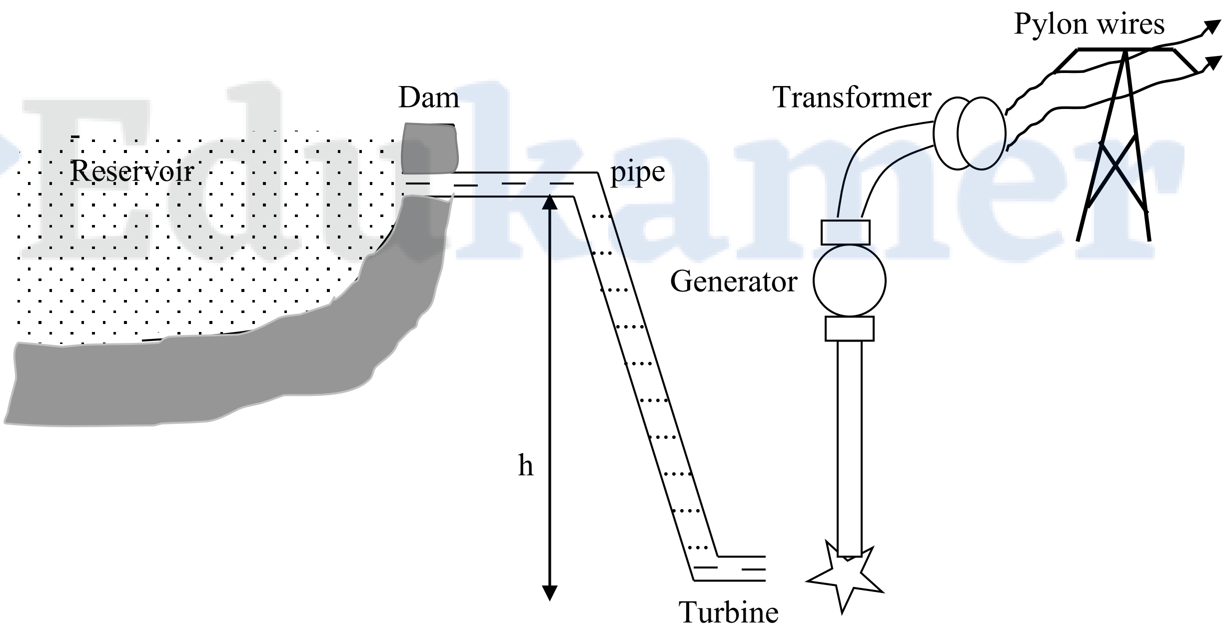
(B) **<u>Simple pendulum</u>**

When a simple pendulum is oscillating there is energy transformation from P_e to K_e to P_e and thereafter it repeats itself.



(C) **<u>Hydro – electric power generation</u>**

In hydro – electric power generation, water is trapped in the reservoir by building a dam across a river. From the dam the water goes into pipes which fall through a great height ‘h’ in order to increase the potential energy.



When water falls through the height ‘h’ , the potential energy is converted to kinetic energy which will rotate the turbine connected to the generator. The generator converts the mechanical energy ($P_e + K_e$) into electrical energy which is transmitted to the consumers.

<u>ENERGY SOURCES</u>

The raw material for energy production are called energy sources. These may be non – renewable or renewable.

NON – RENEWABLE SOURCES

These are energy sources that diminish. Once used up these cannot be replaced.

(i) **Fossil fuels**

These include coal, oil and natural gas formed from the remains of plants and animals which lived many years ago and obtained energy originally from the sun.

Burning fossil fuels in power stations and in cars pollutes the atmosphere with harmful gases this has an effect on the environment which is considered to be bad. Acid rain is caused by sulphur dioxide emission and carbon monoxide aggravates the green house effect.

(ii) **NUCLEAR ENERGY**

There are two types of nuclear energy reactions

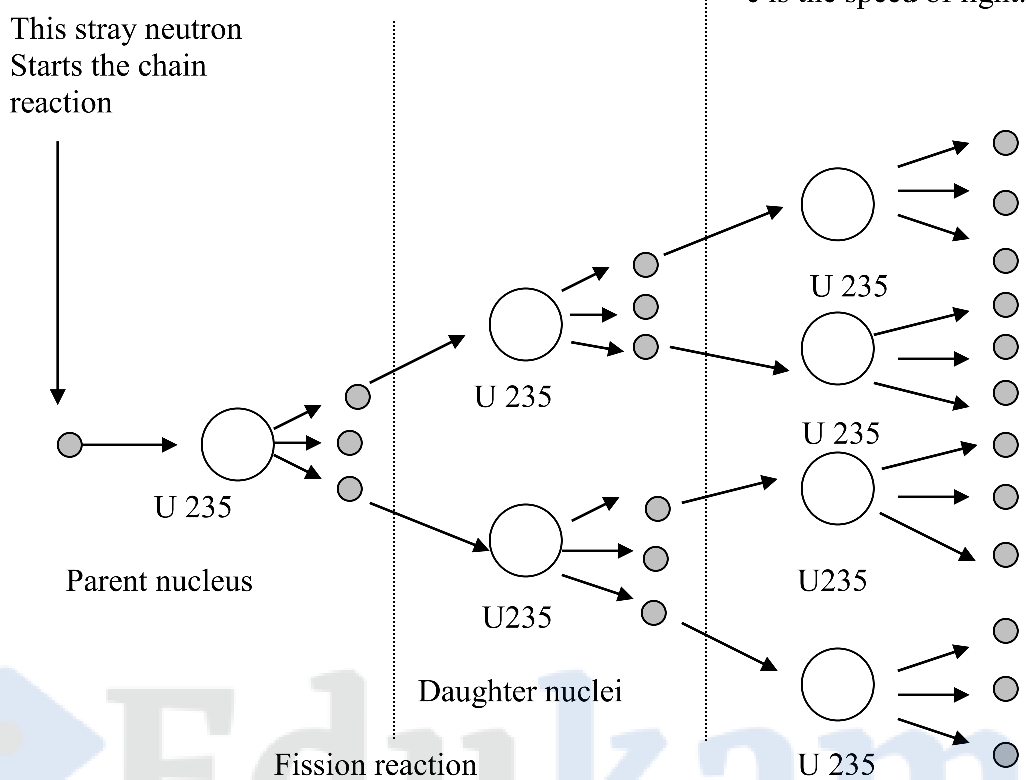
(a) FISSION

In a nuclear electricity installation the heat required for raising steam is provided by a nuclear reactor.

The Uranium 235 used in the reactor is quite spontaneous. Some of these Uranium 235 atoms explode or disintegrate to form other atoms of smaller mass. The lost mass will appear as energy from the nucleus of the atom together with small high speed particles called neutrons. If one of these neutrons strike the nucleus of a neighbouring atom this may also disintegrate, with a further evolution of energy and the production of more neutrons. This splitting up of the nucleus is called **fission**, and it forms a chain reaction.

The amount of energy released is given by the **Einstein's** theory of the equivalence of mass and energy which is

$E = \Delta mc^2$ where E is energy released
Δm is lost mass and
c is the speed of light.



This type of energy production however create environmental problems if the radiation leakage occurs, and from the need to dispose of dangerous waste materials with long radioactive lives.

(b) FUSION

This is opposed of fission. Energy can be obtained from the fusion of two hydrogen nuclei to form a heavier one. This is called thermonuclear reaction and it's the source of the sun's energy. Under the extremely high-temperature conditions in the interior of the sun, hydrogen nuclei fuse together to form helium nuclei and the resulting loss in mass is emitted in the form of radiations. Fusion reaction produces more energy than fission reaction.

Two advantages of the non – renewable fuels are

(i) their high energy density (i.e. they are concentrated sources) and the relatively small size of the energy transfer device (e.g. a furnace) which releases their energy and
(ii) their ready availability when energy demand suddenly increases or to meet the seasonal changes in demand.

- RENEWABLE ENERGY SOURCES

These cannot be exhausted and are non – polluting

(i) SOLAR ENERGY

The energy falling on the Earth from the sun is mostly in the form of light and in an hour equals the total energy used by the world, in a year, Unfortunately its low energy density requires large collecting devices and its availability varies. Its greatest potential use is as an energy source for low temperature water heating. This uses solar panels as the energy transfer devices which convert light into hest energy. Solar energy can also be used to produce high temperature heating, up to 3 000^oC or so if a large curved mirror (i.e. solar furnace) focuses the sun's rays on to a small area. The energy can then be used to turn water to steam for driving the turbine of an electric generator in a power station. Solar cells, made from semi conducting materials convert sunlight into electricity directly.

(ii) WIND ENERGY

Windmills (called wind turbines) drive electrical generators.

(iii) WAVE ENERGY

The rise and fall of sea waves has to be transferred by some kind of wave – energy converter into the rotary motion required to drive a generator.

(iv) TIDAL AND HYDRO - ELECTRIC ENERGY

The flow of water from a higher to a lower level from a behind a tidal barrage (barrier) or the dam of a hydro-electric scheme is used to drive a water turbine connected to a generator.

(v) GEOTHERMAL ENERGY

This is energy from the heat under the earth. It is a hard rock protrudes on the surface of the earth a hot spring can be formed from the under ground rivers which a heated by the heat from the core.

If cold water is pumped down a shaft into hot rocks below the earth's surface it comes up another shaft as steam. This can be used to drive turbine and generate electricity.

(vi) BIOMASS (VEGETABLE OR MANUAL FUEL)

These include cultivated crops, crop residues, natural vegetation, tree grown for their wood, animal dung and sewage. Bio fuels such as alcohol (ethanol) and methane gas are obtained from them by fermentation using enzymes or decomposition by bacterial action in the absence of air. Liquid biofuels are lead and sulphuric-free and so cleaner. Bio gas is mix of methane and carbon dioxide. It is mostly used for heating and cooking.

(C) **POWER**

Power is defined as the rate of doing work.

$$Power = \frac{work}{time}$$

$$P = \frac{w}{t}\left[\frac{J}{s}\right]$$

The S.I unit of power is $\frac{j}{s}$ which is given a special name a watt [w]

From the formula for power

$p = \frac{w}{t}$ { Where w = f x d } replacing in the equation for power

$$p = \frac{fxd}{t}$$

$p = f\left(\frac{d}{t}\right)$ { but $v = \frac{d}{t}$ }

$$\therefore p = fxv$$

Therefore power is the product of force and average velocity

e.g. Calculate the power when a force of 10N accelerates a body from 5m/s to 25m/s.

$$\text{Average velocity} = \frac{5+25}{2} = \frac{30}{2} = 15m/s$$

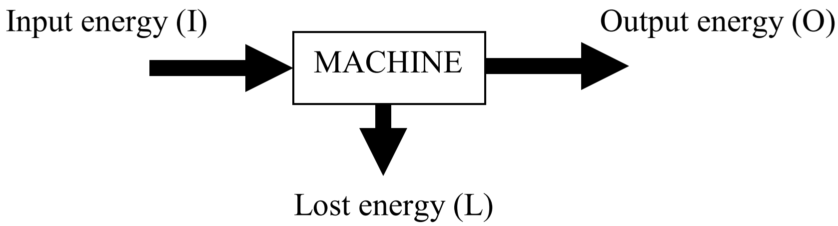
$$p = fxv$$
$$p = 10x15$$
$$p = 150w$$

EFFICIENCY

Efficiency is defined as the ratio of the output energy (or power) to the input energy (or power)

$$Efficiency = \frac{Output\ energy}{Input\ \ energy}$$

Efficiency can be expressed as a percentage by multiplying by 100%. Efficiency will never be 100% (or 1) because not all the input energy will be given out as useful energy. Part of the input energy will be lost to other forms of unwanted energies e.g. sound and heat due to friction.



Input energy (I) = Output energy(O) + Lost energy (L)

$$I = O + L$$

$$O = I - L$$

$$Efficiency = \frac{O}{I} = \frac{I - L}{I}$$

$$Efficiency = \frac{I}{I} - \frac{L}{I} = 1 - \frac{L}{I}$$

$$Efficiency = 1 - \frac{L}{I}$$

$$Efficiency = 1 - \frac{Lost\ \ energy}{Input\ energy}$$

<u>EXAMPLES</u>

(1) A ball of mass 1kg is dropped from a height of 7m and rebounds to a height of 4.5m. Calculate

(a) Its kinetic energy before impact
(b) Its velocity just before impact
(c) Its rebound velocity and kinetic energy
(d) Account for the loss of the kinetic energy

<u>Solution</u>

(a)

$$ke = \frac{1}{2}mv^2$$
$$v^2 = u^2 + 2as$$
$$v^2 = 0 + 2(10)(7)$$
$$v^2 = 140$$
$$\therefore ke = \frac{1}{2}(1)(140)$$
$$\underline{ke = 70j}$$

(b) From (a) above

$$v^2 = 140$$
$$v = \sqrt{140}$$
$$\underline{v = 11.83m/s}$$

(c) Pe at 4.5m height = Ke on rebound

$$\therefore mgh = \frac{1}{2}mu^2$$
$$(1)(10)(4.5) = \frac{1}{2}(1)(u^2)$$
$$u^2 = 90$$
$$\underline{u = 9.49m/s}$$

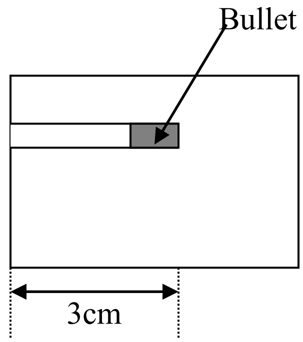
or

$$v^2 = u^2 + 2as$$
$$0 = u^2 + 2(-10)(4.5)$$
$$u^2 = 90$$
$$u = \sqrt{90}$$
$$\underline{u = 9.49m/s}$$

$$ke = Pe = mgh$$
$$ke = (1)(10)(4.5)$$
$$\underline{ke = 45J}$$

(d) Energy is lost in the form of heat and sound.

(2) A bullet of mass 12g strikes a solid surface at a speed of 400m/s. If the bullet penetrates to a depth of 3cm, calculate the average net force acting on the bullet while it is being brought to rest.



u = 400m/s
v =0m/s
s = 0.03m
m = 0.012kg

$$F = ma \text{ (Newton's second law) and}$$

$$\text{from } v^2 = u^2 + 2as$$

$$0 = 400^2 + 2(a)(0.03)$$

$$-0.06a = 160\ 000$$

$$a = \frac{160\ 000}{-0.06}$$

$$a = -2\ 666\ 666.67 m/s^2$$

$$F = ma$$

$$F = 0.012(-2\ 666\ 666.67)$$

$$F = -32\ 000N$$

Alternatively using the work energy theorem

$$\text{Work done} = \text{Change in } (K_e) \text{ energy}$$

$$\text{Work done} = \text{Final kinetic energy} - \text{Initial kinetic energy}$$

$$W = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$F \ x \ s = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$

$$F \ x \ 0.03 = 0 - \frac{1}{2}(0.012)(400)^2$$

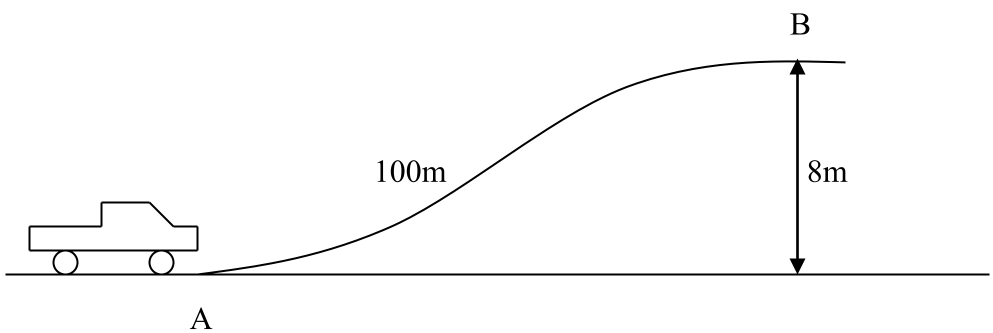
$$0.03F = -960$$

$$F = \frac{-960}{0.03}$$

$$F = -32\ 000N$$

(3) The 2000kg car shown below is at point A moving at 20m/s when it begins to coast (the engine is switched off). As it passes point B it's speed is 5m/s.

(a) how large is the average friction force which retards it's motion
(b) assuming the same friction force, how far beyond B will the car go before stopping.



Solution

(a)

Initial velocity at A (u) = $20m/s^2$
Final velocity at B (v) = $5m/s^2$
Distance from A to B (s) = 100m
Height climbed from A to B (h) = 8m

The kinetic energy at A = Potential energy at B + Kinetic energy B + work done against friction

$$\frac{1}{2}mv^2 = mgh + \frac{1}{2}mu^2 + f\,x\,s$$

$$\frac{1}{2}(2000)(20)^2 = 2000(10)(8) + \frac{1}{2}(2000)(5)^2 + f\,x100$$

$$400\,000 = 160\,000 + 25\,000 + 100f$$

$$400\,000 = 185\,000 + 100f$$

$$400\,000 - 185\,000 = 100f$$

$$100f = 215\,000$$

$$f = \frac{215\,000}{100}$$

$$\underline{\underline{f = 2150N}} \text{ Which is the friction force}$$

Alternatively using the work energy theorem

$$Total\ energy\ at\ A = \frac{1}{2}mu^2 = \frac{1}{2}(2000)(20)^2$$
$$= \underline{\underline{400\,000J}}$$

$$Total\ energy\ at\ B = \frac{1}{2}mv^2 + mgh$$
$$= \frac{1}{2}(2000)(5)^2 + 2000(10)(8)$$
$$= 160\,000 + 25\,000$$
$$= \underline{\underline{185\,000J}}$$

$Work\ done = Change\ in\ energy$

$f\ x\ s = 400\,000 - 185\,000$

$f\ x\ 100 = 215\,000$

$$f = \frac{215\,000}{100}$$

$\underline{\underline{f = 2150N}}$

(b) At B

$u = 5m/s$

$v = 0m/s$

$f = 2150N$ $\quad a = \frac{f}{m} = \frac{2150}{2000}$

$m = 2000kg$ $\quad \underline{\underline{a = -1.075m/s^2}}$

$v^2 = u^2 + 2as$

$0 = 5^2 + 2(-1.075)s$

$2.15s = 25$

$$s = \frac{25}{2.15}$$

$\underline{\underline{s = 11.63m}}$

(4) A car of mass 1.5t is driven from rest with uniform acceleration and reaches a speed of 50km/h in 30s.
Find
  (a) the useful force exerted by the engine in newtons
  (b) the power developed in kilowatts at 50km/h

Solution

$m = 1\,500kg$
$u = 0m/s$
$v = 50km/h = 13.89m/s$
$t = 30s$

$v = u + at$
$13.89 = 0 + (a)30$
$a = \frac{13.89}{30}$
$a = 0.46m/s^2$

Substitute in the equation for $F = ma$

$$F = 1\,500 \; x \; 0.46$$
$$F = 694.4N$$

(b) $P = \frac{w}{t}$ but $w = f \; x \; s$

$\therefore P = \frac{f \; x \; s}{t}$

$s = \left(\frac{v+u}{2}\right)t$
$s = \left(\frac{13.89 + 0}{2}\right)30$
$s = 208.35m$

$P = \frac{f \; x \; s}{t}$
$P = \frac{694.4 \; x \; 208.35}{30}$
$P = 4\,822.6watts$
$P = 4.8kw$

(5) Calculate the work done when a body of mass 2kg is accelerated from 10m/s to 25m/s

Work done = change in (K_e) *energy*

$$w = \frac{1}{2}mv^2 - \frac{1}{2}mu^2$$
$$w = \frac{1}{2}(2)(25)^2 - \frac{1}{2}(2)(10)^2$$
$$w = 625 - 100$$
$$w = 525J$$

(6) (a) A school girl climbs to the top of a fire lookout in one hour. If she does 180 000J of work against gravity during her climb what average power is involved?

(b) If her body transforms energy to work with efficiency of 10%, how much chocolate cake (30MJ/kg) will she need to consume to fuel her climb?

Solution

(a) The work done against gravity (w) = 180, 000J in time (t) = 60sec

$$P = \frac{w}{t}$$

$$P = \frac{180,000}{60}$$

$$P = 3000J$$

$$Efficiency = \frac{Output\ energy}{Input\ energy} x100\%$$

$$10\% = \frac{180000}{Input\ energy}\ x\ 100\%$$

(b) $$Input\ energy = \frac{180\ 000}{10\%}\ x\ 100\%$$

$$Input\ energy = 1\ 800\ 000J$$

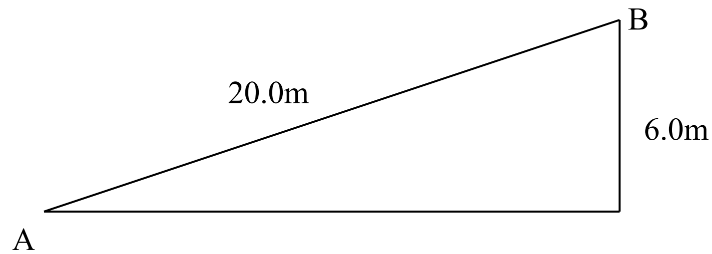
$$Amount\ of\ \ chocolate\ required = \frac{1\ 800\ 000}{30\ 000000}$$

$$Amount\ of\ \ chocolate\ required = 0.06kg$$

EXERCISE

(1) Find the work done when a load of 50kg is lifted vertically through 10m
(2) .The velocity of a body of mass 0.5kg is reduced from 12m/s to 5m/s in a distance of 1.5m. What force is acting on the body?
(3) A constant force acts on a body of mass 2kg and does 45J of work. The effect on the body is that its velocity is 2m/s more than its initial velocity. Find the initial velocity of the body.
(4) A bullet of mass 40g strikes a fixed piece of wood 10cm thick with a velocity of 300m/s and emerges with a velocity of 120m/s. Find the average resistance of the wood.
(5) Calculate the work done against gravity by a person of mass 80kg in walking up a flight of 12 steps each of which is 200mm high.
(6) Calculate the work done in lifting a mass whose weight is 500N through a vertical height 6.0m.

The mass can be raised to the same height by pulling it from A to B up a ramp of length 20.0m shown in the figure below. If the surface of the ramp is sufficiently smooth for friction between the surface and the mass to be neglected.



Calculate the force acting parallel to AB required to pull the mass up the ramp at constant speed.

(7) What kinetic energy is gained by a body of mass 3kg on falling freely through a height of 4m?

(8) A stone of mass 3kg thrown upwards with a kinetic energy of 240J. Neglecting air resistance, calculate the height to which it will rise

(9) A crate of mass 300kg is raised by an electric motor through a height of 60m in 45sec. Calculate
(a)The weight of the crate
(b) The work done by the motor
(c) The useful power of the motor

(10) A hydro – electric power station takes from a lake whose water level is 50m above the turbines. Assuming an overall efficiency of 70%, calculate the mass of water which must flow through the turbines each second to produce a power output of 1MW.

(11)

<u>MACHINES</u>

A machine is a mechanical device or system of deices in which the applied force (the effort) acting at one point is transmitted and used, to overcome another force (the load) acting at another point.

In the process the machine makes doing work easier, faster and safer. But the machine does not reduce the amount of work to be done. However, the machine enables the useful power output to increase since shorter time is taken to do the same work. Machines range from simple ones such as levers, gears to complex ones such as the engine of the vehicle, gear box of vehicles, hydraulic system etc.

MECHANICAL ADVANTAGE (MA)

The mechanical advantage (Ma) is the ratio of the load it is able to overcome to the applied effort.

Mechanical Advantage = $\frac{\text{Load}}{\text{Effort}}$

$$M.A = \frac{L}{E}$$

The mechanical advantage has no units since it's a ratio of two forces. Some machines can overcome a load much greater than the effort used e.g. a spanner, used to undo a tight bolt or a screw jack to lift a car. In such cases the mechanical advantage is greater than 1.

In some machines the mechanical advantage is less than 1, and in these the effort is greater than the load. The bicycle is an example of a machine with mechanical advantage less than 1. Under normal conditions the resistance to the motion of a bicycle is very small and therefore a large mechanical advantage is unnecessary. Thus although the cyclist works at a 'Mechanical disadvantage' be nevertheless gains in speed with which he can travel. The fact that the mechanical advantage of a bicycle becomes painfully obvious when we begin to ascend a hill. Whereas previously only a small amount of work had to be done against friction and air resistance we have to do a vastly increased amount against our own weight and that of the bicycle. Under these conditions it is usually easier to dismount and walk unless the mechanical advantage of the bicycle can be increases by using a lower gear.

Some machines have mechanical Advantage equal to 1 like a single fixed pulley as seen later.

VELOCITY RATIO (or speed ratio) (V.R.)

The velocity Ratio of a machine is the ratio of the distance moved by the effort to the distance moved by the load in the sometime.

Velocity Ratio = $\frac{\text{distance moved by the effort}}{\text{Distance moved by the load in the sometime}}$

$$VR = \frac{dE}{dL}$$

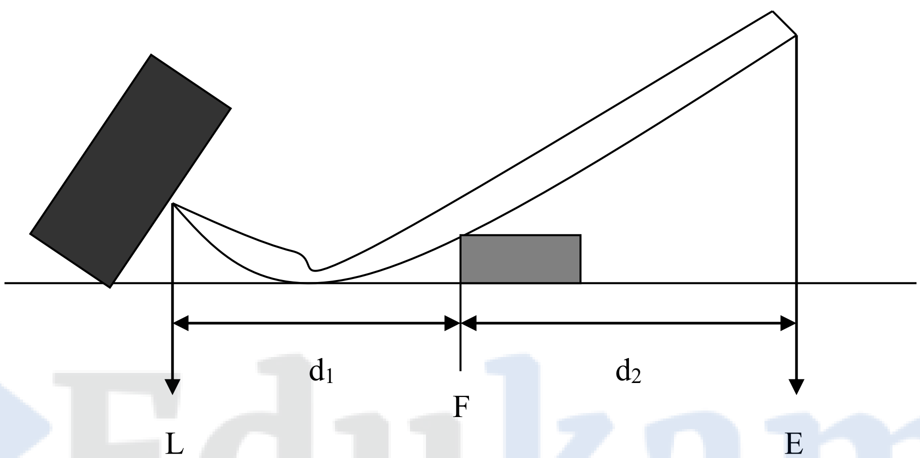
The velocity ratio has no units since it is a ratio of two distances or velocities. In some machines where the mechanical advantage is greater than 1. it might appear that we are getting more out of the machine than we are putting into it. But while in such cases the load is greater than the effort, the effort moves through a greater distance than that of the load. Consequently the work obtained from the machine is equal to the work put into it less any work wasted in machine.

This equation will be found very full for working out problems, but it is not a fundamental definition of efficiency and should not be used as such.

EXAMPLES OF MACHINES

(a) **LEVERS**

The simplest form of a lever is a crow bar, but the term lever may be applied to any rigid body which is pivoted about an axis called the *fulcrum*. Levers are based on the principle of moments. A force called the *effort* is applied at one point on the lever, and this overcomes a force called the *load* at some other point.



If we neglect friction at the fulcrum and the weight of the lever itself (both being comparatively small in more cases) the mechanical advantage is obtained by writing the equation of the moments for the load and effort about the fulcrum.

Moments of load = moment of effort

$$Lxd_1 = Exd_2$$

$$\frac{L}{E} = \frac{d_1}{d_2}$$

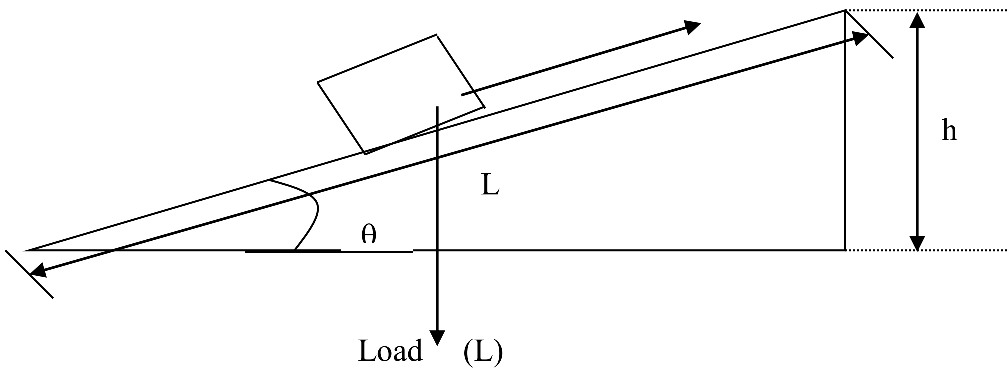
Therefore Mechanical advantage = $\frac{L}{E} = \frac{d_2}{d_1}$

The mechanical advantage depends on the position of the fulcrum in relation to the effort and load.

(b) **INCLINED PLANS**

An included plane is a simple machine that is used to raise a heavy load from the ground to a higher platform by way of putting the load than lifting it.

Effort (E)



The load is pulled up an inclined plane in order to raise it through a longer distance to the length of the inclined plan (L). It must be understood that because the weight of the load acts vertically downwards, the distance through the load is overcome is (h) and not (L).

The magnitude of the effort needed to pull or push the load over an inclined plane depends on the

(i) the length of the plane
(ii) the angle (θ) of inclined plane i.e. of the plane
(iii) the friction force between the plane and the load

The effort needed is smaller when the angle of the inclination θ is very small i.e. the length of the plane is big and when the friction force between the plane and the load is negligible.

Therefore the (MA) of the inclined plane is increased by decreasing the angle of inclination through the use of a longer plane and decreasing the friction between the load (body) and plane.

These measures enable that the effort (E) is kept smaller thereby increasing the (MA)

$$MA = \frac{load}{effort} = \frac{L}{E}$$

If there is no friction

$$E = L\sin\theta$$

$$\therefore MA = \frac{L}{L\sin\theta} = \frac{1}{\sin\theta}$$

If there is friction

$$E = L\sin\theta + F$$

$$\therefore MA = \frac{L}{L\sin + F}$$

The velocity ratio: (VR) of the inclined plane is equal to

$$VR = \frac{distance\ \ moved\ \ by\ \ effort}{distance\ \ moved\ \ by\ \ load}$$

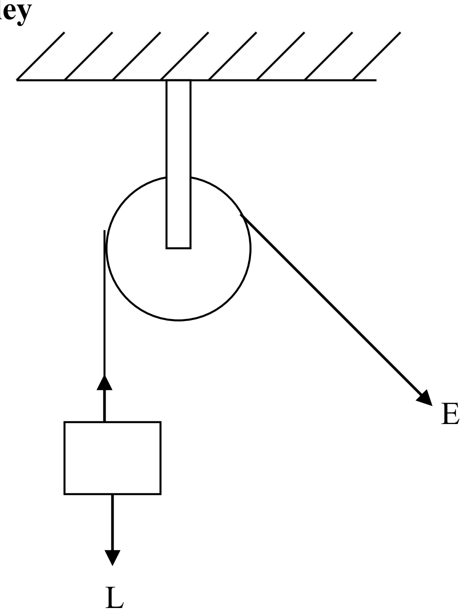
$$= \frac{length\ \ of\ \ plane}{height\ \ of\ \ plane} = \frac{L}{h}$$

$$VR = \frac{L}{L\sin\theta} = \frac{1}{\sin\theta}$$

(c) <u>THE PULLEYS</u>

The pulley is a wheel that has a groove over which a rope or chain can be passed. The pulley can either be fixed on a particle axe such that it rotates about a fixed point or it can be a moving pulley.

(i) **The Single fixed Pulley**



If there is no friction about the pivot or the bearing of the fixed pulley, the effort (E) to overcome the load (L) has the same magnitude equal to the load:

$$Load = effort$$

$$Mechanical Advantage = \frac{load}{effort} = 1$$

In this fixed pulley the distance moved by the effort is equal to the distance moved by the load being lifted.

$$VR = \frac{distance\ \ moved\ \ by\ \ effort}{distance\ \ moved\ \ by\ \ load} = 1$$

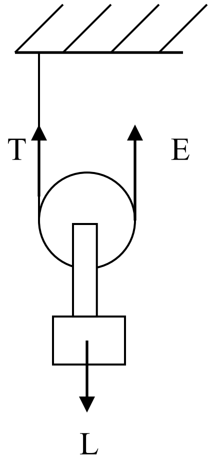
This implies that the efficiency of such a machine will be

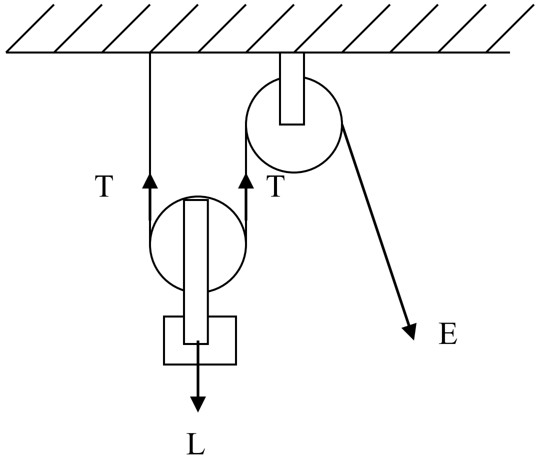
$$\eta = \frac{MA}{VR} x100 = 100\%$$

However when the pulley has friction in its axle or bearings the effort applied has to be greater than the load hence (MA) will be less than 1 and the efficiency will be less than 100%.
In this case although the effort applied is equal to the load raised we obtained greater convenience and ease of being able to stand on the ground and pull downwards instead of having to haul the load and upwards from the top.

(ii) **The Single moving Pulley**

The moving pulley is one that moves with the load being lifted. But the moving pulley is not considered to be part of the load since it is very small weight as compared to the load.





From the figures above the tensions (T) in the string or rope is equal to the effort E i.e. E = T. The total upward pull on the moving pulley (T + T) is equal to the load (L).

L = T + T
L = 2T
But E = T
$\therefore$ L = 2E

$$\frac{L}{E} = 2$$

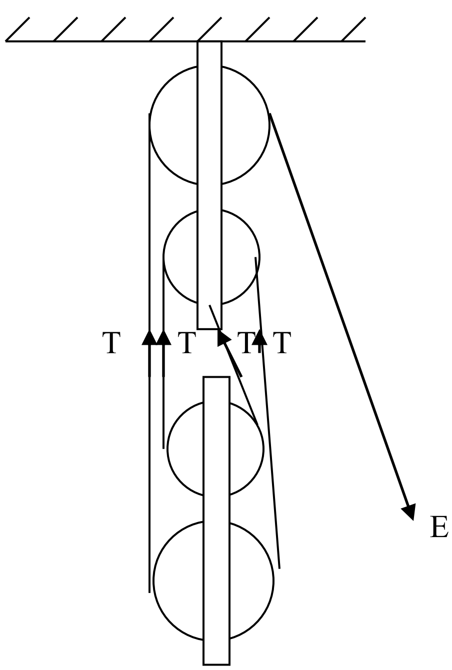
$$MA = \frac{L}{E} = 2$$
$$MA = 2$$

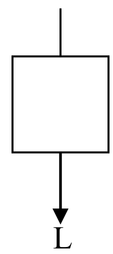
To raise the load by 1 m requires each side of the rope supporting the load shortened by 1 m. The effort end must therefore move through 2 m and so

$$VR = \frac{dE}{dL} = \frac{2}{1} = 2$$
$$VR = 2$$

(iii) **BLOCK AND TACKLE**

This type of a pulley system is used in cranes and lifts. It consists of two blocks each with one or more pulleys. In the arrangement shown below (a) the pulleys are shown one above the other for clarity. In practice they are side by side on the axle in (b). The rope passes each pulley in turn.





From the above, the tension in the string is equal to the effort E = T.
It will be seen from the figure that the lower block is supported by four sections of the string. Incidentally, the number of sections of the string supporting the lower block is always equal to the number of pulleys in the two blocks together.
The total upward force acting on the lower block is 4T since it supported by four parts of the rope.

$$L = 4T \, (but E = T)$$

$$\therefore L = 4E$$

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

$$MA = \frac{L}{E} = 4$$

If we neglect friction and weight of the moving parts of the system.

Notes

1. The lower pulley block and the load pan are also raised by the effort but are not included as part of the load. They become less important as the load increases and MA and efficiency both increase for the particular system.
2. The efficiency is less than 100% because the system is not frictionless and the moving parts are not weightless.

(iv) **WHEEL AND AXLE PRINCIPLE**

A screwdriver and the steering wheel of a car use the wheel and axle principle. One of the main applications of the principle is found in a gear box where toothed wheels of different diameters engage to give turning forces at low speed (large mechanical advantage), or high speed (small mechanical advantage) according as to which gear is the driver and which the driven.

Another example which uses the principle is the wheel and axle is shown below.

The effort is applied by a string attached to the rim of the large wheel while the load is raised by a string wind round the axle on the small wheel. For one complete turn the load and effort move through distances equal to the circumferences of the wheel and axle respectively. The velocity ratio is therefore given by:

$$VelocityRatio = \frac{distance\ moved\ by\ effort}{distance\ moved\ by\ load}$$

$$= \frac{2\pi\ x\ radius\ of\ wheel}{2\pi\ x\ radius\ of\ axle}$$

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

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

The MA for a 'perfect' wheel and axle may be found by applying the principle of work otherwise it may be found by taking moments of the load and effort about the axis of rotation.

Load x Radius of axle = Effort x radius of wheel

$$Lxr = ExR$$

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

$$MA = \frac{L}{E} = \frac{R}{r}$$

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

Note: For gear wheels remembering that the effort and load are applied to the strofts of the gears.

$$VR = \frac{No.\ of\ teeth\ in\ driven\ wheel}{No.\ of\ teeth\ in\ driving\ wheel}$$

(v) **HYDRAULIC PRESS**

This will be discussed in details under Pressure. The velocity ratio between the two cylinders of a hydraulic system may be found by using the fact that the volume of the liquid which leaves the pump cylinder is equal to that of which enters the ram cylinder.
If x is the distance moved by pump piston and y is the distance moved by ram piston then equaling volumes.

x x Area of pump piston = **y** x Area of the ram piston.

Or $VR = \frac{x\ area\ of\ ram\ piston}{y\ area\ of\ pump\ piston} = \frac{\pi R^2}{\pi r^2} = \frac{R^2}{r^2}$

$$VR = \frac{R^2}{r^2}$$

PRESSURE

Pressure is defined as the force acting normally per unit area (hence the word normally means perpendicular)

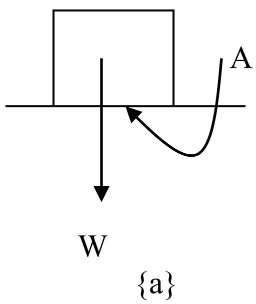
$$\text{Pressure} = \frac{force[N]}{area[m^2]}$$

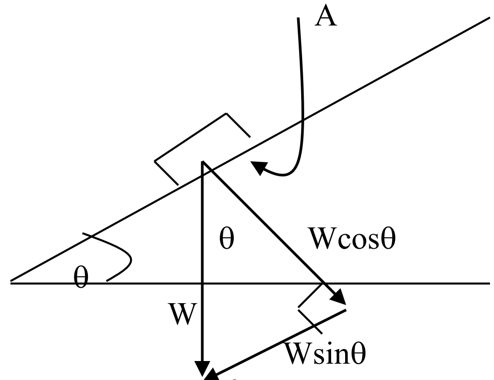
$$P = \frac{F}{A}$$

S.I unit of pressure is therefore Newton per square metre (N/m^2)/(Nm^{-2}) and is given a special name called a Pascal [Pa]

Pressure exerted by solids

Consider the following situations where a body of weight 'W' and cross sectional area 'A' lies on a flat surface.





$P = \frac{W}{A}$ \ $P = \frac{W\cos\theta}{A}$

In situation (a), the weight 'W' is perpendicular to the cross sectional area therefore P = $^W/_A$ but in (b) it is the component W cos θ of the weight which is perpendicular to the cross sectional Area. Therefore pressure in (b) is given by

$$P = \frac{W\cos\theta}{A}$$

<u>Other units of pressure</u>

The S.I unit of pressure is in N/m^2 where

1 N/m^2 = 1 Pa

But for meteorological purposes the unit called a Bar is used, where
1 bar = 10^5 N/m^2
= (100 000 N/m^2)

The commonly used sub unit is the millibar
1 milli bar = 100 N/m^2

Here on earth we are living at the bottom of a sea of air. The atmosphere has got a height and owing to this, the atmosphere exerted pressure at the surface of the earth.

At sea level this approximately equal to 1.01 x 10^5 N/m^2 which is referred to as an atmosphere.
∴ 1 atmosphere = 1.01 x 10^5 N/m^2
1 atmosphere = 101 000 N/m^2

Pressure can also be given depending on the height of the liquid (level of liquid) it can support. Mercury being a liquid of high density is the one which is used for liberating purposes. At sea level the height of mercury which can be supported at standard temperature (0ºC) is 76 mm Hg and this is taken as the standard atmospheric pressure.

1 atm = 1.01×10^5 N/m^2

Therefore standard temperature and pressure (s.t.p.) is 0ºC and 1.01×10^5 N/m^2.

Example

A television tube has a flat rectangular end of size 0.40 m by 30 cm. Calculate the thrust exerted on this end by the atmosphere if the atmospheric pressure is 1.01×10^5 N/m^2.

Solution

Area = 0.40 x 0.3 = 0.12 m^2
P = 1.01×10^5 N/m^2
= 1.01 x 100 000
= 101 000 N/m^2

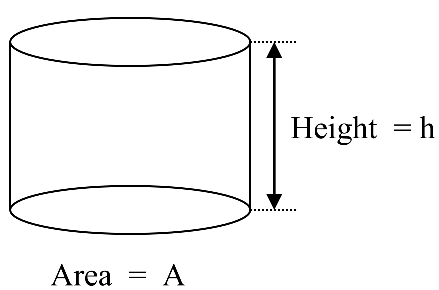
$$P = \frac{F}{A}$$

$$F = P \times A = 101000 \times 0.12$$

$$\therefore Thrust = 12120 N$$

PRESSURE IN FLUIDS AT REST

Liquids and gases are called fluids because they can flow. If a piece of cork is pushed below a surface of a pool of water and then released, the cork rises to the surface again. The liquid thus exerted an upward force on the cork and this is done to the pressure exerted on the cork by the surrounding liquid. Gases also exert pressure e.g. when a thin closed metal can is evacuated, it usually collapses with a bang. The surrounding air exerts a pressure on the outside is no longer counter – balanced by the pressure inside and so there is a resultant force suppose you pour a liquid in a container of cross sectional area A in m^2 to the depth h in m.



Volume of the liquid V = Ah

Given that the density of the liquid is $\rho = \frac{m}{v}$

Mass of liquid M = ρ x V = ρAh
Weight of liquid W = Mg = ρAhg
The pressure exerted by the column of the liquid on the area A is therefore,

$$\rho = \frac{W}{A} = \frac{\rho Ahg}{A} = \rho gh$$

$$\rho = \rho gh \ in \ N/m^2 \ or \ Pa$$

It is important to note the area A doesn't appear on the final expression for pressure. The pressure in the liquid at rest depends only on the height 9h) and density (ρ) of the liquid ρ α h and ρ α g.

i) **Pressure in a liquid increases with depth**

This fact can be demonstrated by the following e.g. Take a tall measuring cylinder with three outlet tubes at different depths as shown below. Fill the cylinder with water and keep the level of water constant by adding water from the tap. The speed with which water rushes out through the holes will be greatest with the lowest hole and least with highest hole. Showing that the pressure of the liquid increases with depth.

ii) **Pressure in a liquid is the some at all points on the same horizontal level in it**

This can be demonstrated by pouring water or any other liquid into the communicating tubes as shown below it stands at the same level in each tube. This explains the popular say that "water finds its level.'

When the liquid is at rest in the vessel, the pressure must be the same at all points along the same horizontal level, otherwise the liquid would move until the pressure is equalized. The fact that the liquid stands at same height in the tubes whatever their shape confirms that for a given liquid the pressure at a given point within it varies only with the vertical length of the point below the surface of the liquid.

Pressure in a liquid at a point at rest acts in all directions. This can be demonstrated as shown below. A water Jet emerges from each hole regardless of the position where the hole is on the surface because the H_2O (water) pressure acts in all the directions.

The fact can be also be demonstrated by several thistle funnels bend at different angles having their rubbers securely tied over their mouth.
These are connected one at a time by rubber tubing to (U) tube containing H_2O. If a pressure is exerted on the rubber by hand, the air inside is compressed and pushes the H_2O (water) in the arrangement of indicating (throughout measured) pressure acts in all directions. When the funnels are lowered to the same point into the H_2O the U tube indicates the same pressure, which ever funnel is in use thereby showing that pressure in the H_2O acts in all directions.

The facts about fluid pressure can be characterized as follows:

a) Pressure in a liquid increases with depth
b) Pressure in a liquid is the same at all point on the same horizontal level in it.
c) Pressure in a liquid at a point acts equally in all directions.

TRANSMISSION OF PRESSURE

When the fluid is completely enclosed in a vessel and pressure applied to it at any point of it's surface e.g. by means of cylinder and piston connected to the vessel then the pressure is equally transmitted throughout the whole fluid. This fast is called the principle of transmission of pressure in fluids. This is stated in Pascals law which states that: Without change to every point of the liquid, whatever the shape of the liquid.

(a) **HYDRAULIC PRESS**

A hydraulic press is designed to squeeze an object using too much smaller force.

This applied force 'f' acts on a piston of area (a) exerting pressure (P) in the oil cylinder. The pressure is transmitted to the wide-piston of area (A) to compress the object in the frame with a force (F) (on smaller piston).

$$P=\frac{F}{A}(F=PA)-on\ larger\ piston$$

$$P=\frac{f}{a}(f=Pa)-on\ smaller\ piston$$

$$Getting\ the\ ratios \qquad \frac{F}{f}=\frac{PA}{Pa}$$

$$\frac{F}{f}=\frac{A}{a}$$

$$\therefore \underline{F = f \ x \ \frac{A}{a}}$$

Since (A) is greater than (a) the force (F) is greater than (f). Air must be absent from the system otherwise the pressure is used to compress the air instead of transmitting through the oil.

(b) **HYDRAULIC BRAKES**

Before this was done the hemisphere could be pulled apart easily, since the pressure outside was balanced by the pressure inside. On removal of the air from inside only the external. Pressure acted and presses the hemispheres together Two terms of horses each were harnessed to the atmosphere and driven in the opposite direction. They proved unable to separate the hemispheres until air was admitted through the slop cork.

MEASUREMENT OF ATMOSPHERIC PRESSURE

The atmospheric pressure can be measured using an instrument called a Barometer. There are two types: Fortin Barometer and Aneroid Barometer.

(a) **Fortin Barometer**

The simplest Fortin Barometer is a simple mercury barometer. The simple mercury barometer can be made by a glass tube about a metre long and closed at one end and filling it almost to the top with clean mercury. The tube is then inverted and placed vertically with its end well below the surface of some mercury in a dish.

It will be noted that the mercury contained in a tube falls until the vertical difference in the level between the surfaces of mercury in the tube and the dish is 760 mm. The height of the mercury column remains constant even when the tube is tilted. Unless the top of the tube is less than 760 mm above the level in the dish in which case the mercury completely fills the tube.

Torricellian explained that the column in the tube was supported by atmospheric pressure acting on the surface of the mercury in the dish and pointed out that small changes in the height of the column, which are noticed from day to day, are due to variations in atmospheric pressure.

The space above the mercury in the column is called the Torricellian Vacuum. It contains a little mercury vapour and in this respect differs from a true vacuum. From $P = \rho gh$ at sea level, The atmospheric pressure is about 1.01×10^5 N/m^2. The column of mercury which can be supported by that pressure is

$$P = \rho g h$$

$$h = \frac{P}{\rho g} = \frac{10.1 x 10^5}{13600 x 9.8} = 0.76 m = 760 mm$$

$\therefore$ We need a tube about 1 metre in length to construct a barometer with mercury. If instead H_2O was used then

$$h = \frac{P}{\rho g} = \frac{1.01 x 10^5}{1000 x 9.8} = 10.3 m$$

We need a tube more than 10 m to measure that pressure which is very inconvenient. Mercury is preferred to be used as a barometric fluid because

- It has high density therefore a shorter tube of about 1 m is used
- It does not wet the glass
- It is opaque
- It's vapour pressure is very low hence doesn't evaporate easily

THE ANEROID BAROMETER AND ALTIMETER

Barometer of the aneroid (without liquid) type are commonly used as weather glasses. The idea being that low pressure, or sudden fall in pressure, generally indicates unsettled weather while a rising barometer or high pressure is associated with fine weather. The essential part about the aneroid barometer is the flat cylindrical metal box or capsule, corrugated for strength and hermetically sealed after having been partially exhausted of air.

Increasing in atmospheric pressure causes the box to curve in slightly while a decrease allow it to expand. The movements of the box are magnified by a system of levers and transmitted to a fine wrapped round the spindle of a pointer. While the pointer moves over a suitable calibrated scale. Aneroid Barometer movements are also used in the contraction of altimeter with weight.

VARIATIONS OF ATMOSPHERIC PRESSURE WITH HEIGHT

The density of a liquid varies very slightly with pressure. At sea level the density of the atmosphere is about 1.2 kg/m^3 at 1 000 m above sea level it is about 1.1 kg/m^3. Hence the pressure will be lower at the height. The pressure in the liquid varies with density and height ($P = \rho gh$) but if we consider the variation of density to be negligible we can calculate the pressure difference of the base and summit.

Example

The air pressure at the base of the mountain is 75 cm of mercury and at the top is 60.0 cm. Given that average density of air is 1.25 kg/m^3 and density of mercury 13 600 kg/m^3. Calculate the height of the mountain.

i) Firstly, find the pressure difference

75 cm Hg - 60 cm Hg = 15 cm Hg

ii) Convert 15 cm Hg to S.I. Unit ($P = \rho gh$)

$P = 13\,600 \times 10 \times 0.15$

P = 20 400 Pa

The column of air which supports that pressure is P = ρgh
20 400 = 1.25 x 10 x h

$$h = \frac{20400}{1.25x10} = 1632m\,(height of\ mountain)$$

<u>The U – tube Manometer</u>

This is used to measure excess pressure of a gas above or below the atmospheric pressure. The manometer consists of a U – tube containing a liquid (e.g. H_2O or Hg). When both arms are open to the atmosphere, the same atmospheric pressure is exerted on the liquid.

The surfaces (A) and (B) are therefore on the same horizontal levels as in (a)

In order to measure the pressure for the gas, the side A is connected to the gas supply. The gas supplies pressure on surface A, with the result that level B rises or falls until pressure at C on the same horizontal level as A becomes equal to gas pressure (P_g).
Pressure of gas = atmospheric pressure $\pm$ pressure due to column BC of liquid

$$P_g = P_a + h \text{ if } P_a < P_g \text{ or } P_g = P_a - h \text{ if } P_a > P_g$$

The pressure of the liquid column BC is excess pressure of the gas above atmospheric pressure and is equal to ρgh in N/m^2.

The height h is called the head of the liquid in the manometer and it is convenient to express the excess pressure simply in terms of h only. In this case the units generally used are millimeters of the liquid e.g. mm of H_2O.

<u>Examples</u>

An open U – tube pressure gauge containing H_2O shows a difference in level of 15 cm of H_2O when connected to a gas supply.

a) Find in N/m^2 the excess pressure of the gas above atmospheric pressure (ρ of water 1000 kg/m^3).
b) the total or absolute pressure of the gas given that the atmospheric pressure is 760 mm

Hg and g = 10 m/s^2

Solution

a) Excess pressure = h = 15 cm H_2O

$P = \rho gh = 1000 \times 10 \times 0.15$

$\therefore$ $\underline{P = 1500 \text{ N/m}^2}$

ARCHIMEDES' PRINCIPLE AND FLOATATION

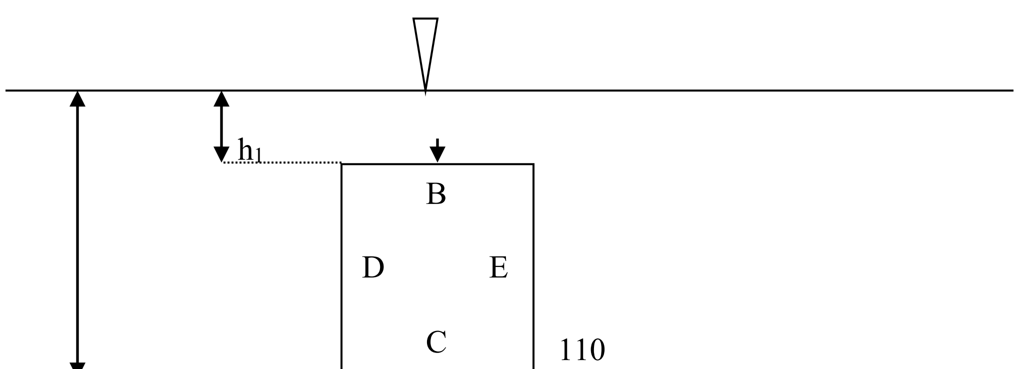
An object immersed in a fluid experiences a resultant upward force owing to the pressure of the fluid on it. This upward force is called the **up thrust** of the fluid on the object.

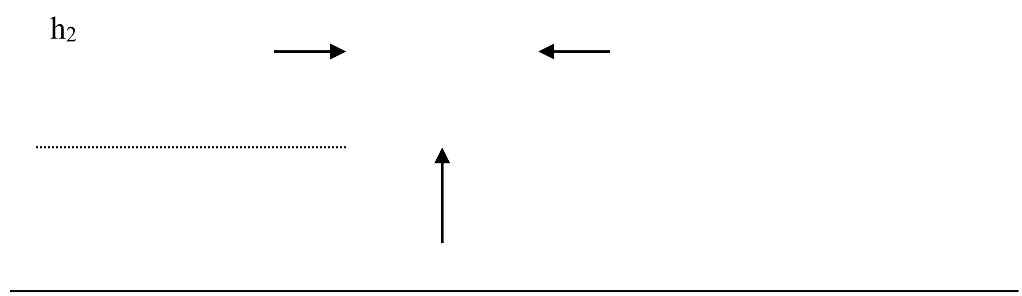
Experiments to measure the up thrust of a liquid were first carried out by a Greek scientist Archimedes who lived in the third century BC. The result of his work was a most important discovery which is now called **Archimedes' principle** which states that
'A body partially or wholly immersed in a fluid experiences an up thrust equal to the weight of the displaced fluid.'
Up thrust is directly proportional to the volume of the immersed body and the density of the displaced fluid.

PROOF OF THE ARCHIMEDES' PRINCIPLE

(a) ANALYTICAL

Consider a rectangular block which is wholly immersed in a fluid





The pressure on the surface 'C' is greater than on the surface 'B' since the pressure at the greater depth h_2 is more than that at h_1.

The force on each of the four surfaces is calculated from F = P x A, remembering that vector addition is needed to sum forces. With a simple rectangular shaped solid and sides D and E vertical it can be seen that

(i) The resultant horizontal force is zero.

(ii) The upward force on C = Pressure x Area

$= \rho g h_2 A$ Where ρ is the density of the fluid and

downward force on B = Pressure x Area

$= \rho g h_1 A$

Thus the resultant force (up thrust) on the solid

$= $ Upward force

$= \rho g h_2 A - \rho g h_1 A$

$= (h_2 - h_1)\rho g A$

but $(h_2 - h_1)A$ = volume of the solid 'v' (which is also equal to the volume of the displaced fluid.

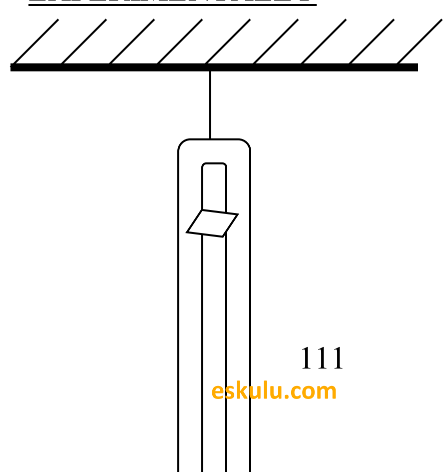
Up thrust $= v_s \rho_s g = v_l \rho_l g$

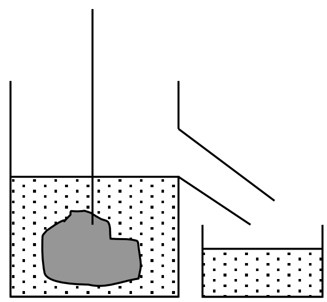
from $\rho = \frac{m}{v}$ mass of the fluid $m_l = \rho_l v_l$

up thrust $= m_l g$

up thrust = weight of the displaced fluid.

(b) <u>EXPERIMENTALLY</u>





A piece of metal is weighed in air using a spring balance. The body, still attached to a balance is then carefully lowered in a displacement can. When it is completely immersed its new weight is noted. The displaced water is collected in a beaker and weighed.

RESULTS

Weight of the body in air = w_1
Weight of the body in water = w_2
Weight of the beaker = w_3
Weight of the beaker plus displaced water = w_4
Apparent loss in weight of the body (Equal to up thrust U) = $w_2 - w_1 = U$
Weight of the water displaced = $w_4 - w_3 = mg$
The apparent loss in weight of the body or the up thrust on it should be equal to the weight of the displaced water.

$$\therefore w_1 - w_2 = w_4 - w_3$$
$$U = mg$$

APPLICATION OF ARCHIMEDES' PRINCIPLE TO FIND RELATIVE DENSITY OF SUBSTANCES

SOLIDS

$$\text{Relative density} = \frac{\text{mass of a substance}}{\text{mass of an equal volume of water}}$$

$$\text{Relative density} = \frac{\text{mass of a substance x g}}{\text{mass of an equal volume of water x g}}$$

Relative density = $\frac{\text{weight of a substance}}{\text{weight of an equal volume of water}}$

If we take a sample of solid and weigh it in air first and then in water. The apparent loss in weight is equal to the weight of a volume of water equal to that of the sample.

$\therefore$ Relative density = $\frac{\text{weight of a substance}}{\text{apparent loss in weight of the sample in water}}$

LIQUIDS

Using the same procedure a sinker is first weighed in air and then in a liquid e.g. methylated spirit and then finally in water.

Since the same sinker is used in both liquids, the two apparent losses in weight will be the weights of equal volume of methylated spirit and water respectively

Relative density = $\frac{\text{weight of any given volume of spirit}}{\text{weight of an equal volume of water}}$

THERMAL PHYSICS

KINETIC THEORY OF MATTER

From careful observation of behavior of matter and from the result of many experiments, scientists believe that all material are made up of a very large number of very small particles called atoms. This is called the atomic theory of matter.

An atom is the smallest part of an element which can take part in a chemical change where a molecule is the smallest part of an element or compound which can exist by itself.

For our present purpose it does not really matter weather we are dealing with atoms or molecules. The important thing to realize is that matter is made up particles which are in motion. This idea is expressed in kinetic theory of matter. This theory states that:

(i) Matter is composed of small particles which are in a state of constant, random motion.
(ii) Molecules in solids vibrate about a fixed positions. In liquids they move randomly within a fixed volume. In gases they move freely in all directions.
(iii) The rapidly moving particles (molecules) collide with one another and with the walls of the container elastically. There is no loss of kinetic energy during the collisions. It is these collisions of molecules with the walls of a containing vessel which produce gas pressure.

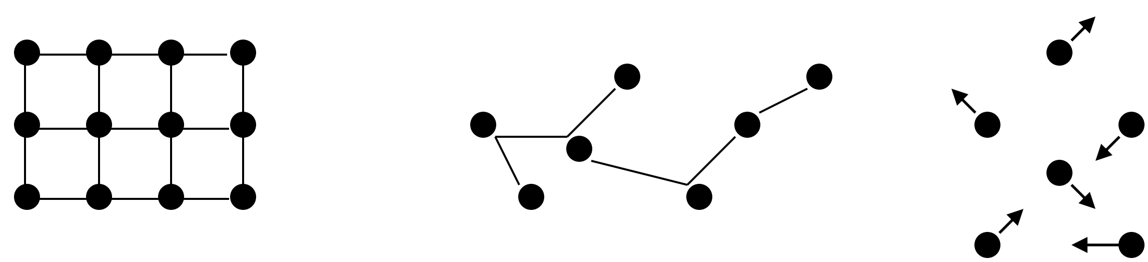
(iv) There are inter – molecular forces of attraction between molecules called the cohesive forces. The cohesive forces are large in solids, much smaller in liquids and negligible in gases.
(v) In case of gases the molecules are negligible compared with thw volume of the gas.
(vi) When heat is supplied the kinetic energy of the molecules increases, since the mass of the molecules is constant, the speed must increase. This increase in energy usually produces expansion.
(vii) For change of state to occur, the cohesive forces have to be overcome, the energy needed to do this is the latent heat of fusion or evaporation.

STATES OF MATTER

Matter exists in three states solids, liquids and gases. The physical difference between these states lies in the arrangement of the molecules.

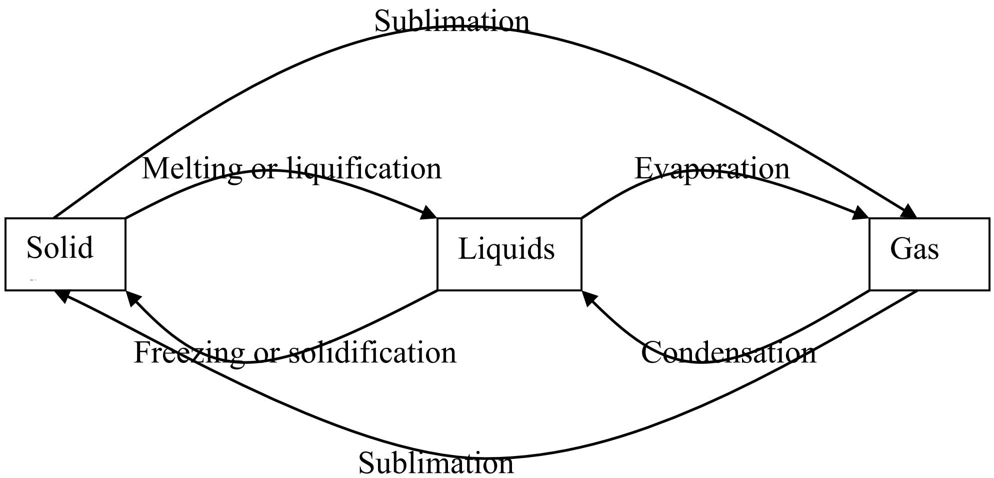
	SOLIDS	LIQUIDS	GASES
1	Definite shape and volume	Definite volume but takes the shape of the containing vessel	No definite shape and volume.
2	Particles vibrate about fixed points and are closely packed.	Particles are free to move about and are widely spread.	Particles are even further apart and have more freedom to move.
3	Stronger cohesive forces	Weaker cohesive forces	Negligible cohesive forces
4	Incompressible	Incompressible	Compressible
5	Cannot flow	Can flow	Can flow

From the properties of the three states of matter we can draw a qualitative molecular model of matter.



Solid Liquids Gas

The change of phase from one state to another is called change of phase, each change has it's specific name

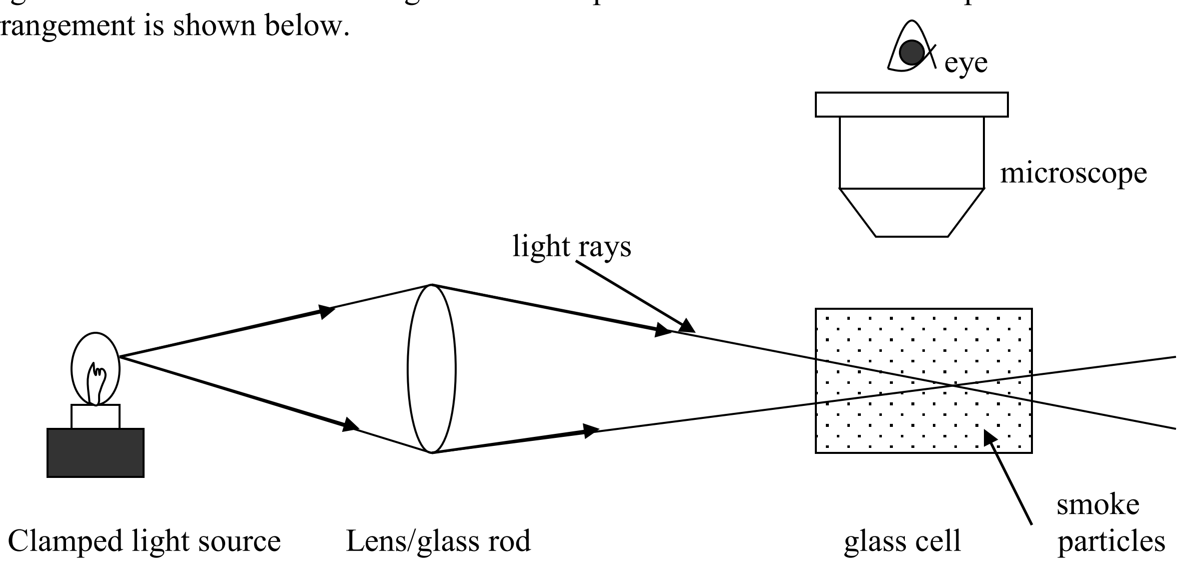


EXPERIMENTAL EVIDENCE OF THE KINETIC THEORY OF MATTER

(A) BROWIAN MOTION

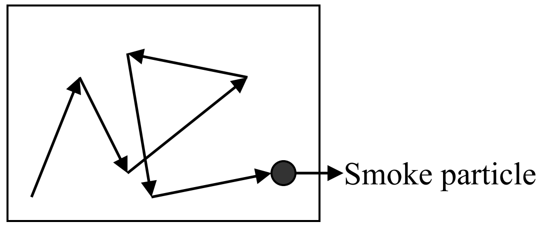
This phenomenon was first observed by Robert brown who while studying pollen grains under water observed that the pollen particles were constantly moving about in a random motion. The same phenomenon can be observed by studying smoke particles in air.

A small glass cell in which smoke is trapped is viewed through a microscope. A converging lens or glass rod is used to focus the light from a lamp into the smoke cell. The experimental arrangement is shown below.



When light strikes the smoke particles it is scattered and the smoke particles are observed as bright specs of light. They are also seen to be moving about in a zig – zag manner. This zig –

zag movement is due to the collision of the invisible air molecules that are also moving about randomly in the smoke cell. The zig – zag pattern of the movement is illustrated below.



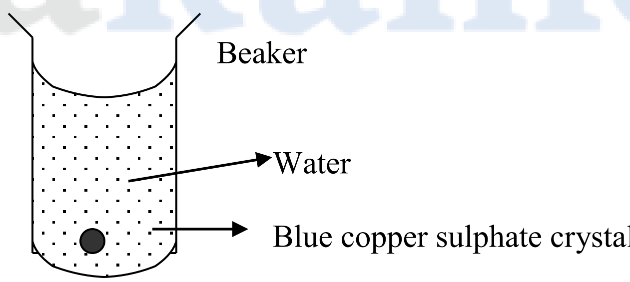
Zig – zag motion

(B) DIFFUSION

This is the process by which different substances mix as a result of the random motion of their molecules. The substance move freely from their region of high concentration to the region of low concentration at their on pace. The rate of diffusion depends on the temperature and the density of the substances involved

(i) DIFFUSION IN LIQUIDS

Lower a small block of copper (II) sulphate crystals to the bottom of the beaker containing water



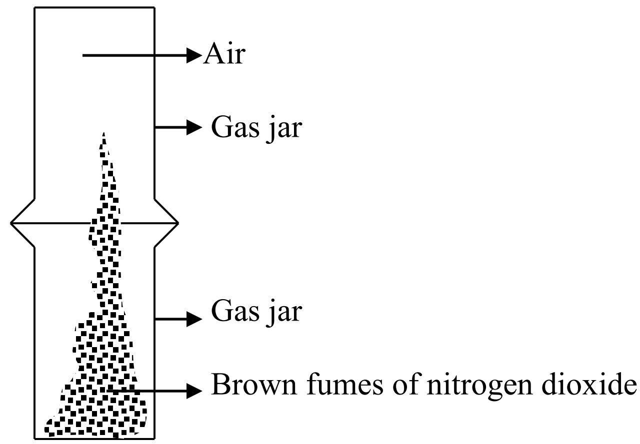
It will be observed that after a few days the whole solution ha turned blue. This is because the copper sulphate crystal have diffused into the water. Repeat the experiment using hot water, the rate of diffusion is faster.

(ii) DIFFUSION IN GASES

When a person wearing a strong perfume walks into a room the smell can easily be detected by a someone sitting at the far end of the room within a short period of time. This suggests that the molecules of the perfume spread quickly in the air.

TO DEMONSTRATE DIFFUSION BETWEEN NITROGEN DIOXIDE (NO_2) AND AIR

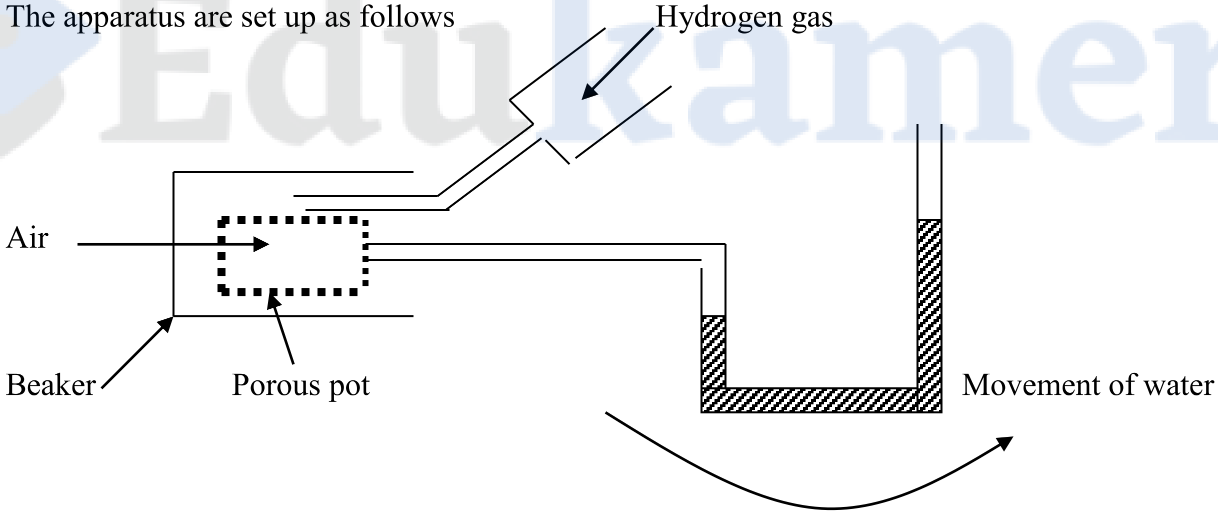
A gas jar of air molecules is inverted over the gas jar of Nitrogen dioxide fumes (which are brown in colour)

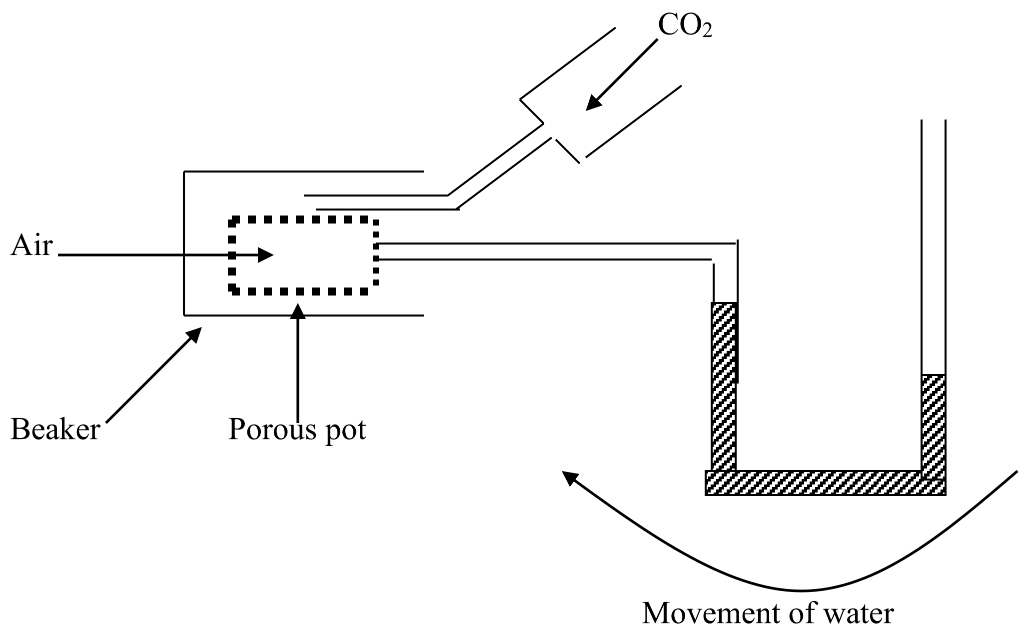


After a small while you will observe that brown fumes slowly start to move into to gas jar which contained the air molecules

TO COMPARE THE DIFFUSION OF HYDROGEN GAS AND AIR WITH THAT OF CARBON DIOXIDE AND AIR.

The apparatus are set up as follows





When hydrogen gas is released into the beaker you will notice that the water in the glass U – tube will start to move away from the porous pot. If the experiment is repeated using carbon dioxide gas instead of hydrogen gas the water in the U – tube will be drawn towards the porous pot.

These two experiments suggests that :

(a) The hydrogen gas diffuses through the porous pot and exerts a pressure on the water surface in the tube.
(b) In case of carbon dioxide, air diffuses out of the porous pot and creates a vacuum which draws the water.

From the experiments of diffusion looked at it can be summarized that

(a) The rate at which substances diffuse into each other depends on their temperature. Experimental results indicate that the rate of diffusion is directly proportional to the temperature.
(b) The diffusion of gases depends on their densities. This is stated in Graham's law of diffusion which sates that
'At constant temperature gases diffuse at the rates which are inversely proportional to the square roots of their densities'
(c) The speed of diffusion of gas depends on the speed at which the molecules move and that the rate of diffusion is greater for lighter molecules. When hydrogen gas molecules which are lighter than air molecules were introduced into the beaker. The hydrogen molecules diffused out of the porous pot faster than the air molecules diffuses out resulting in the water being forced away from the pot. However, the carbon dioxide molecules diffuses through the pot at a slower rate than the air molecules (being lighter)

diffused out of the pot. This resulted in the formation of a weak vacuum which draw the water towards the pot.

(C) EVAPORATION

Evaporation is the effect of escaping of liquid molecules from the surface of a liquid. This takes place regardless of the temperature and occurs when the molecules acquire sufficient kinetic energy to overcome the intermolecular forces within the liquid. The more energetic molecules escape, leaving behind molecules which are less energetic.

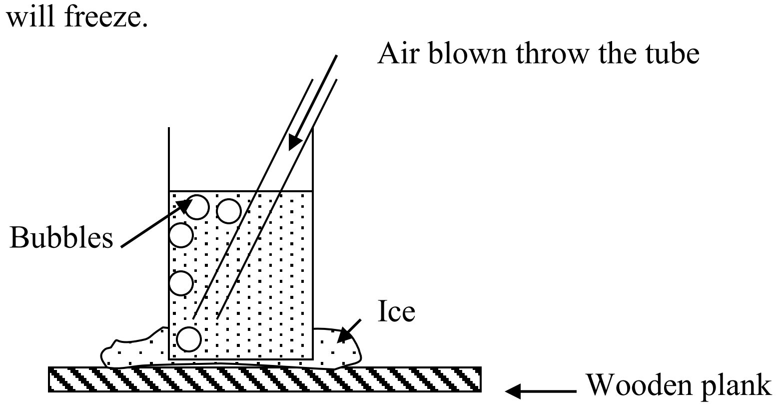
THE COOLING EFFECT OF EVAPORATION

The molecules of the liquid have an average kinetic energy which increases with temperature. The molecules near the surface which happen to be moving faster have high kinetic energy and can break the intermolecular forces attraction of their neighbors and escape out of the liquid. In this way the liquid loses its most energetic molecules while the less energetic ones are left behind. The average kinetic energy of the remaining molecules is therefore reduced and this results in a fall in temperature.

If energy is supplied to the liquid molecules (for example by heating) the rate of evaporation increases. If this energy comes from the surrounding, then the surrounding lose energy and experiences a drop in temperature. The cooling effect can be demonstrated by the following experiment.

TO DEMONSTRATE THE COOLING EFFECT OF EVAPORATION

A beaker of about one – third full of ether is stood in a small pool of water on a flat piece of wood. A current of air is then bubbled through the ether by means of a straw. The ether forms some bubbles and vapour is carried quickly away as the bubbles rise to the surface and burst, thus increasing the rate of evaporation. The energy required for this increased rate of evaporation comes from the internal energy of the of the liquid ether itself with the result that it soon cools well below 0ºC. At the same time heat becomes conducted through the walls of the beaker from the pool of water below it and eventually the water cools to 0ºC and it will freeze.



The cooling effect of evaporation is utilized in refrigeration. A refrigerator basically transfers heat from the inside cabinet to the outside environment. The principle involves a liquid that is constantly evaporating and thereby drawing energy (or heat) from the inside of the cabinet. The transfer of the heat from inside to the outside is quite rapid and the inside becomes very cool. Once outside the cabinet heat is transferred to the surrounding environment through the thin tubing containing the vapour is condensed back to liquid. A pumping mechanism ensures the movement of the liquid vapour round a closed system of conducting pipes keeping the same liquid flowing continually.

DIFFERENCES BETWEEN EVAPORATION AND BOILING

	EVAPORATION	BOILING
1	Take place at all temperatures	Take place at a constant temperature called the boiling point.
2	Takes place on the surface of the liquid	Takes place throughout the liquid

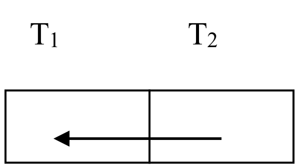
GAS PRESSURE AS EXPLAINED FROM KINETIC THEORY

From the kinetic theory of matter, a gas consists of a vast number of molecules moving with random high velocities colliding with one another and bouncing off the walls of the containing vessel. A force is thus set up on the walls which is given by the rate of change of momentum as they bounce off (because the velocity changes). The pressure of the gas is the value of this force per unit area. When a gas is heated the molecules gain kinetic energy and there velocities increases. This led to the increased rate of collision between the molecules and the containing vessel this led to the increased pressure.

MEASURENT OF TEMPERATURE

Temperature is the number which shows the degree of hotness or coldness of a body.

Heat is the form of energy transferred between two bodies which are at different temperature values. Heat is transferred between two bodies when they are in thermal contact.



$T_2 > T_1$

The heat will continue to flow until the two bodies are at the same temperature. When this condition has been reached it means that the bodies are in thermal equilibrium.

Temperature is measured using an instrument called a Thermometer in degrees Celsius (ºC). Any property of matter which vary linearly with temperature can be used to measure temperature. That property is called the thermometric property. Examples of thermometric properties are:

(a) Expansion (or change in volume)
   (i) liquids in liquid - in - glass thermometer
   (ii) gases in constant volume gas thermometer
   (iii) solid in bimetallic thermometer

(b) Electric current
In thermometric thermometers (thermocouple or thermopile) which are based on the electric current which is generated when a junctions of two different metals are set at different temperatures.

CONSTRUCTION OF THE LABORATORY THERMOMETER (MERCURY OR ALCOHOL)

One end of a length of clean capillary tube is heated until the glass softens and seals the end of the tube. The tube is withdrawn from the heat and a small bulb is blown at the end. By repeating this operation the size of the bulb may be increased to the required size. The thermometer is then placed with its open end beneath the surface of the mercury in a jar and the bulb gently heated. The air inside expands and bubbles through the mercury. On cooling, the air contracts and some mercury runs up into the bulb. The thermometer is then taken out and the bulb heated to boil the mercury. When the mercury vapour has expelled all the air the open end is quickly inverted once more in the mercury. On cooling, the mercury rises and completely fills the bulb and stem.

The thermometer is now taken out and heated to a temperature somewhat higher than the maximum for which it is to be used. While at this temperature the end of the stem is rotated in a small blowpipe flame, drawn out and sealed. The thermometer is now read to be graduated.

Mercury and Alcohol vapour is very dangerous when inhaled, therefore protective material has been used to cover the mouth and nostrils when doing the construction.

GRADUATION OF THE THERMOMETER

The principle underlying the graduation of the thermometer is to choose two fixed points. A fixed point is a point where all thermometers will register the same value of temperature. There are two fixed points called the upper and lower fixed point.

(a) UPPER FIXED POINT

This is the temperature of steam from boiling water under standard atmospheric pressure of 760mmHg of mercury which is 100ºC.

The temperature of boiling water itself is not used as the fixed point for two reasons.
   (i) local overheating may occur, accompanied by “bumping” as the water boils
   (ii) any impurities which may be present will raise the boiling point.

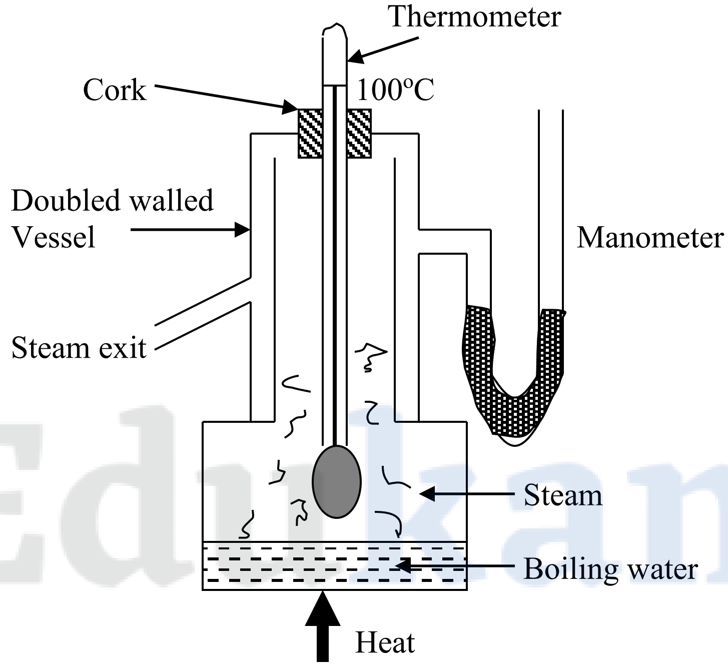
The temperature of steam above the boiling water will always be constant and depends on the barometric pressure at the time.

(b) THE LOWER FIXED POINT

This is the temperature of pure melting ice taken as 0ºC. The ice must be pure because the presence of impurities will lower the melting point.

DETERMINATION OF THE UPPER FIXED POINT

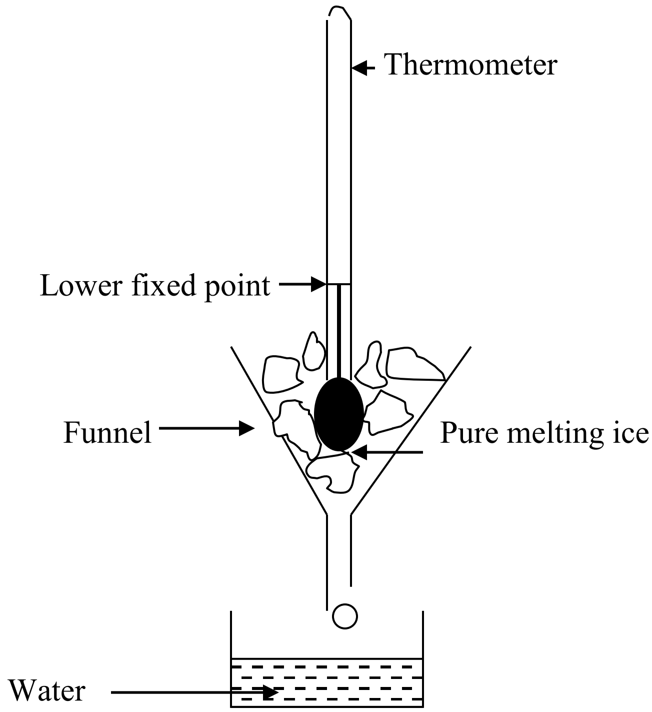
This is done by using a double walled vessel called a Hypsometer. Water is steadily boiled in the lower part of the hypsometer thus keeping the bulb surrounded by pur water vapour at atmospheric pressure.



The thermometer is adjusted so that the mercury level is just visible above the top of the cork. When thread has remained steady for some minutes its level is marked on the stem. The double wall reduce loss of heat and consequent cooling of the vapour surrounding the thermometer, while the manometer gives warning, should the pressure inside the hypsometer differ from the atmospheric pressure. If the barometric pressure at the time is not equal to 760mmHg, then the true boiling point for the prevailing pressure must be read from the table giving the variation of boiling point with pressure.

DETERMINATION OF THE UPPER FIXED POINT

The thermometer is placed in a funnel of pure melting ice. The mercury thread is allowed to show just above the top of the ice. When the level of the thread has remained steadily for sometime, it's position is marked as illustrated in the diagram. The length between the lower and upper fixed point is called the **Fundamental interval**.



The difference between the temperature of the lower fixed point and that of the upper fixed point is called the **Range.** In this case 0ºC to100ºC let the

HEAT TRANSMISSION

Heat can be transmitted from one place to another by any of the three processes conduction, convection and radiation.

A. CONDUCTION

This mode of heat transfer occurs mainly in solids. When a metal bar is heated at one end, heat soon reaches the other end. This transfer happens in two forms;

(i) When the metal is heated the free electrons which it contains begin to move faster i.e. their kinetic energy increases . The hot electrons then drift towards the cooler parts of the metal and at the same time there is drift of slower – moving (cooler) electrons in the reverse direction. Most of the heat traveling through a metal is transferred by these free electrons.

(ii) However a small part of the heat is transferred by the vibration of atoms. When one end of the metal rod is heated, the atoms that receive the heat vibrate more and transmit part of this vibration energy to the adjacent atoms. Energy therefore passes from one atom to another in the form of high frequency waves which are transmitted in tiny energy packets called phonons.

Since the movement of the electrons and lesser extent the vibration of atoms are involved in conduction if follows that for a substance to be good conductor it should have free electrons around its atoms and the atoms should be close together. Most metals are good conductors of heat because of these properties.

In non – metals which have no free electrons heat is conducted entirely by phonons therefore they are poor conductors.

Atoms and molecules in liquids are generally farther apart than in solids and as a result liquids are very bad conductors of heat (mercury and other molten substances are exceptions). Gases are extremely bad conductors of heat because their molecules are even farther apart compared to those of liquids.

'Conduction is therefore the flow of heat through matter from places of higher temperature to places of lower temperature without the movement of the matter as a whole.'

GOOD AND BAD CONDUCTORS

(a) GOOD CONDUCTORS

These are used whenever heat is required to travel quickly through something. Saucepans, boiler and radiators are made of metals such as aluminium, iron, and copper which are good conductors.

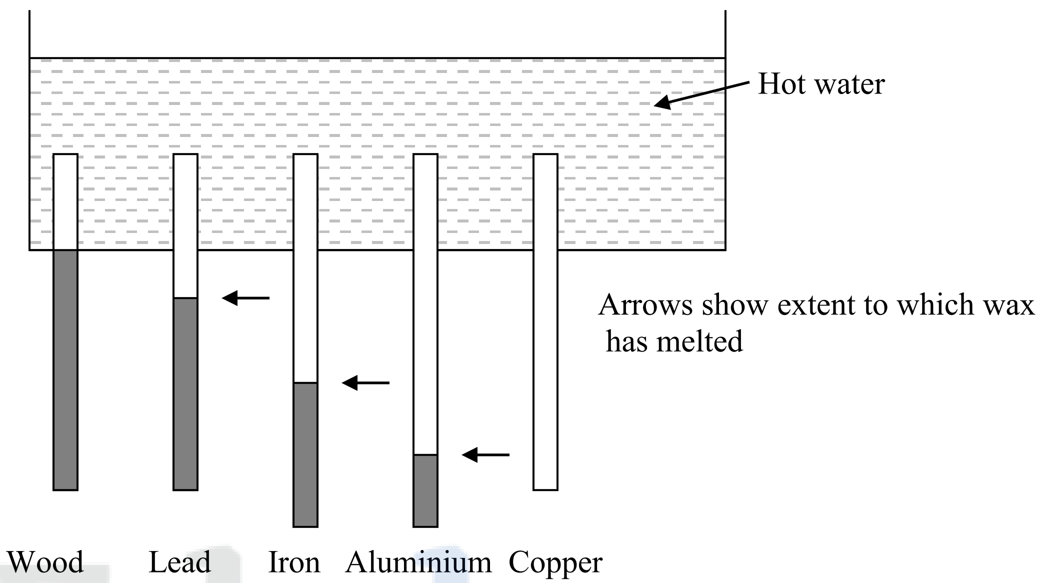
(b) BAD CONDUCTORS

Bad conductors have a very wide applications

- Air is one of the worst conductors (best insulators). This is why houses with cavity walls (i.e. two walls separated by an air space) and double – glazed windows keep warmer in winter and cooler in summer.
- Woolen sweaters keeps us warm during the cold weather by trapping air in the numerous spaces between the fibres. This air prevents much of the heat of the body from being conducted to the outside.
- Materials which trap air e.g. wool, felt, feather, polystyrene, fiberglass are bad conductors, some of these materials are used as lagging (the technique of stopping or reducing heat loss by conduction) to insulate water pipes, hot water cylinders, ovens, refrigerators and walls and roofs of houses.

COMPARISON OF CONDUCTIVITIES OF DIFFERENT METALS

Rods of different materials but having the same length and diameter are passed through corks inserted in holes in the side of a metal trough. The rods are first dipped into molten paraffin wax and withdrawn to allow a coating of ax to solidify on them.

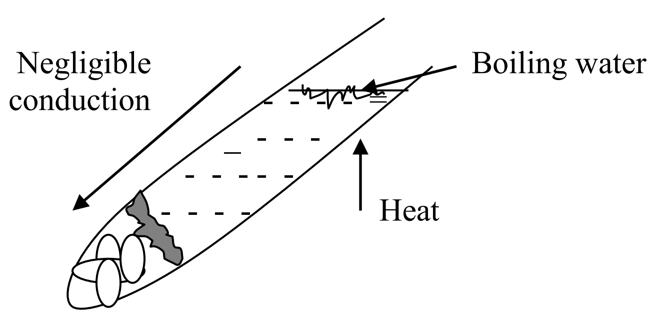


Boiling water is then poured into the trough so that the ends of the rods are all heated to the same temperature. After some time have elapsed it is noticed that wax has melted to different distances along the rods, indicating differences in the thermal conductivities.

CONDUCTION OF HEAT THROUGH LIQUIDS

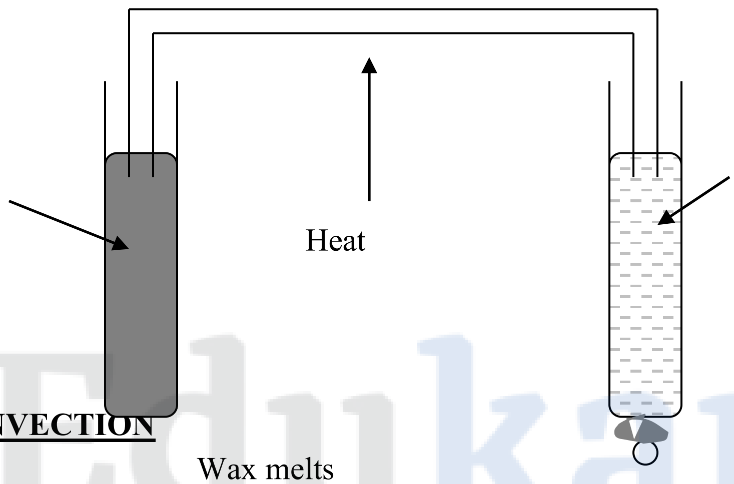
All ordinary liquids, with the exception of mercury and other molten liquids are poor conductors of heat.

Water can be shown to be a bad conductor of heat by wrapping a piece of ice in gauge to make it sink and placing it at the bottom of a test – tube nearly full of water. By holding the top of the tube in a Bunsen flame, the water at the top may be boiled vigorously while the ice at the bottom remains unmelted.



TO COMPARE THE CONDUCTUVITY OF WATER AND MERCURY

Mercury may be shown to be a better conductor than water by taking two test – tubes containing mercury and water respectively and attaching a cork to the bottom of each melted wax. A piece of copper wire in each of the liquids as shown. On heating the centre of the wire, heat is conducted through the metal equally into the water and mercury. In a very short time the wax on the mercury – filled tube melts and the cork falls of . Very prolonged heating is necessary before the same occurs with the water filled tube.



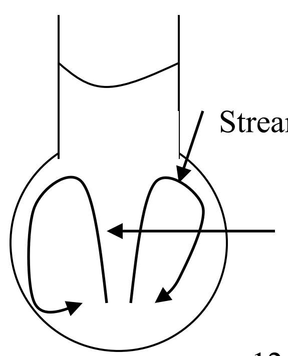
B . CONVECTION

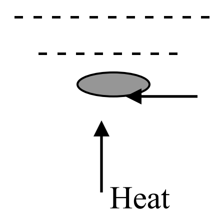
Convection is the u[illegible]ua heat travels in fluids i.e. liquids and gases. When a vessel containing a liquid is heated at the bottom a current of hot liquid moves upwards and its place is taken by a cold current downwards. Streams of warm moving fluids are called convection currents. They arise when a fluid is heated because it expands, becomes less dense and is forced upwards by surrounding cooler denser fluid which moves under it.

'convection is the flow of heat through a fluid from places of temperature to places of lower temperature by movement of the fluid itself.'

TO DEMONSTRATE CONVECTION IN WATER

Place a crystal of potassium permanganate at the bottom of a flask full of water (using a length of glass tube). Heat the bottom of the flask as shown below.

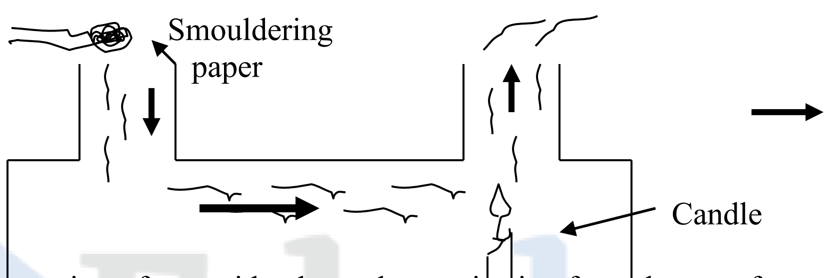




On heating the bottom of the flask an upward current of coloured water will ascend from the place where the heat is applied. This coloured stream reaches the top and spreads out. After a short time it circulates down the sides of the flask showing that a convection current has been set up.

TO DEMONSTRATE CONVECTION CURRENT IN AIR

The figure below shows the laboratory model of demonstrating convection in air



It consists of two wide glass tubes projecting from the top of a rectangular wooden box with glass front. A short of candle is lit at the base of one of the tubes. When a piece of smouldering brown paper is held over the top of the other tube the direction of the convection currents will be rendered visible by the passage of smoke through the box.

USES AND EXAMPLES OF CONVECTION

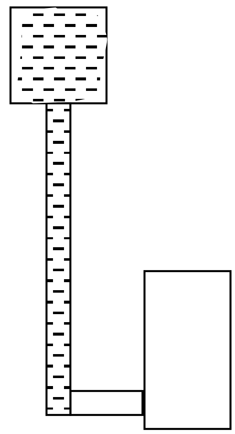
(i) BRAZIER

The common brazier at home has large number of holes in its sides. When the charcoal is burning in the brazier the air just above it heats and rises. Cooler air is then drawn in through the holes to take the place of the air that has risen. In this way a convection current is set up which results in charcoal burning.

(ii) ELECTRIC KETTLE

In the electric kettle, the heating element is placed near the bottom. As the element heats the water around is set up. The hot water around the element rises and cooler water is drawn in towards the element. Eventually all the water is at the same temperature as it begins to boil.

(iii) DOMESTIC HOT WATER SYSTEM



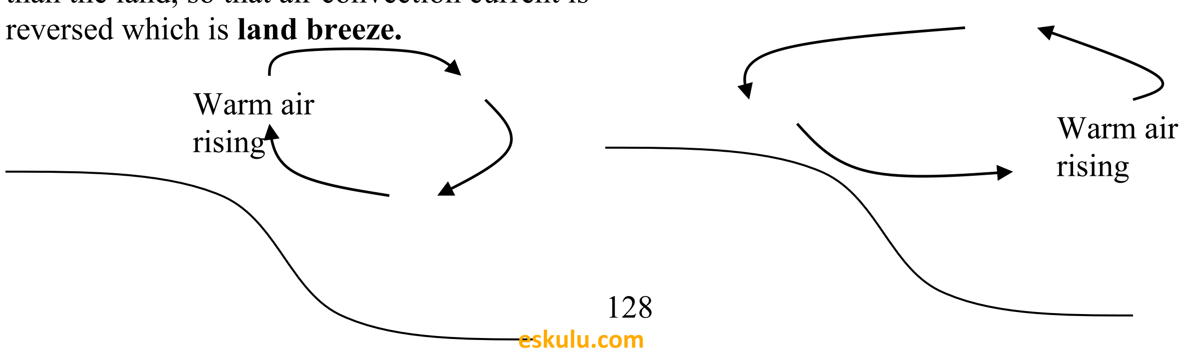
The figure shows a common hot system in which the water is heated in a boiler. When the water is heated it rises through pipe C and goes to the top of the hot water tank. Cold water enters the pipe through pipe B from the bottom of the hot water tank take its place and be heated also. A convection current is therefore set up. If the water is overheated, it expands through the expansion pipe D and may even flow into the cold water tank.

(iv) LAND AND SEA BREEZES

At places on the coast in summer time it is noticeable that a breeze generally blows from the sea during the day, while at night the direction of the wind is reversed. These breezes are local convection currents.

During the day the land is heated by the sun to a temperature high than the sea. There are two reasons for this. First, water has a higher specific heat capacity than the earth; secondly the surface of the sea is in constant motion, leading to mixing of the surface water with cooler layers below. Air above the land is therefore heated, expands and rises while cooler air blows in from the sea to take its place. The circulation is completed by a wind in the upper atmosphere blowing in the opposite direction this is called **sea breeze.**

At night the land is no longer heated by the sun and cools very rapidly. On the other hand, the sea shows practically no change in temperature, since it has been heated to greater depth than the land and consequently acts as a larger reservoir of heat. By comparison, the sea is now warmer than the land, so that air convection current is reversed which is **land breeze.**



Day – time (sea breeze) Night – time (land breeze)

C. RADIATION

Both conduction and convection are ways of conveying heat from one place to another which require the presence of a material substance, either solid, liquid or gas.

There is a third process of heat transmission which does not require a material medium. This is called **radiation**, and is the means by which energy travels from the sun across the empty space beyond the earth's atmosphere.

Radiant heat consists of invisible electromagnetic waves which are able to pass through a vacuum. These waves are partly reflected and partly absorbed by objects on which they fall. Radiant heat which has passed through a vacuum can be easily felt by holding the hand near a vacuum – filled electric lamp when the current is switched on.

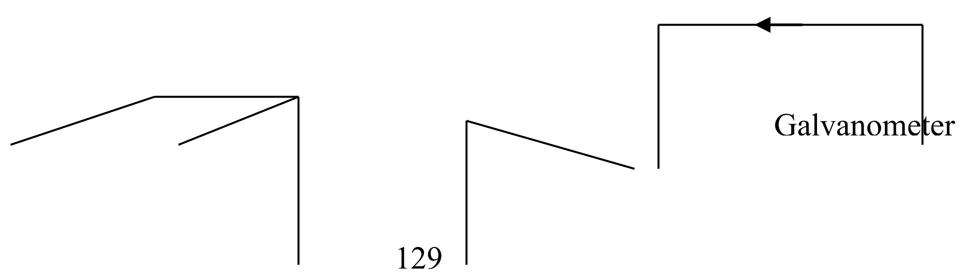
TO COMPARE THE RADIATION FROM DIFFERENT SURFACES

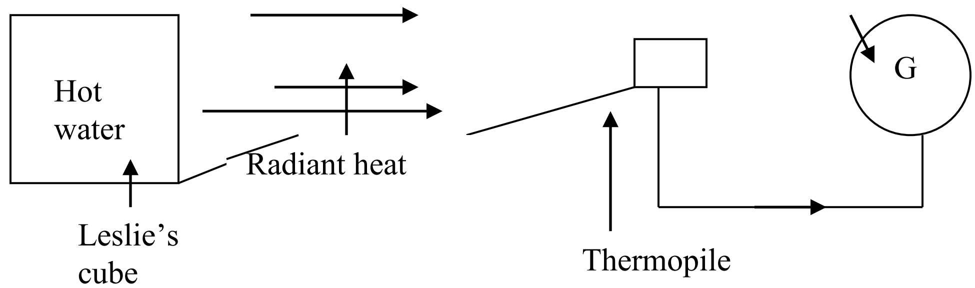
The rate at which a body radiates heat depends on
(a) its temperature
(b) its surface area
(c) the nature of the surface

Its is found that, for a given temperature, a body radiates (emits) most heat when its surface rough dull black and least when its surface is highly polished and shine.

This can be demonstrated by using a **Leslie's cube**. It is a copper cube, each side of which had different surface. One may be highly polished, another coated with lamp black by holding it in the flame of a candle, while the remaining two surfaces may be painted in a light and dark colour respectively.

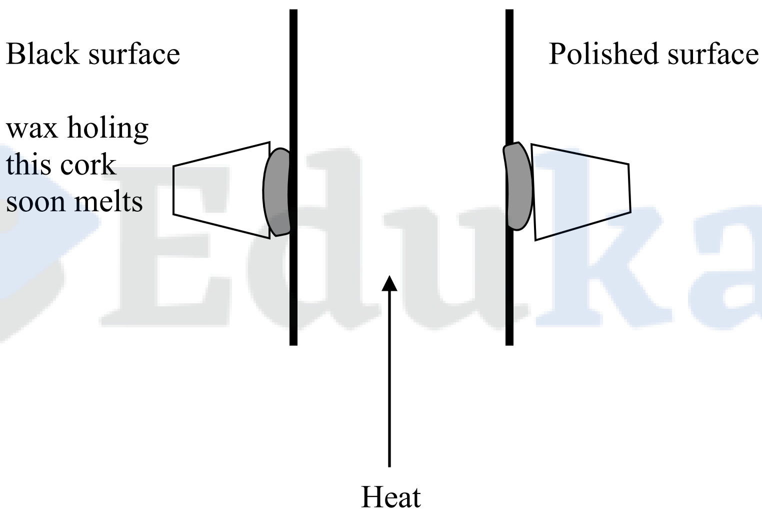
The cube is filled with hot water and a thermopile placed at the same distance from each face in turn. In each case the steady deflection obtained on the galvanometer is recorded. The results shows that the dull black surface produces the largest, and the polished surface the smallest deflection. Of the painted surfaces, the darker one is usually better, but this is not always the case. The texture of the surface appears to be a more important factor than its colour.





ABSORPTION OF RADIANT HEAT BY A SURFACE

The absorbing powers of a dull black and a polished surface may be compared by using two sheets of metals, one polished and the other painted black

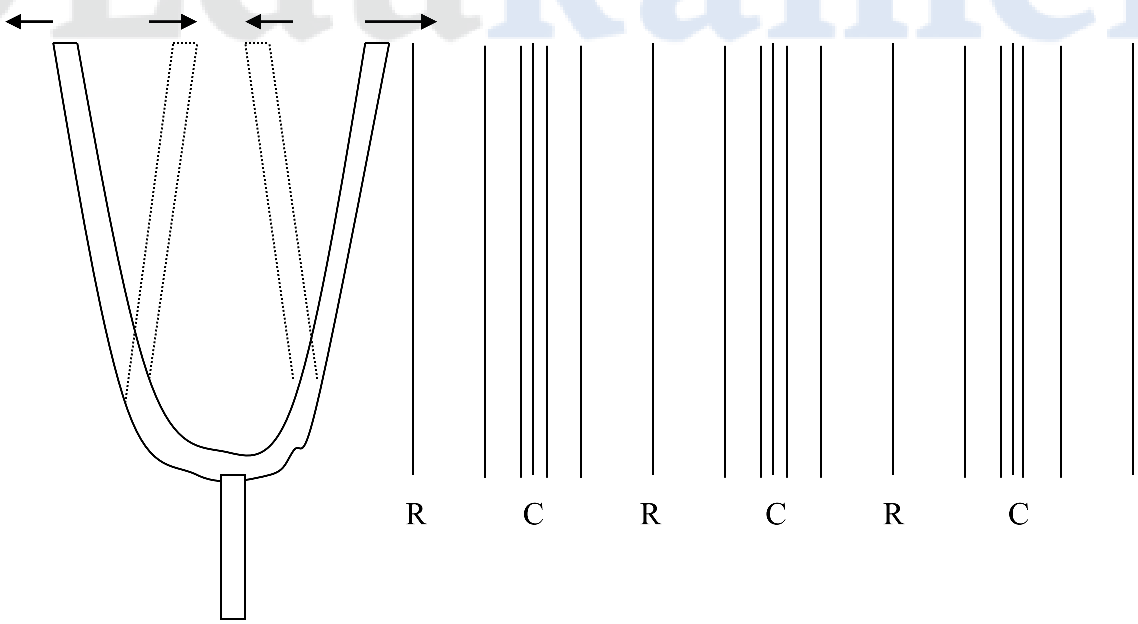


On the reverse side of each plate, a cork is fixed by means of a little paraffin wax.

SOUND WAVES

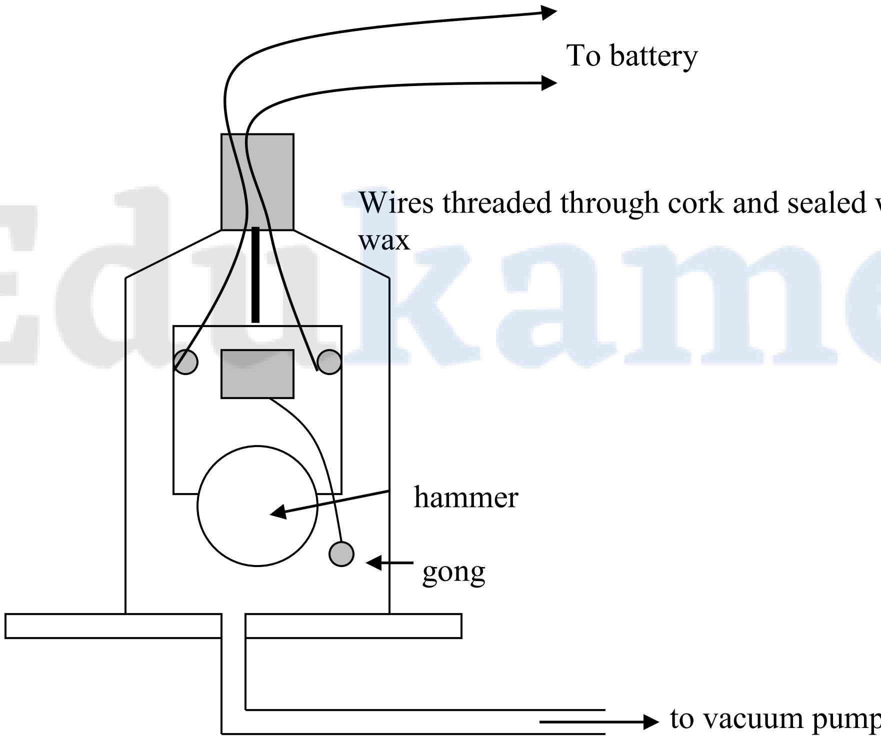
Sound waves are caused by vibrations, which must have a material medium through which to travel. Sound will not pass through a vacuum.

Sound waves are therefore **mechanical** and **longitudinal** in nature. Sound waves can be produced by a tuning fork, as the prongs vibrate a series of compressions and rarefactions are sent



TO DEMONSREATE THAT SOUND WAVES REQUIRE MATERIAL MEDIUM FOR TRANSMISSION

An electric bell is suspended inside a bell jar by means of elastic bands. The wires go through the cork so that no part of the bell touches the glass. When the bell is connected up, we can both hear the both it ringing and see the hammer hitting the gong. The air pump is started and as the air is drawn out the sound of the bell gets fainter and fainter. If a real good vacuum can be produced we can not hear the bell at all, although it can be seen to still working. When the air is let in the bell jar the sound returns, so the conclusion is that sound will not travel in a vacuum but light does.



Although sounds usually travel through the air, they will travel through other substances. Sounds travels at different speeds in different substances. The table below gives the velocity of sound in some common substances.

Substance	**Velocity**
Air at 0ºC	331m/s
Air at 20ºC	355m/s
Water at 20ºC	1457m/s
Iron	5000m/s (approx)

Wood	4000m/s (approx)
Rock	2500m/s (approx)

MEASURING THE VELOCITY OF SOUND IN AIR

(a) RECIPROCAL FIRING

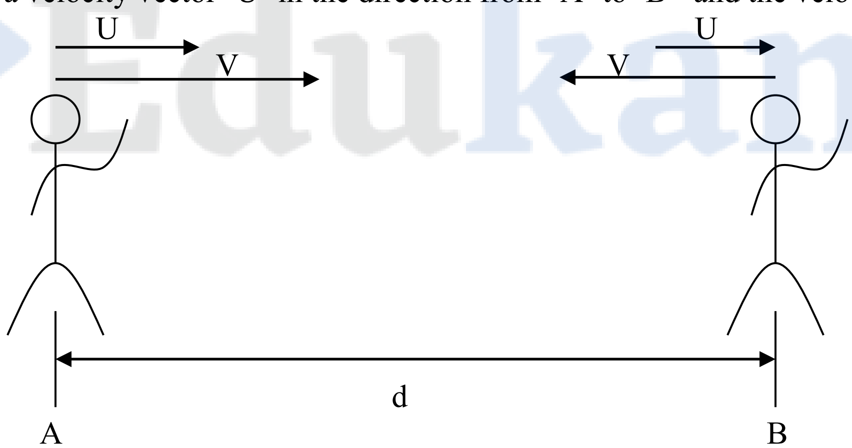
Two experimenters 'A ' and ' B' stand at a measured distance 'd' from each other in an open space. 'A' fires a canon and 'B' measures the time taken 't_1' taken for sound to reach 'B ' after seeing the flash. Find the speed as follows

$$S_1 = \frac{d}{t_1}$$

'B' fires a canon and 'A' records the time ' t_2' to receive sound after seeing the flash

$$S_2 = \frac{d}{t_2}$$

The speeds S_1 and S_2 are not equal due to the error introduced by wind flow. Let the wind to have a velocity vector 'U' in the direction from 'A' to 'B' and the velocity of sound in air be V.



$S_1 = V + U$ and $S_2 = V - U$

By taking the average of the two the error due to wind, to some extent will be eliminated.

$$\text{Velocity of sound} = \frac{S_1 + S_2}{2} = \frac{V + U + V - U}{2}$$

$$= \frac{2V}{2}$$

$$= V$$

Example

A and **B** are two observers 1km apart. There is a steady wind blowing. When a gun is fired at **A** the time interval between the flash and the report observed at **B** is 3.04sec. When a gun is fired at **B** the interval between the flash and report observed at **A** is 2.96sec. Calculate the velocity of sound in air and the velocity component on the wind in the direction **B** to **A**

Solution

Let the velocity of sound in air be V and wind from B to A be U.

Total speed in the direction AB = $V - U = \frac{1000}{3.04}$

$$V - U = 328.95$$

Total speed in the direction BA = $V + U = \frac{1000}{2.96}$

$$V + U = 337.84$$

$$V - U = 328.95$$
$$V - U = + 337.84$$
$$2V = 666.79$$

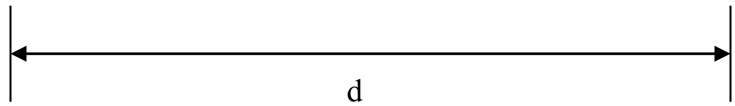
$$\frac{2V}{2} = \frac{666.79}{2}$$

$$V = 333.39 m/s$$

$$V - U = 328.95$$
$$U = V - 328.95$$
$$U = 333.39 - 328.95$$
$$U = 4.44 m/s$$

(b) ECHO METHOD

In this method one experimenter stands at a measured distance 'd' from a cliff or wall in an open space. He fires a gun and records the 't' time taken for the echo to reach him from the cliff.



$$\text{Speed} = \frac{\text{total distance}}{\text{time}} = \frac{d + d}{t}$$

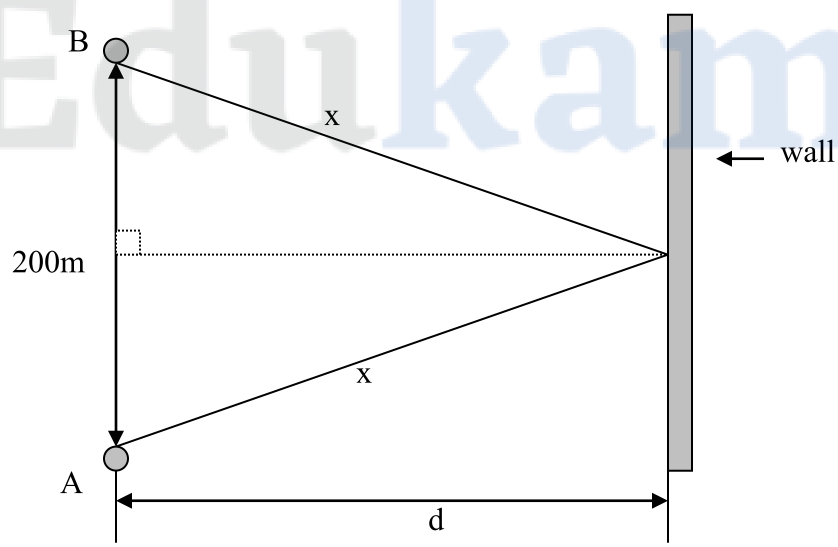
$$\text{Speed} = \frac{2d}{t}$$

Example

Two men stand facing each other 200m apart, on one side of a high wall and at the same perpendicular distance from it. When one fires a pistol the other hears a report 0.60sec after the flash and a second report 0.25sec after the first. Calculate

(c) the velocity of sound in air
(d) the perpendicular distance of the men from the wall

solution



(a) The time taken for sound to travel from A directly to B is 0.60sec.

$$S = \frac{d}{t}$$

$$\text{Velocity of sound in air} = \frac{200}{0.6} = 333.33\text{m/s}$$

(b) Let the perpendicular distance of the men from the wall be 'd'.
The distance covered by sound from one man to the wall to the other man is 2x, where

$$x = \sqrt{100^2 + d^2}$$

$$2x = 2\sqrt{100^2 + d^2}$$

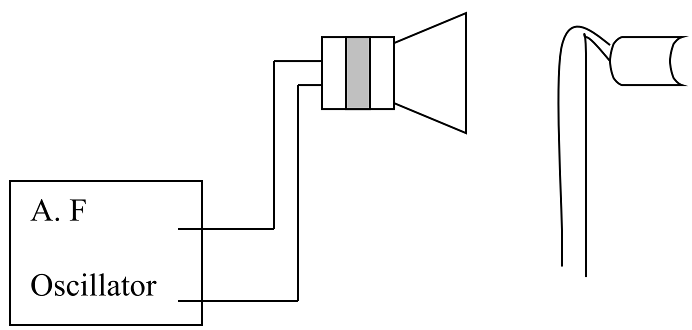
$$\text{Speed} = \frac{2x}{0.85} = \frac{2\sqrt{100^2 + d^2}}{0.85} = 333.33$$

$$\sqrt{100^2 + d^2} = \frac{333.33x0.85}{2} = 141.67$$

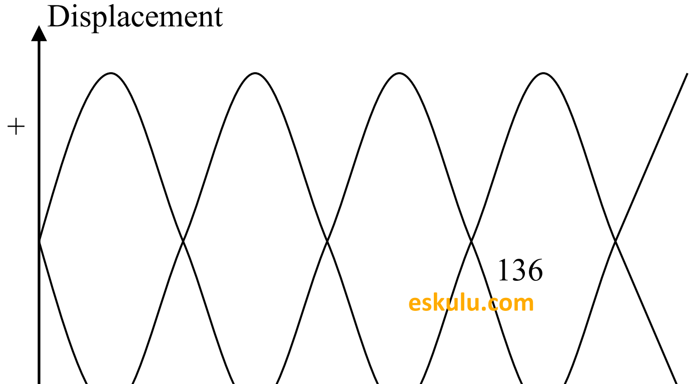
$100^2 + d^2 = 20069.445$
$d^2 = 20069.445 - 10000$
$d^2 = 10069.445$
$\underline{d = 100.347}$

(c) INTERFERENCE METHOD

The figure shows the method of measuring the speed of sound in free air by an interference method.



Sound waves of constant frequency (f) travel from a loudspeaker L towards a vertical board M. Here the waves are reflected and interfere with the incident waves. The two waves traveling in opposite directions produce a stationary wave between the board M and L.



0

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At the node ‘a’ the particles on either side produce a compression (increase of pressure) from the direction of their displacement. At the same instant the pressure at the antinode ‘b’ is normal and that at the node ‘c’ is a rarefaction (decrease in pressure).

A small microphone, positioned in front of the board, is connected to the Y – plates of the oscilloscope. As the amplitude of the waveform seen increases to a maximum at one position ‘A’ as shown. This is the antinode of the stationary wave. When the microphone is moved on, the amplitude diminishes to a minimum (a node) and then increases to maximum again at a position ‘B’ the next antinode. The distance between successive antinodes is $\frac{\lambda}{2}$. So by measuring the average distance ‘d’ between successive maxima, the wavelength λ can be found. Knowing the frequency ‘f’ of the note from the loudspeaker, the speed ‘V’ of the sound wave can be calculated from.

$$V = f\lambda$$

FACTORS WHICH AFFECT THE SPEED OF SOUND IN AIR

The speed of sound in air and other gases was investigated by **Sir Isaac Newton** who showed that the velocity of is proportional to $\sqrt{\frac{Pressure}{Density}}$

(i) **Pressure** In accordance with **Boyle’s** law if the pressure of a fixed mass of air is doubled the volume will be halved. Hence the density will be doubled. Thus at constant temperature the ratio $\sqrt{\frac{Pressure}{Density}}$ will always remain constant, however much the pressure may vary so pressure does not change the speed of sound in air.

(ii) **Temperature** Anything which changes the air density without altering the pressure will cause a change in the velocity of sound. Change in temperature can bring about this. If the temperature increases at constant pressure the air will expand according to **Charles’** law and therefore become less dense. The ratio $\sqrt{\frac{Pressure}{Density}}$ will therefore increase and hence the velocity of sound increases with temperature.

LIGHT

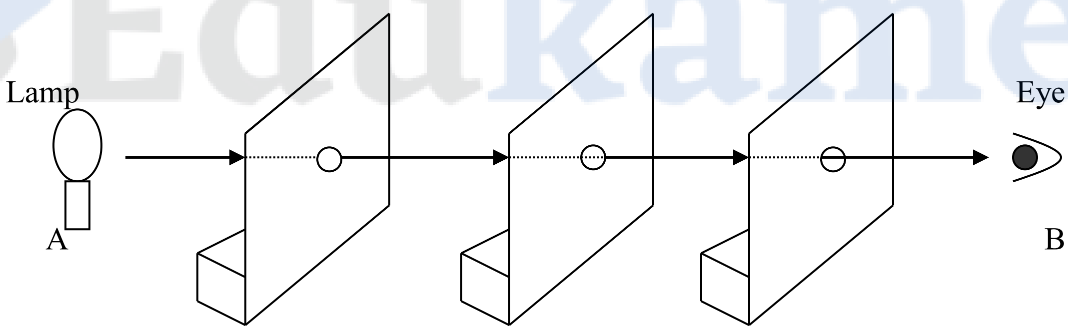
The study of light and optical instruments is called **optics.** Other forms of energy can be converted to light energy e.g. when we switch on a light in our homes, electrical energy is converted into light energy. Light can also be converted to other forms of energy . The leaves of plants use light to make food (chemical energy).

Objects that produce their own light are called **luminous objects**. e.g. candle flame, a star and glowing electric light filament e.t.c.

We see objects around us because they reflect light. These objects are called **non – luminous objects** e.g. a paper, moon and people e.t.c.

RECTLINEAR PROPAGATIONATION OF LIGHT

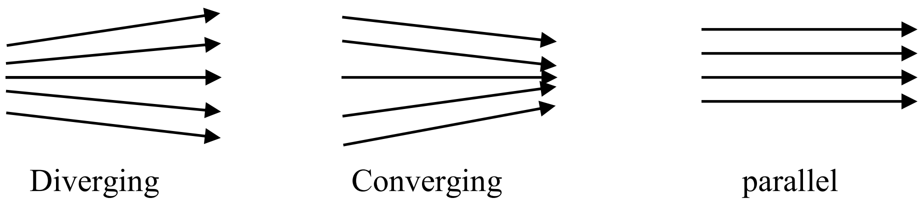
The sharp edges of shadows make us make realize that light travels in straight lines. We can demonstrate this fact by a simple experiment with three cardboard screens having small holes in their centers. These are set up so that the holes are in straight line by threading a string and pulling it taut.



Light from a lamp at A can be received by an eye at B. If one of the screens is moved so that the holes are no longer in a straight line the light is cut off at B. Light is a form of wave energy and it can under go all properties of waves i.e. reflection, refraction, diffraction, interference e.t.c.

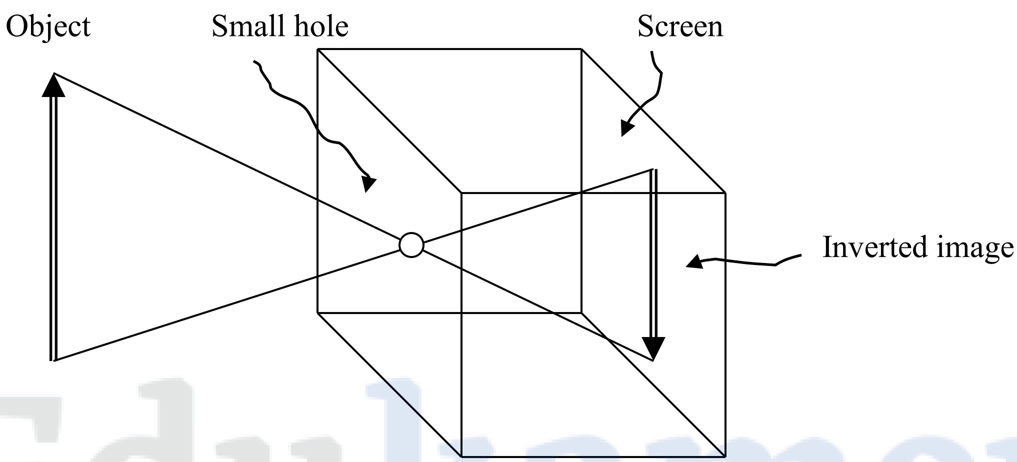
LIGHT RAYS AND BEAMS

- A ray is the direction of the path taken by light energy. In diagrams rays are represented by lines with arrows on them.
- A beam is a stream of light energy and may be represented by a number of rays which may be diverging, converging or parallel.



THE PIN HOLE CAMERA

It consists of a box with a pin hole in a metal plate at one end and a screen of tracing paper at the other.



Since light travels in a straight line it follows that a given point on the screen will be illuminated by light coming in a straight line through the pin hole from a certain point on the object. Rays of light from various parts on the object outside will thus travel in a straight lines through the pin hole and form a multitude of tiny patches on the screen. These tiny patches combine to form an inverted image of the object. If a line is drawn through the pin hole perpendicular to the object and image it can be proved by similar triangles that

$$\frac{height\ of\ image}{height\ of\ object} = \frac{distance\ of\ the\ image\ from\ pinhole}{distance\ of\ the\ object\ from\ pinhole}$$

This fraction is called magnification (m). If the screen is replaced by a photographic plate or film very satisfactory pictures of still objects can be taken with this camera with time exposure of suitable length.

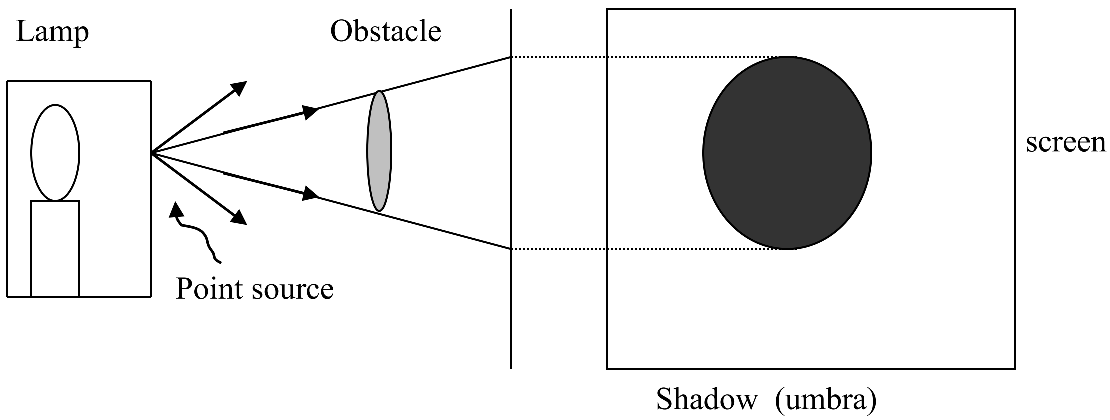
SHADOWS

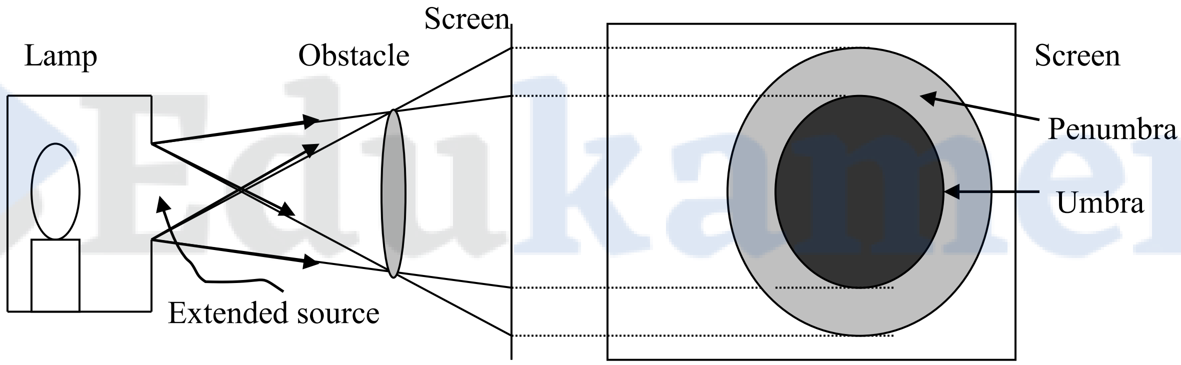
Shadows are formed fort two reasons

(a) Because some objects which are said to be opaque do not allow light to pass through them.
(b) Because light travels in a straight line.

The sharpness of the shadow depends on the size of the light source. A very small source of light called a **point source** gives a sharp shadow which is uniformly dark all over.

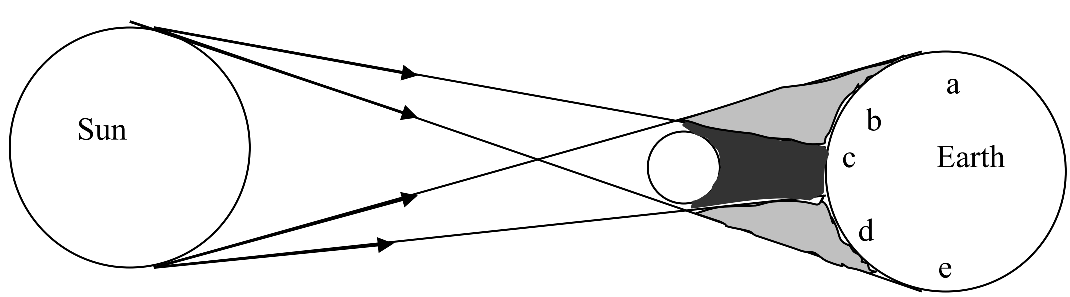
If an **extended** source is used the shadow is seen to be edged with a border of partial shadow called the **penumbra** distinguish if from total shadow called **umbra**. Points inside the penumbra receive a certain amount of light the source, but not as much as it would receive if the obstacle were removed. screen



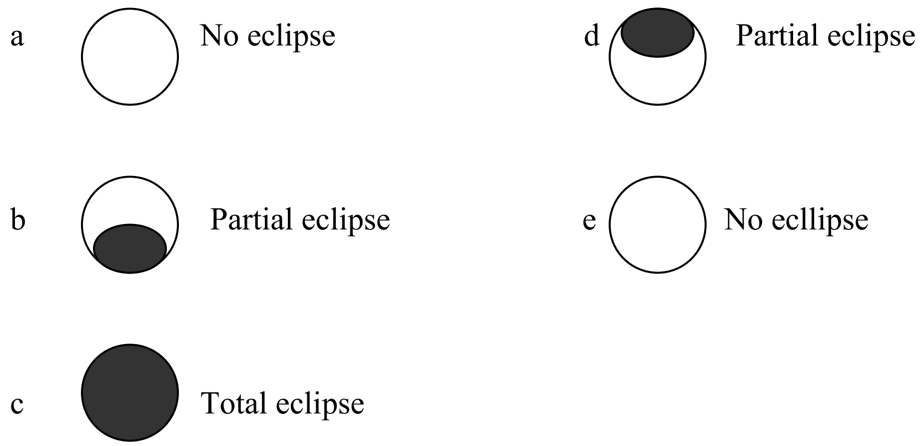


ECLIPSE OF THE SUN

An eclipse of the sun by the moon occurs when the moon passes between the sun and the earth and all three are in a straight line. The figure below shows how the umbra and penumbra are produced and the appearance of the sun as seen from various positions on the earth's surface.

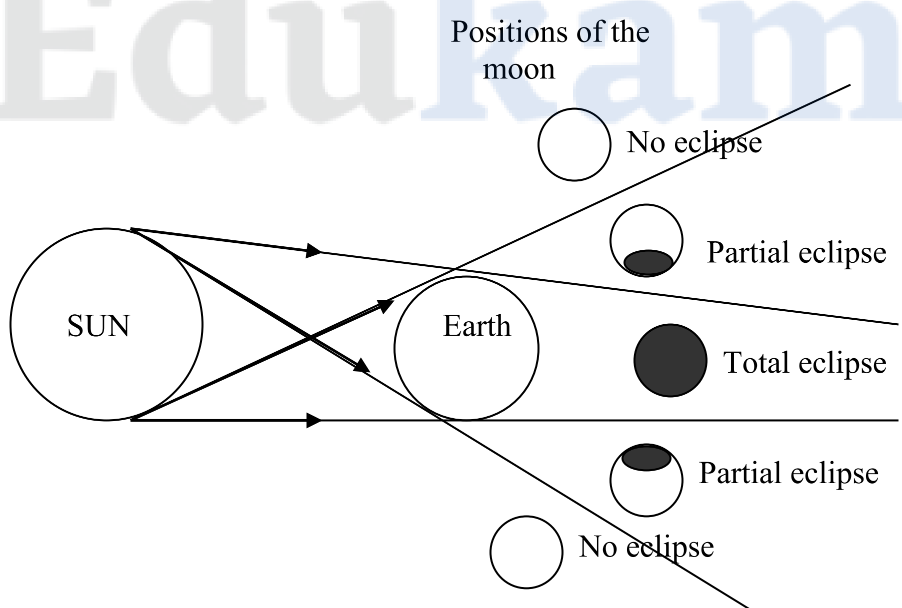


Sun's appearance at different positions of the earth



ECLIPSE OF THE MOON

An eclipse of the moon by the earth occurs when the earth passes between the sun and the moon and all the three are in a straight line. The shadow of the earth is cast on the moon as shown below



THE NATURE OF LIGHT

Light consists of streams of tiny wave like packets of energy called photons which travel at a speed of 3×10^8m/s. The general outline of the nature of light is listed below.

(i) **Light transfers energy from one place to another.**

Energy is needed to produce light. Materials gain energy when they absorb light. Mostly this causes an increase in their internal energy. The solar cells change some of the energy in sunlight directly into electrical energy

(ii) **Light is a form of radiation**

Radiation is a general term applied to almost anything that travels outwards from its source but can't immediately be identified as solid, liquid or gas like the more familiar forms of matter.

(iii) Light is a form of wave motion

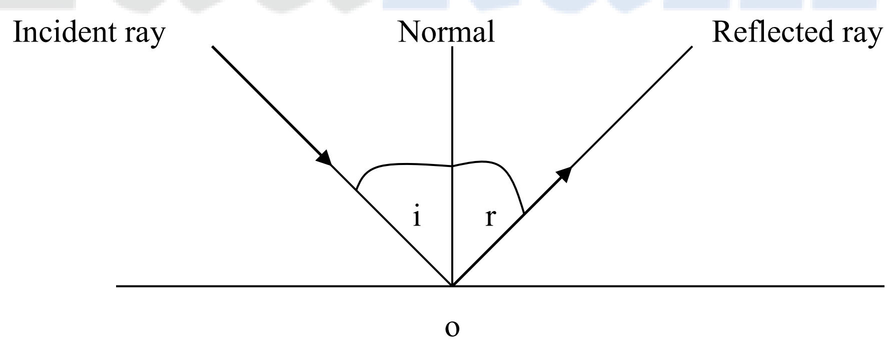
The way in which light radiates from it's source is similar in many ways to the to the way in which ripples spread outwards across a pond when a pebble is dropped into the water. In case of light the ripples are electric and magnetic in nature.

(iv) **Light is something detected by the human eye.**

Objects emit many types of radiations, most of which are not detectable by the human eye. Light is the wave given to radiations which the eye can detect.

REFLECTION OF LIGHT

Since light is a form of wave motion, it can reflected and the laws of reflection apply



i - angle of incidence r - angle of reflection

LAWS OF REFLECTION OF LIGFT

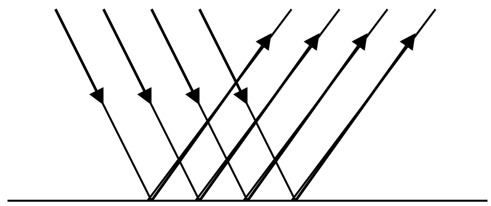
(i) The incident ray, the reflected ray and the normal at the point of incident all lie in the same plane.
(ii) The angle of incidence is equal to the angle of reflection.

$$i = r$$

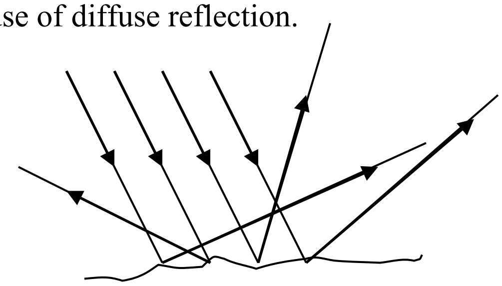
DIFFUSE AND REGULAR REFLECTION

When a set of parallel light rays strike a plane flat surface such as a mirror or polished sheet of metal, the reflected rays are also parallel. This is called regular or specular reflection.

When a set of parallel light rays strike an irregular surface such as a piece of paper or concrete path, the rays are scattered in different directions. This is called diffuse reflection. We see most of the objects around us because of diffuse reflection.



Regular reflection



Diffuse reflection

Because of the difference between diffuse and regular refection, images of objects can be seen in plane mirrors or polished surfaces but not in paper or other irregular surfaces.

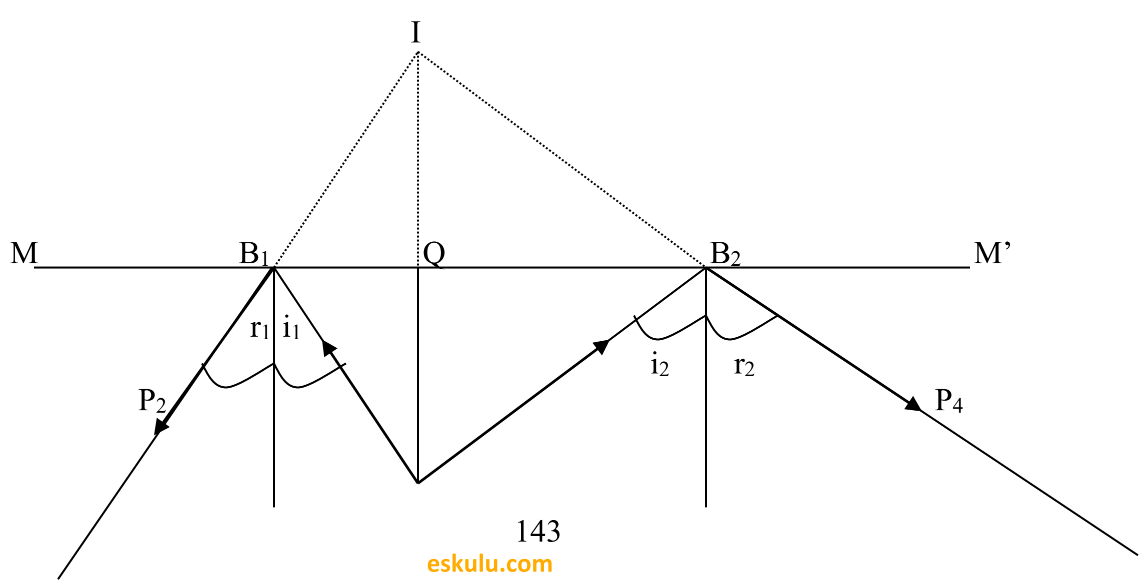
TO VERIFY THE LAWS OF REFLECTION OF LIGHT

A strip of plane mirror is set up, with its silvered surface on the line MM’ drawn on a sheet of white paper on a drawing board. A pin O to serve as an object is stuck into the paper.

With the eye in some convenient position E_1, two pins $P_1$and P_2 are stuck into the paper so as to be in a straight line with the image I of the pin O seen in the mirror.

The same procedure is carried out with the eye at E_2 and pins P_3 and P_4 are stuck so that they are in the same straight line with the image I of the pin O seen in the mirror. When this is done the mirror and the pins are removed and the positions of the pins are marked.

The points P_1 and P_2 also P_3 and P_4 are then joined to cut the line MM’ at B_1 and B_2 respectively. These lines are produced backwards behind the mirror and they will intersect at I the position of the image.



P_1 N_1 O N_2 P_3

The lines OB_1 and OB_2 represents the incident rays and B_1P_1 and B_2P_3 are their corresponding reflected rays. Normals B_1N_1 and B_2N_2 are constructed and in each case i = r verifying the second law of reflection.

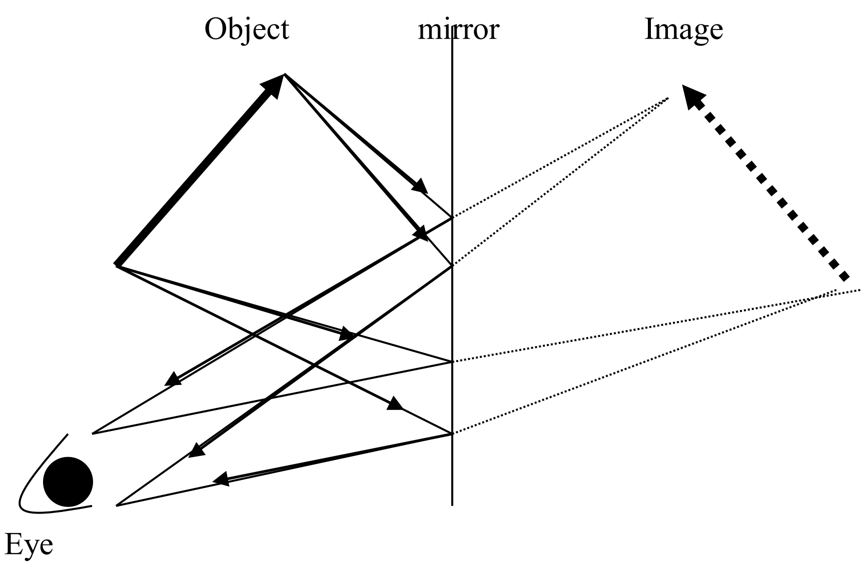
i	r

This experiment can be performed on a flat drawing board only if the mirror is set at right angle to the board. This verifies the first law of reflection.

If IO is joined, cutting MM' at Q it is found that IO = OQ and IO is perpendicular to MM'. We therefore infer, that the line joining object and image is as far behind the mirror as the object is in front.

IMAGES OF REAL OBJECTS

In reality, objects do not occupy single points. The figure below shows how a plane mirror forms an image of an extended objects. As in any diagram an infinite number of rays could be drawn, but two rays from any point on the object are sufficient to establish the position of the image of that point.



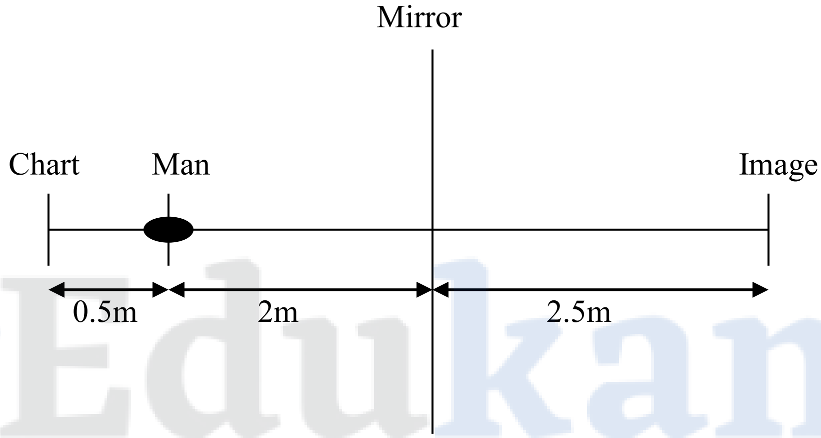
PROPERTIES OF THE IMAGE FORMED BY PLANE MIRRORS

(a) The image formed is the same size as the object.
(b) The image is as far behind the mirror as the object is in front.
(c) The image is virtual.
(d) The image is laterally inverted
(e) A line joining any point on the object to the corresponding point on the image cuts the mirror at right angle.

EXAMPLES

(1) A man sits in an opticians chair, looking into a plane mirror which is 2m away from him and views the image of a chart which faces the mirror and is 50cm behind his head. How far away from his eyes does the chart appear to be.

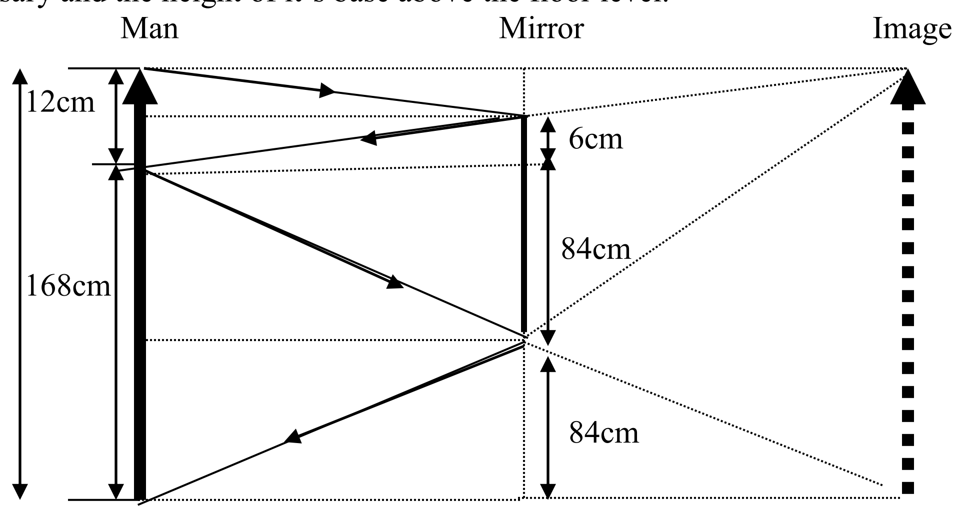
Solution



Distance of image from man is = 2 + 2.5 = 4.5m

(2) Draw a ray diagram to show that a vertical mirror need not be 180cm long in order that a man 180cm tall may see a full – length image of himself in it.

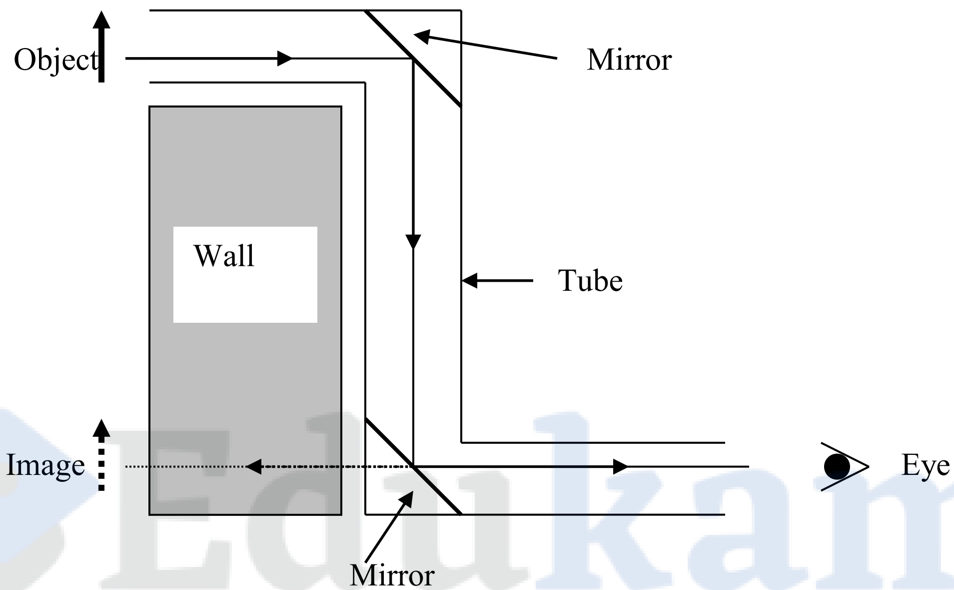
If a man's eyes are 12cm below the top of his head find the shortest length of mirror necessary and the height of it's base above the floor level.



- Shortest length of the mirror = 84 + 6 = 90cm
- Height of it's base above floor level = 84cm

THE MIRROR PERISCOPE

One common use of mirrors is in the mirror periscope. This instrument enables an observer to see above an obstacle as shown below.



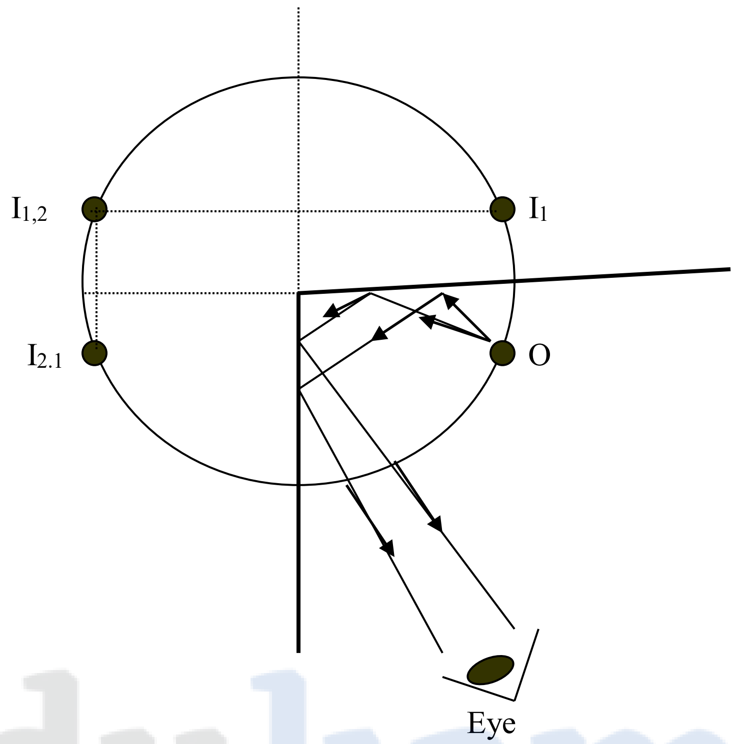
IMAGES FORMED IN TWO MIRRORS INCINED AT 90^0

When two mirrors are inclined at right angle we have not only the I_1 and I_2 formed by single reflection but in addition two extra produced by two reflections. The rays of light by which the eye sees one of these $I_{1;2}$ is shown below. The subscript $_{1,2}$ in the symbol $I_{1;2}$ signifies the order in which the reflection take place from mirror 1 followed by mirror 2

The other image $I_{2,1}$ may be seen by looking into mirror 1.Actually the images $I_{1,2}$ and $I_{2,1}$ are superimposed on one another.

The images I_1 and I_2 themselves acts as objects for the formation of images $I_{1,2}$ and $I_{2,1}$ and the position of these images are found in the usual way i.e. a perpendicular to the mirror is drawn through the object and the image. The object and image distances from the mirror are equal

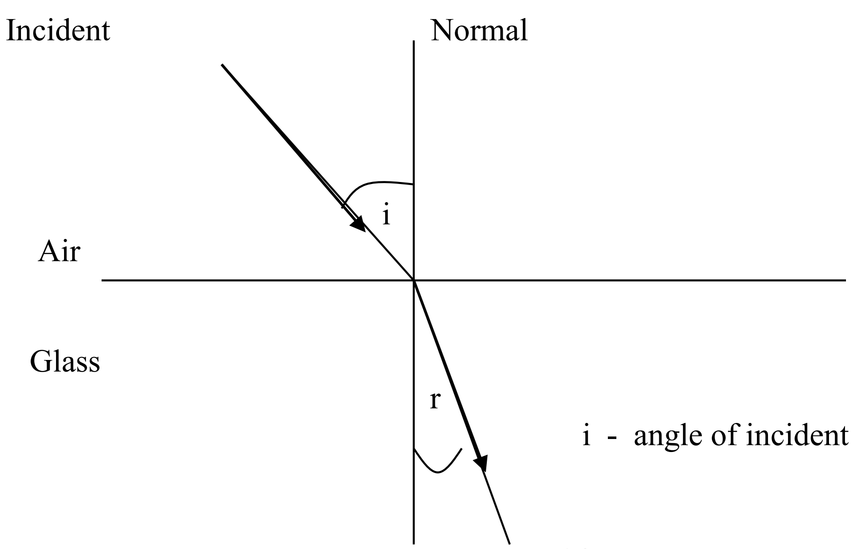
Geometrically the object and all the images lie on a circle whose centre is at the intersection of the mirrors.



REFRACTION OF LIGHT

A swimming pool appear much shallower than they actually are and a stick appears to be bend when you place one end under water. These and many similar effects (optical illusions) are caused by refraction.

'Refraction is the change in direction of light when it passes from one media to another of different optical density at an angle of incidence greater than zero'



r - angle of refraction

refracted ray

Light passing into an optically more denser medium is bent towards the normal; light passing into an optically less dense medium is bent away from the normal. Optical density is only a descriptive term however, and does not necessarily relate to the actual density of the material. Paraffin for example is optically more dense than water because it has a greater refracting effect on light, but it is less dense as a liquid.

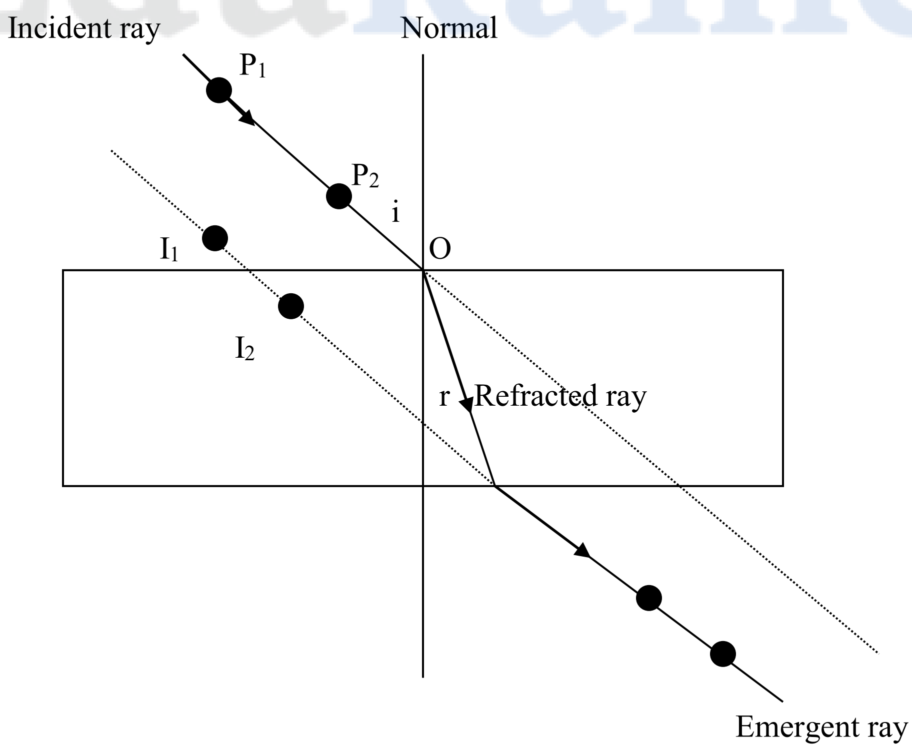
<u>LAWS OF REFRACTION</u>

(1) The incidence ray and refracted ray are on the opposite sides of the normal at the point of incidence and all three lie on the same plane.
(2) The ratio of sine of incidence angle to sine of refracted angle is constant

$$\frac{\sin i}{\sin r} = Cons\tan t$$

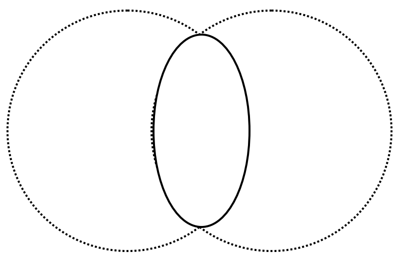
<u>TO VERIFY THE LAWS OF REFRACTION</u>

Place a rectangular glass block on a sheet of paper on a drawing board. Mark its outline. Remove the block temporarily and draw a normal and several lines to represent incident rays. Replace the block right on the outline.

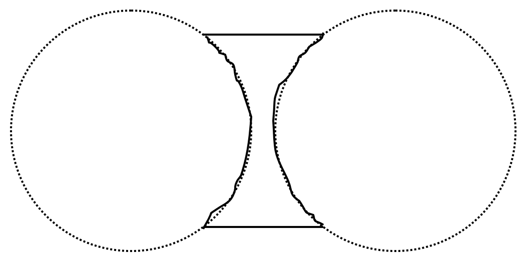


LENSES

A lens is glass or plastic bounded by one or two spherical surfaces. The converging lenses are thicker in the middle than the edges. The diverging lenses are thinner in the middle than at the edges.

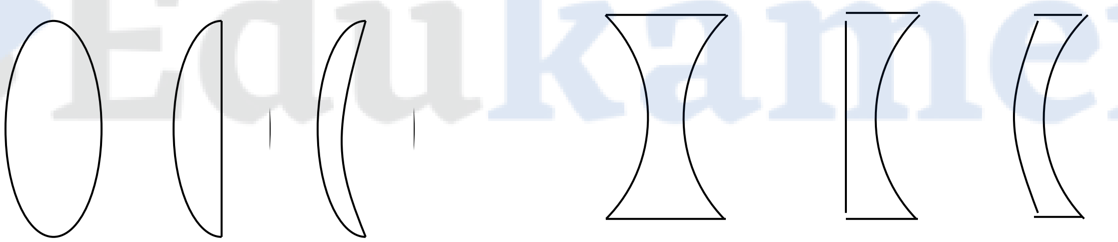


Converging lens



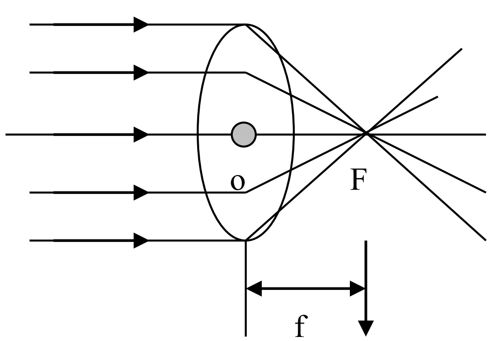
Diverging lens

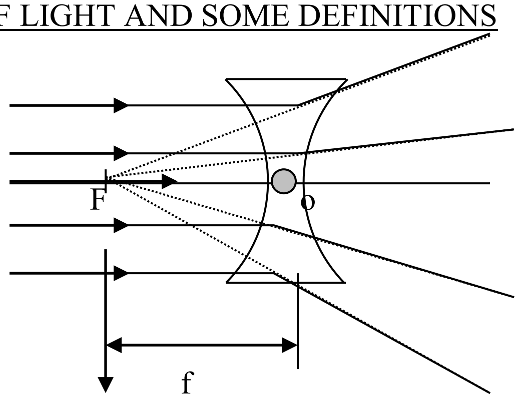
TYPES OF LENSES



Biconvex Plano convex Converging meniscus Biconcave Plano concave Diverging meniscus

ACTION OF LENSES ON A BEAM OF LIGHT AND SOME DEFINITIONS





(a) Centre of curvature (C)
The geometrical centre of the circles whose arcs makeup one or two spherical surfaces

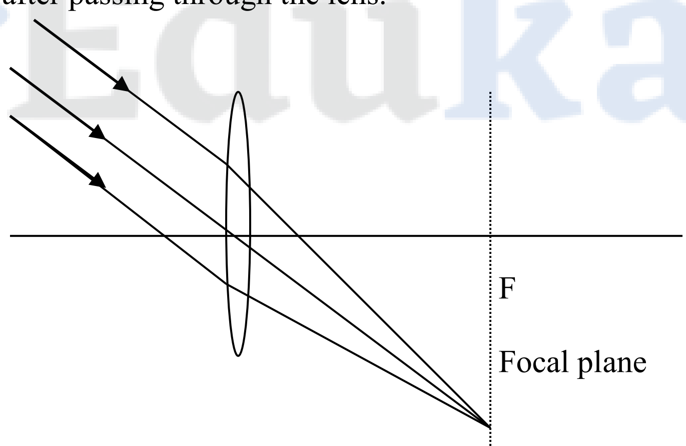
(b) Optic centre (o)
The centre of the lens

(c) Principal axis
The line joining the centre of curvatures of the of the two surfaces and passes through the optic centre and passes through the optic centre.

(d) Principal focus or focal point (F)
The point on the principal axis where a beam of light parallel to the principal axis converge to (convex) or appear to diverge from after passing through the lens. It is real focus for converging lens and virtual focus for diverging lens. Since light can fall on both sides of the lens it has two principal foci, one equidistant from the optic centre (o)

(e) Focal length (f)
The distance between the optic centre and the principal focus. The more curved the lens faces are, the smaller 'f' and the more powerful is the lens.

(f) Focal plane
A plane perpendicular to the principal axis and passing through the principal focus where a beam of light not parallel to the principal axis will converge to or appear to diverge from after passing through the lens.

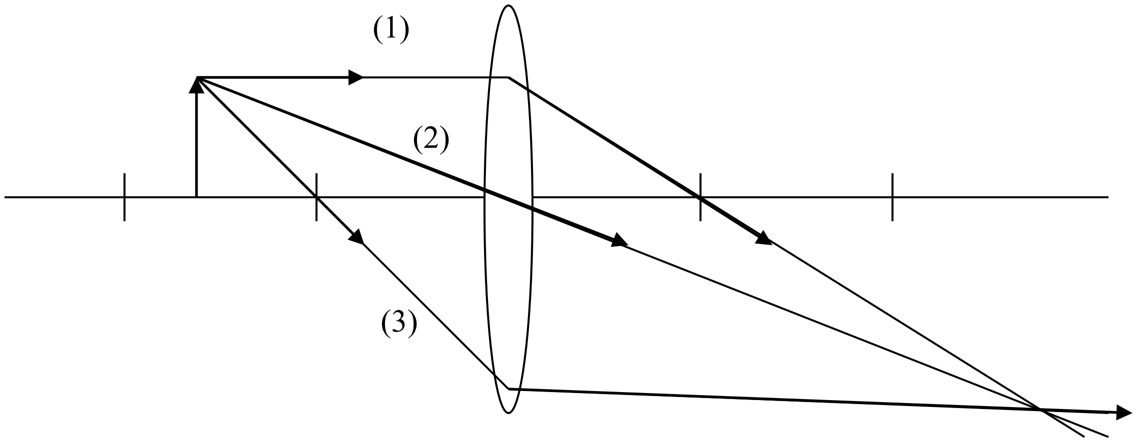


IMAGES FORMED BY LENSES

To locate the image formed by lens three particular classes of rays are used in geometrical construction.

(1) A ray parallel to the principal axis will pass through (for convex) or appear to come from (for concave) the principal focus after refracted through the lens.
(2) A ray through the principal focus will emerge parallel to the principal axis after refraction through the lens.
(3) A ray through the optical centre will be un deviated

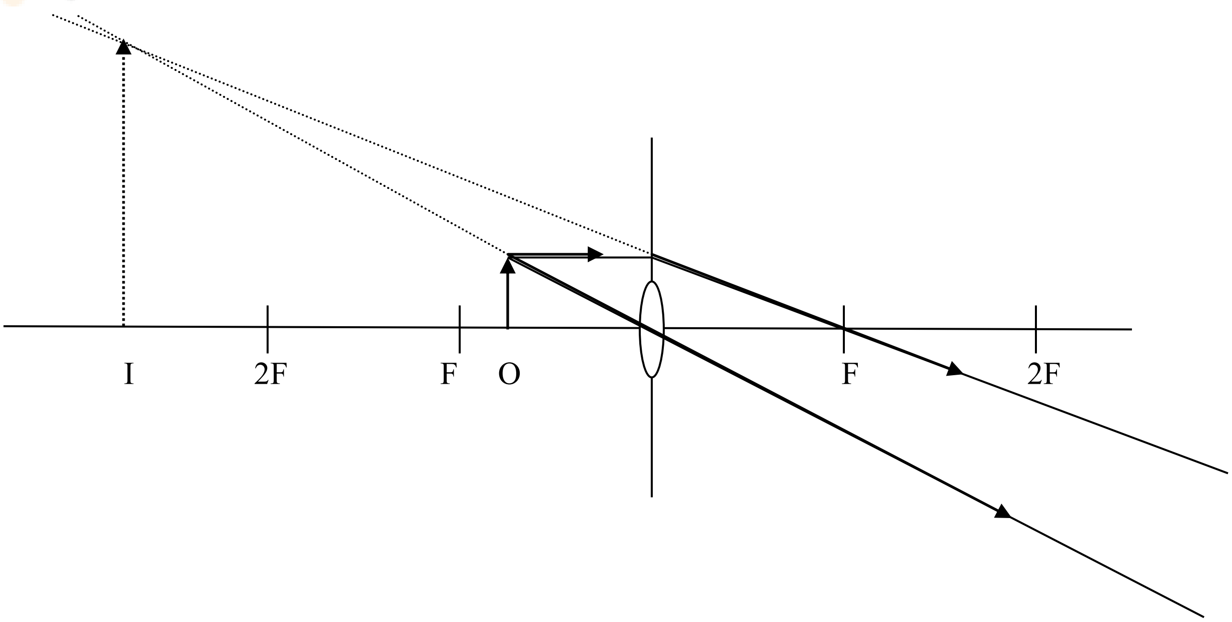
Two of these rays only are sufficient to locate the position of the image, and which particular pair is chosen is merely a matter of convenience.



IMAGES FORMED BY CONVEX LENS

The series of diagrams below shows the type of image formed as the object is moved progressively along the principal axis, starting at a point between the lens and the principal focus.

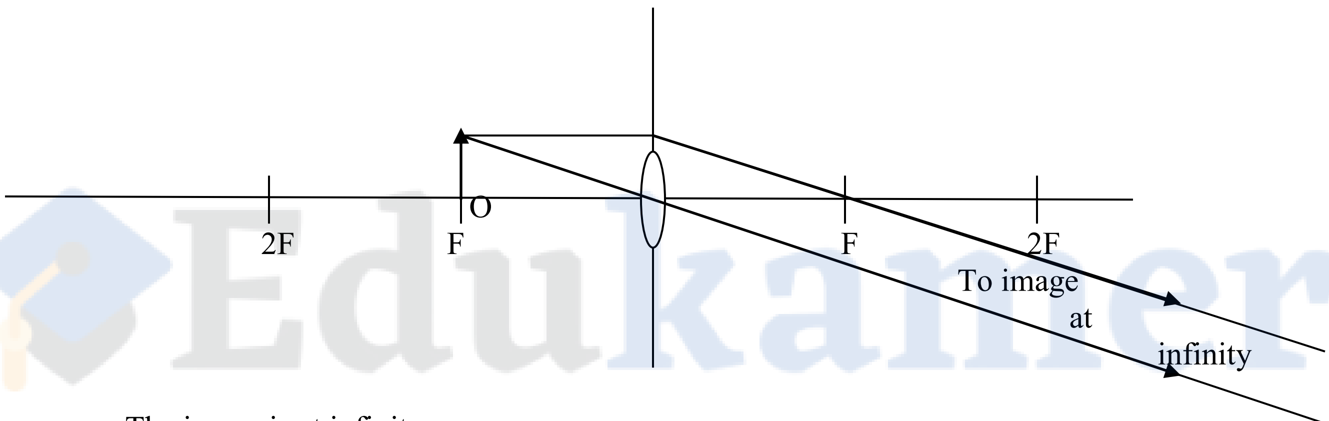
(a) **Object between lens and F**



Properties of the image are

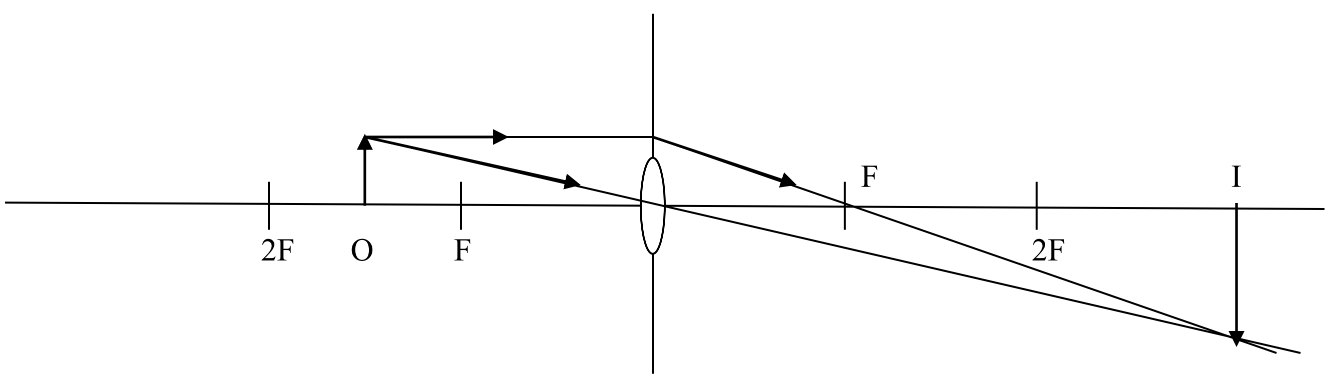
(i) Formed behind the object
(ii) Virtual (not real)
(iii) Erect (upright)
(iv) Larger than the object (magnified)

(b) **Object at F**



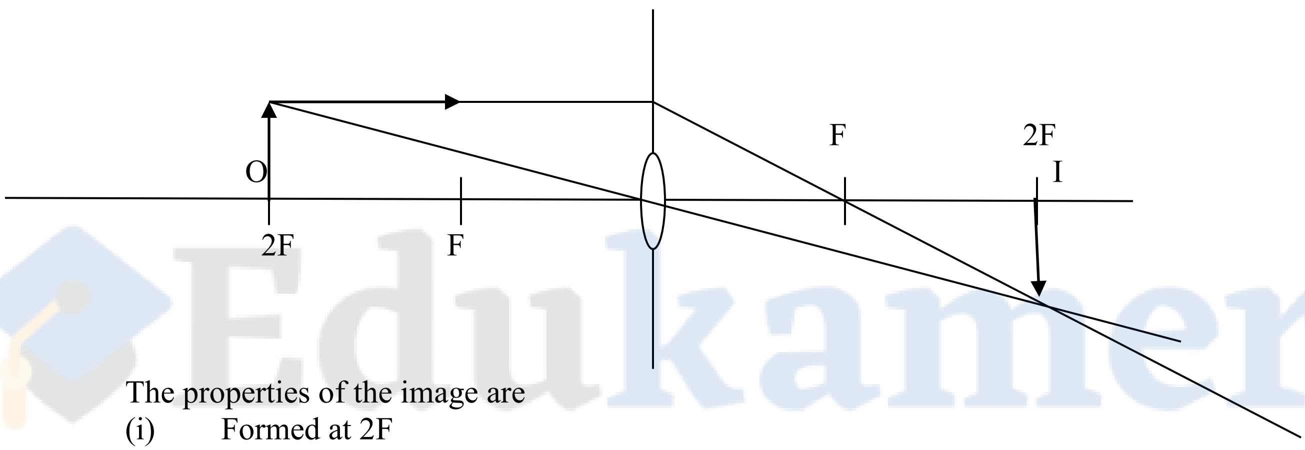
The image is at infinity

(c) **Object between F and 2F**



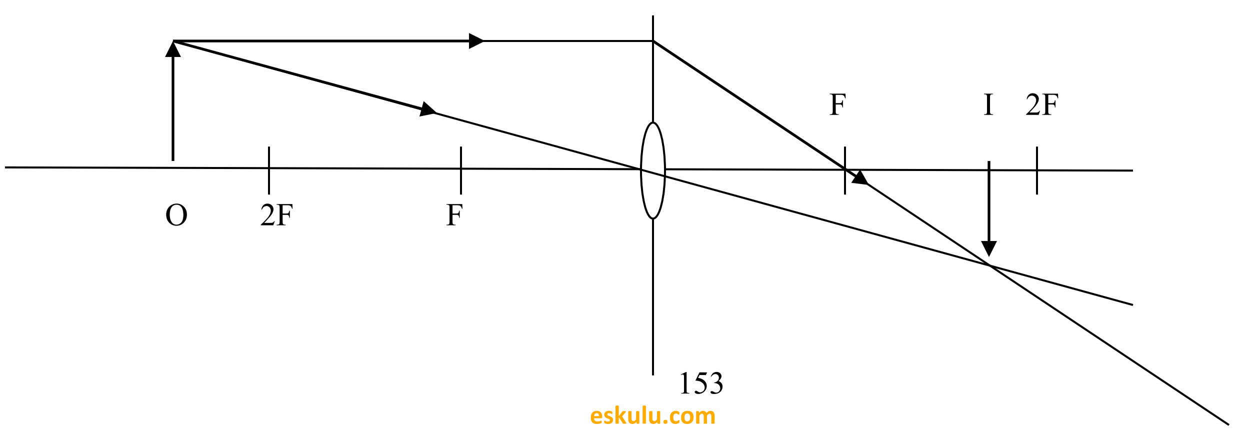
Properties of the image are
(i) Formed beyond 2F
(ii) Real
(iii) Inverted
(iv) Larger than the object (magnified)

(d) **Object at 2F**



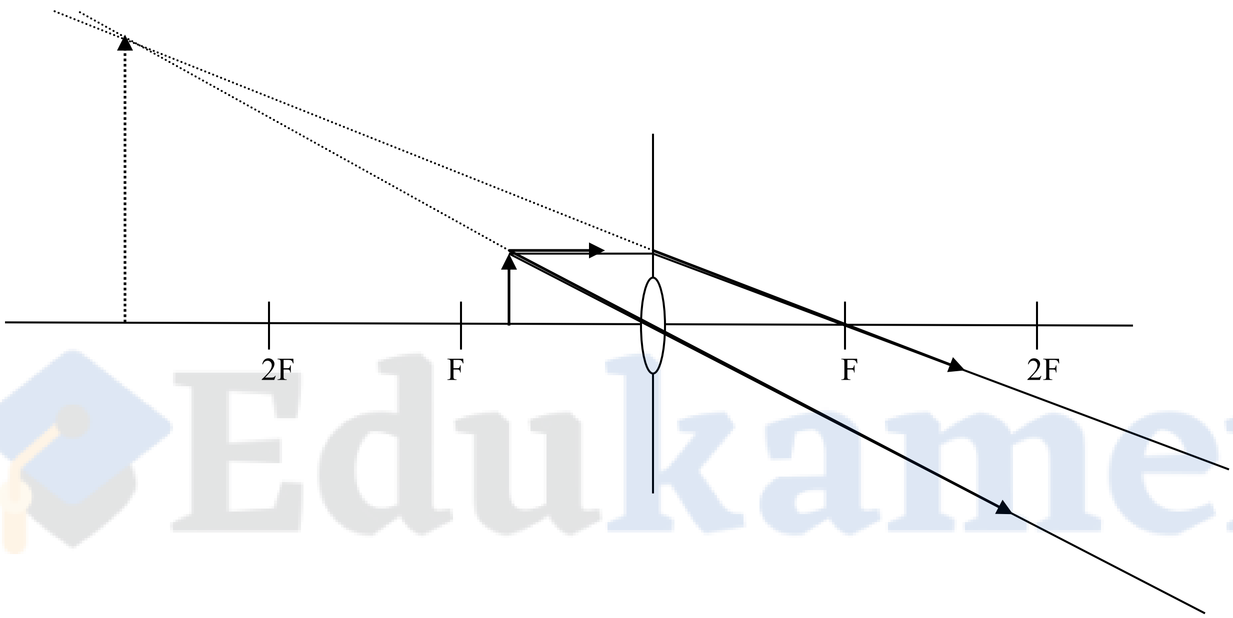
The properties of the image are
(i) Formed at 2F
(ii) Real
(iii) Inverted
(iv) Same size as the object

(e) **Object beyond 2F**



The properties of the image formed are
(i) Formed between F and 2F
(ii) Real
(iii) Inverted
(iv) Smaller than object (diminished)

(f) **Object at infinity**



(g)

MAGNETISM

It was found that certain forms of iron ore, known as magnetite or lodestone, had the property of attracting small pieces of iron. Chemically it consists of iron oxide having the formula Fe_3O_4.

MAGNETIC POLES

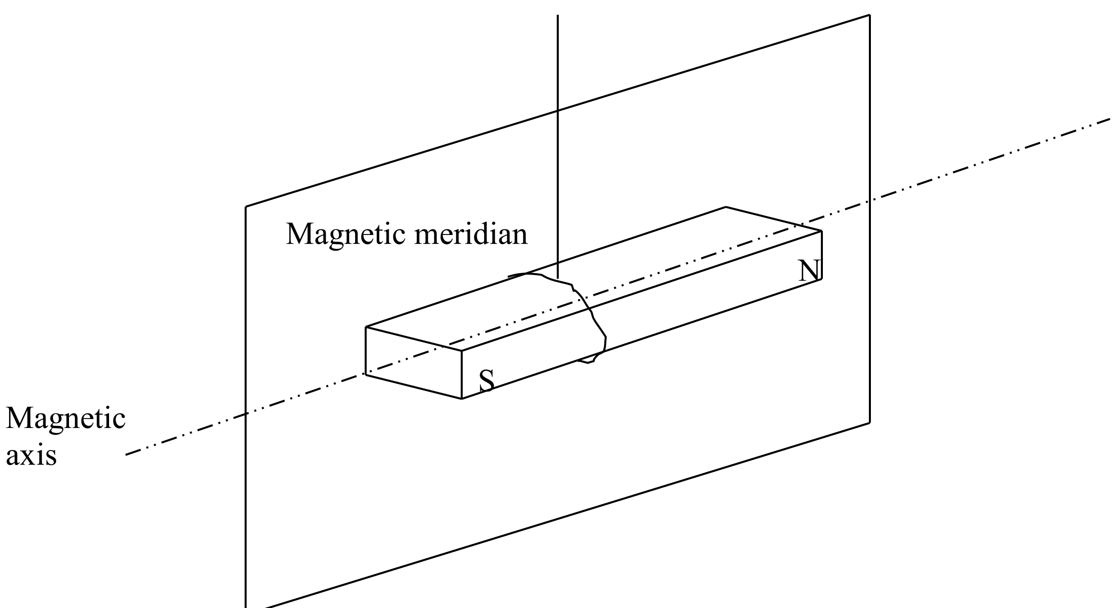
If a piece of lodestone is dipped into iron filings it is noticed that the filings cling in tuffs, usually at two places in particular. When the experiment is performed with a bar magnet the filings are seen to cling in tuffs near the ends.

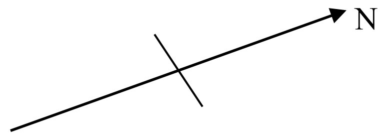
'The places on a magnet where the resultant attractive force appears to concentrated are called the poles'

SUSPENDING A MAGNET, MAGNETIC AXIS, MAGNETIC MERIDIAN

When a bar magnet is suspended freely in the horizontal plane, it oscillates to and fro for a short time and comes to rest in an approximate N – S direction

The magnet have a magnetic axis about which its symmetrical, and it comes to rest with this axis in a vertical plane called the magnet meridian.





The magnetic meridian is a vertical plane containing the magnetic axis of a freely suspended magnet at rest under the action of the earth's magnetic field.

The pole which points towards the north is called the north seeking pole or simply the N pole; the other is called the south seeking pole or S pole.