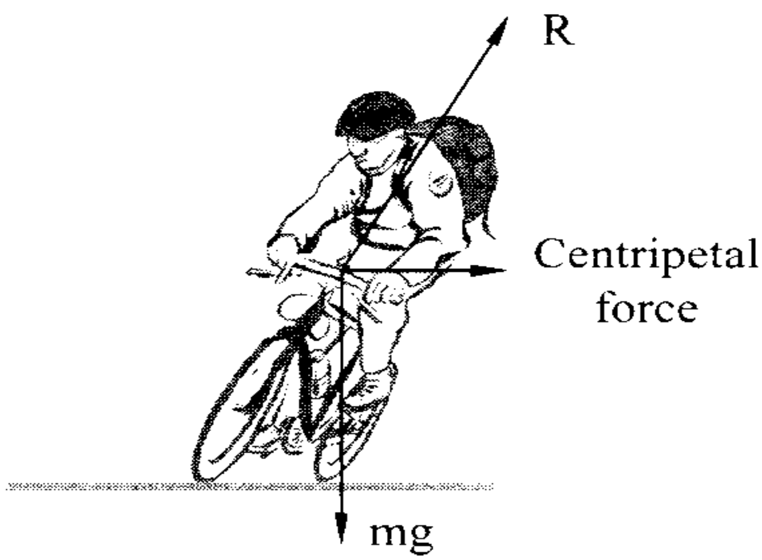
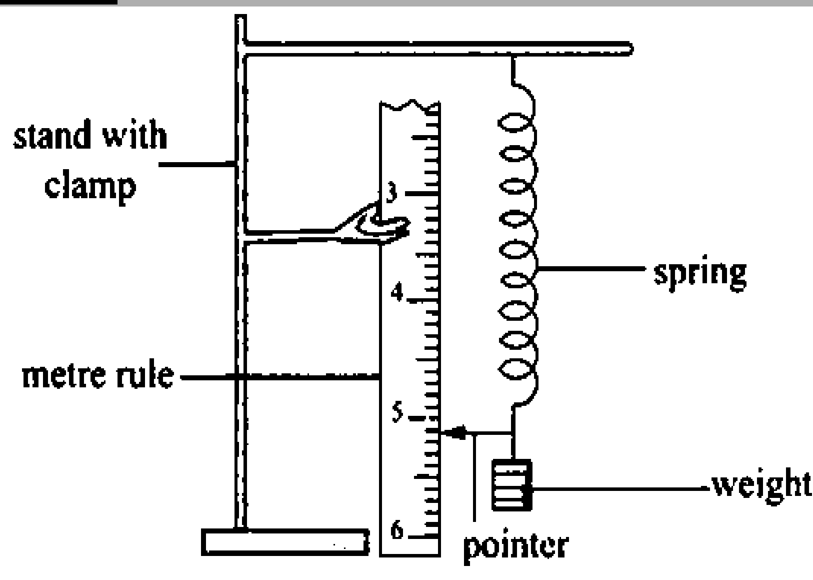


FORM 4 PHYSICS



THE PHYSICS MASTER

NEW HOPE PUBLICATIONS LIMITED

Contents

Chapter 1
THERMAL EXPANSION

A substance increase in size when heated and decrease when cooled.
Expansion is the increase in size of a substance on heating while contraction is the decrease in size on cooling of a substance

TEMPERATURE

Temperature is the degree of coldness or hotness of a body. According to kinetic theory of matter particles of matter are always moving due to kinetic energy.
Temperature is therefore the measure of the average kinetic energy of the molecules of a substance. The temperature of a substance is low if the molecules are moving slowly and high if the molecules are moving fast.
The SI unit of temperature is the Kelvin (K) (named after physicist Lord Kelvin) but commonly used unit of measuring temperature is degree Celsius (^{o}Celsius) (named after Swedish scientist Celcius).

DIFFERENCE BETWEEN HEAT AND TEMPERATURE

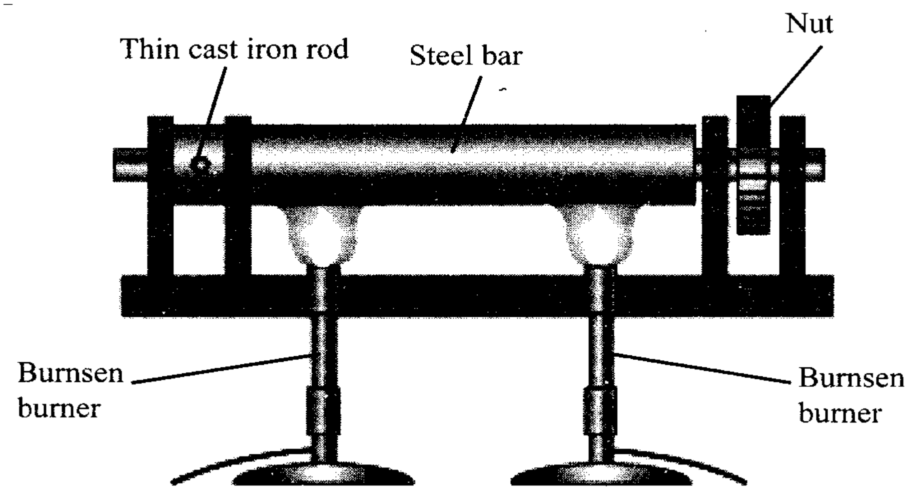
Heat is a form of energy which passes from a body of higher temperature to a body of low temperature. The SI unit of heat energy is Joule (J).temperature is the degree of hotness or coldness of a body hence is a measure of the heat energy of the molecules in a body.

A. THERMAL EXPANSION AND CONTRACTION IN SOLIDS

When solids are heated they
a. Increase in length
b. Increase in volume
c. Increase in area.

DEMONSTRATING THERMAL EXPANSION AND CONTRACTION IN SOLIDS USING THE CAST IRON BAR BREAKER.

A steel bar is fixed in the frame of a bar breaker. The steel bar is locked by inserting the thin cast iron rod in the hole on the steel bar. The steel bar is clamped strongly and heated with two Bunsen burners..



The experiment is repeated by strongly heating the steel bar and insert the cast iron rod through the hole and observe what happens as the steel bar cools.

It can be observed that:

- When the steel bar is heated strongly, the cast iron rod breaks with a loud sound
- When the steel bar is cooled in the repeated experiment the cast iron rod breaks

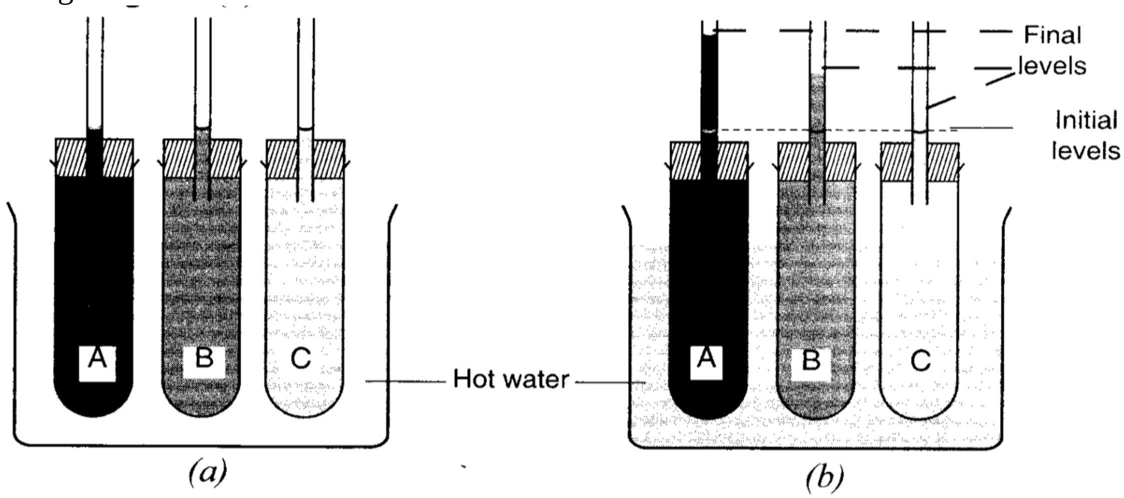
On heating the steel bar expands pushing the cast iron rod against the outer frame of the bar breaker and the rod breaks.
On cooling, the steel bar contracts and pulls the cast iron rod against the inner frame of the bar breaker and the rod breaks.

This shows that solids expand on heating and contract on cooling.

EXPLAINING THERMAL EXPANSION IN SOLIDS
Molecules in a solid are closely packed and are continuously vibrating about their fixed positions. When a solid is heated, the molecules vibrate with larger amplitude about their fixed positions. This makes them to collide with each other with larger forces which push them far apart. The distance between the molecules increases and so the solid expands.

B. THERMAL EXPANSION AND CONTRACTION IN LIQUIDS
Liquids expand on heating and contract on cooling. ***Liquids expand more than solids since they have relatively weaker intermolecular forces.***

DEMONSTRATING THERMAL EXPANSION IN LIQUIDS
Three test tubes A, B and C are filled with alcohol, paraffin and water respectively as shown in the figure.



Some water is heated to boiling point and placed in the water bath. Place the three test tubes in the water bath and observe the water levels after three minutes.

It can be observed that the level of the liquids in the three test tubes ***fall slightly at first*** then start rising again up the capillary tubes after some time.

Alcohol rises to the higher level in the capillary tube followed by paraffin then water.
Heat from the water bath reaches the test tubes first making them to expand and increase volume hence the liquid levels fall.

After some time the heat reaches the liquids and they start expanding. Alcohol expands more than paraffin, while paraffin expands more that water.

EXPLAINING THERMAL EXPANSION IN LIQUIDS

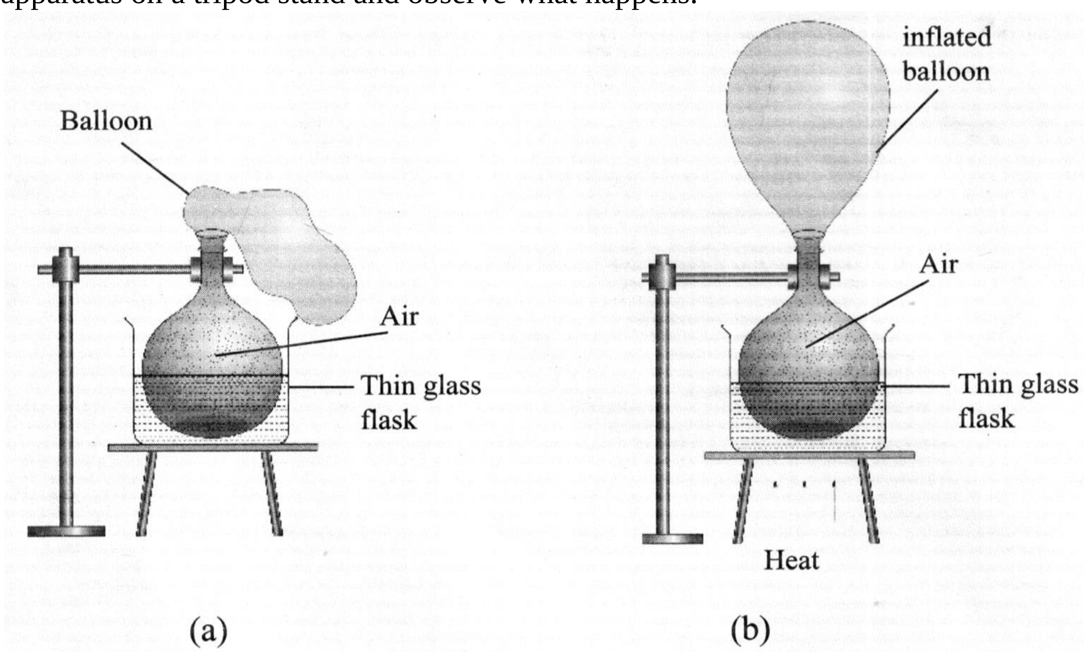
Liquid molecules are loosely packed and move freely. The force of attraction between their molecules is weaker than in solids. On heating, the speed of the molecules increases. The collisions between the molecules increase the distance between them causing the liquid to expand i.e. increase its volume.

C. THERMAL EXPANSION AND CONTRACTION OF GASES

Gases expand on heating and contract on cooling. Gases expand more than liquids and solids because their molecules move furthest on heating.

DEMONSTRATION OF THERMAL EXPANSION OF GASES

A balloon is tied on the mouth of a thin glass flask and immersed in a water bath. Heat the apparatus on a tripod stand and observe what happens.



On heating, the balloon is inflated hence bulges. On heating, the air in the thin glass flask expands, increasing volume in the flask and in the balloon hence inflating the balloon. Gases expand on heating and contract on cooling.

EXPLAINING THERMAL EXPANSION IN GASES

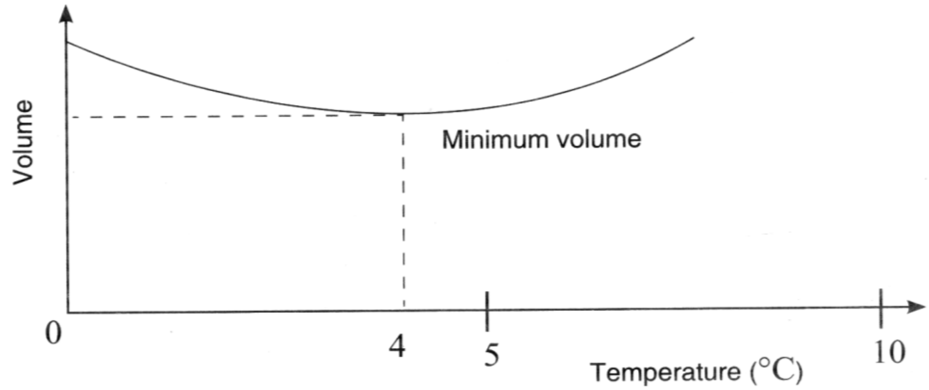
The intermolecular distances in gases are large compared to those in solids and liquids. The forces of attraction between the molecules of a gas are very weak hence the molecules move freely in all directions. When a gas is warmed, the molecules gain more kinetic energy and move far apart hence its volume increases.

Same quantities of different gases expand by the same amount when heated equally and under the same pressure

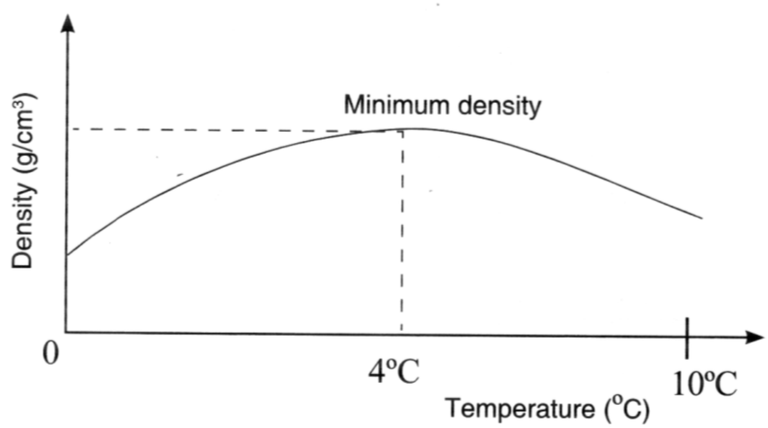
ANOMALOUS EXPANSION OF WATER

Most liquids expand steadily on heating. Water behaves in an unusual manner in the sense that when heated at 0^oC, its volume decreases (contract) as temperature rises from 0^oC to 4^oC, water expands. Beyond 4^oC, water expands like other liquids. This unusual (abnormal) behaviour of water when it is heated from $0^oC$to 4^oC is referred to as anomalous (abnormal) expansion of water.

Thus a fixed mass of water has a minimum volume at 4°C. figure shows a graph of volume against the temperature of water.



From the graph, the volume of a fixed mass of water is minimum at 4°C. at this temperature, the density of water is maximum.
Figure below shows a graph of density against temperature of water.



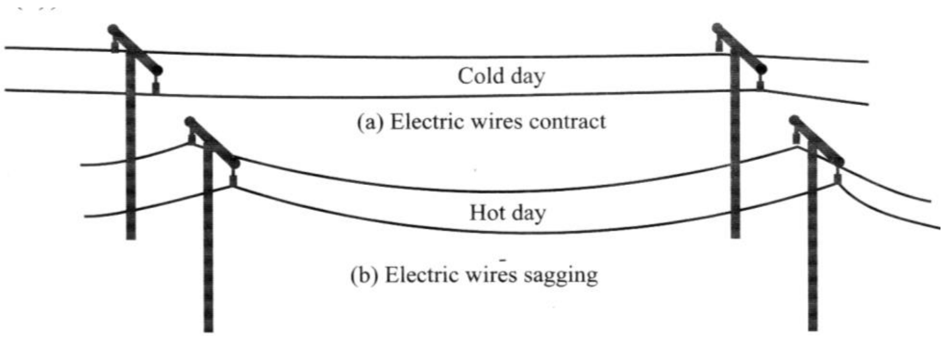
EFFECTS OF ANOMALOUS EXPANSION OF WATER

a. SURVIVAL OF AQUATIC ORGANISMS IN FREEZER OF LAKES AND PONDS.
As the temperature of air above the lake falls from 10°Cto 4°C, the density of water increases. This denser water at the top sinks to the bottom of the lake and remains there in liquid form. The water on the top freezes to ice at 0°C and floats. The fish and other aquatic animals and plants survives in the liquid water at 4°C below the ice during the cold weather.
b. BURSTING OF WATER PIPES
Water pipes can burst when water flowing through them cools from 4°C to 0°Cand freezes to ice. This is because on freezing, the volume of water increases.
c. WEATHERING OF ROCKS
When water freezes in the cracks of a rock, the volume of water increases on cooling from 4°C to 0°C. This causes the rock to break into small pieces resulting into weathering of rocks to form soil.

APPLICATION OF THERMAL EXPANSION

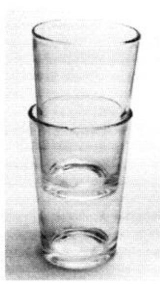
Thermal expansion and contraction, though on one hand is a nuisance, on the other hand is quite useful. The following are some applications of thermal expansion and contraction.

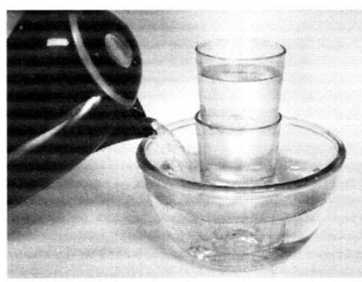
a. LOOSE FITTINGS OF ELECTRICAL CABLES
The electrical wires transmitting electricity on the national grid are loosely held. This gives room for expansion and contraction as weather changes.



This explains why the wires are seen to be sagging during hot days due to expansion and seen taut and straight on cold days due to contraction. If the wires were tightly held, they would break during cod days causing a lot of destruction.

b. SEPARATING STUCK TUMBLERS/GLASSES
Tumblers which are stuck together are easily separated by placing them upright in warm water and pouring very cold water in the inner tumbler. The outer tumbler will expand more than the inner one hence can be separated.


(a)

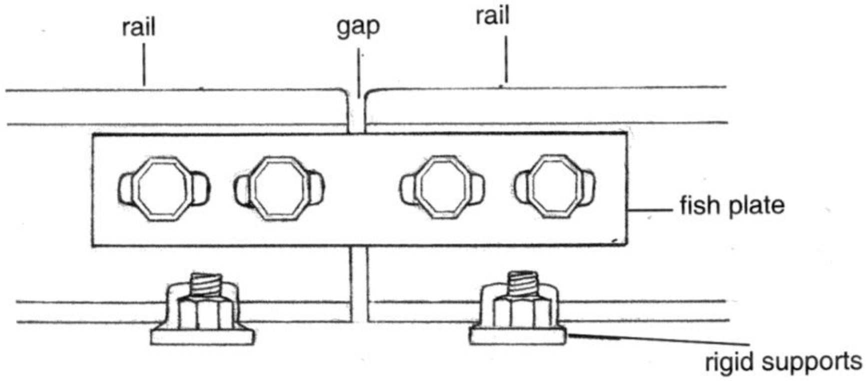

(b)

c. TOOTH FILLING
The material used to refill holes in the teeth must have the same co-efficient of thermal expansion as the tooth itself. This will make both the material and the tooth expand and contract uniformly.

d. REMOVING TIGHTLY SCREWED COVERS
Bottle tops and container lids are sometimes hard to open. To open them, place the bottle in cold water and heat or pour hot water on the cover/lid. The bottle contracts while the bottle top or cover expands making it easier to open the bottle top/lid.

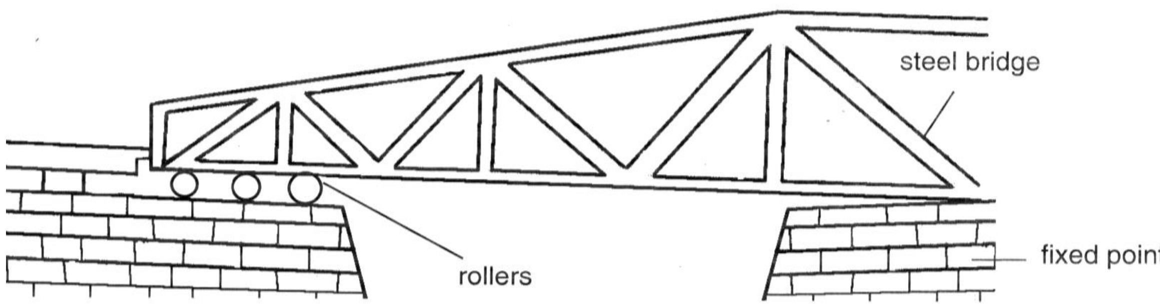
e. USE OF ALLOYS
The measuring tapes used by surveyors for measuring land are made of an alloy of iron and nickel (called invar). Invar has a very small change in length when temperature changes.

f. GAPS IN RAILWAY TRACKS
Gaps are left between the rails when railway tracks are laid. The rails joined together by fish plates bolted to rails. The oval shaped bolt holes allow the expansion and contraction of the rails when the temperature changes.

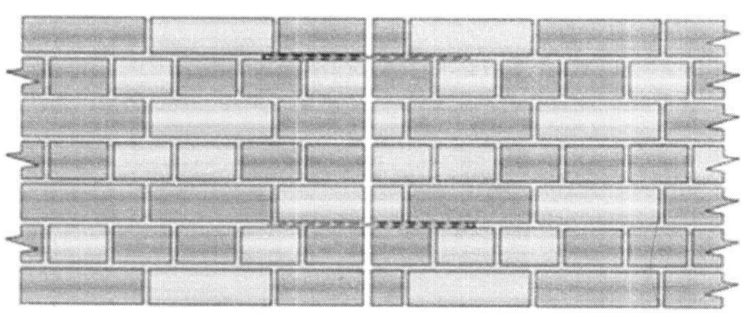


Invery hot weather, the gaps may not provide enough room for expansion if the expansion is large causing the rails to buckle out.

g. ROLLERS ON BRIDGES
The ends of steel and concrete bridges are supported on rollers. During hot or cold weather, the change in length of the steel bridge may take placefreely without damaging the structure.



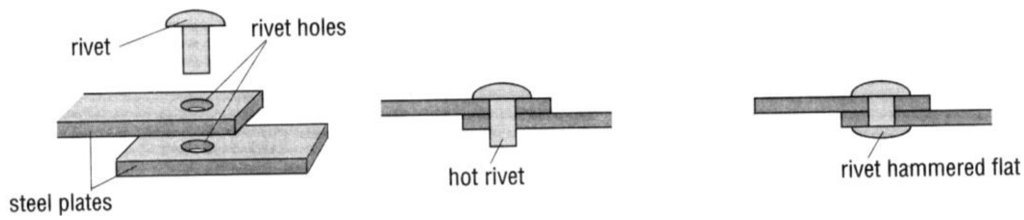
h. EXPANSION GAPS IN FENCES
Expansion joint/gaps are usually created in walls to allow room for expansion of the bricks or blocks. They breakthe wall into segments toprevent caracking caused by changes in temperature, moisture expansion, elastic deformation, settlement and creep. The joints may be horizontal or vertical. They are formed by leaving a continuous opening between the bricks. The opening may be fiiled with highly compressible material that allows the joint to partially close as the brick layers expand.



i. SHRINK FITTING
Shrink fiiting is a method used to make mechanical joints when tubes or axles to be fitted inside other hollow tubes or parts. The hole or the hollow space is made slightly narrower than the tube or axle to be fitted in it. The hollow tube or part is heated to expand and while still hot the axle or the other tube is fitted. The joint is then left to cool. On cooling, the

initially hollow part contracts (shrinks) and makes a very tight grip of the tube or axle fitted in it. It becomes impossible to separate the two parts without heating.

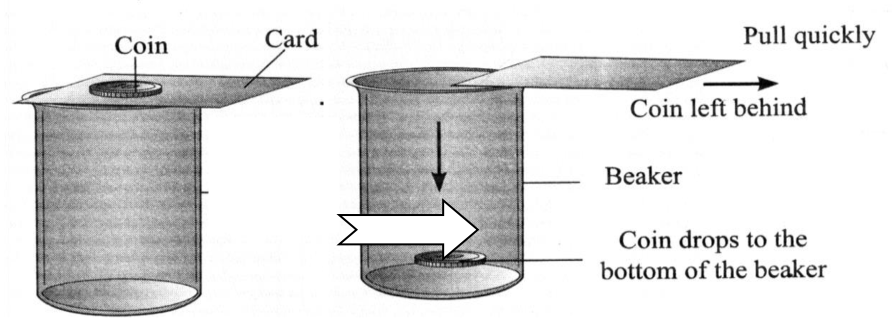
Shrink fitting is also applied to enhance the joining of metal plates using rivets.
Hot revet are placed in th rivet holes and their ends hammered when still hot. On cooling the force of contraction pulls the plates firmly together.



Chapter 2
NEWTON'S LAWS OF MOTION

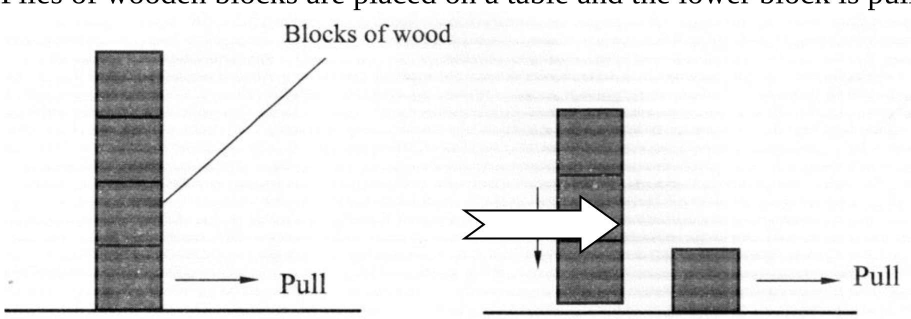
A. FIRST LAW OF MOTION (LAW OF INERTIA)
This law states that a body cotinues in its state of rest or uniform motion in a straight line unless compelled by some external force toact otherwise.
This law defines force as that quantity which produces motion of a body at rest or that which alters its existing state of motion.
Inertia (laziness in Latin) is the reluctance of a body to change its state of motion i.e. either to remain at rest or to continue moving .

DEMONSTRATION OF INERTIA ON A COIN ON A CARDBOARD
A coin is placed on smooth carboard placed over a beaker. Push/pull the cardboard away suddenly.



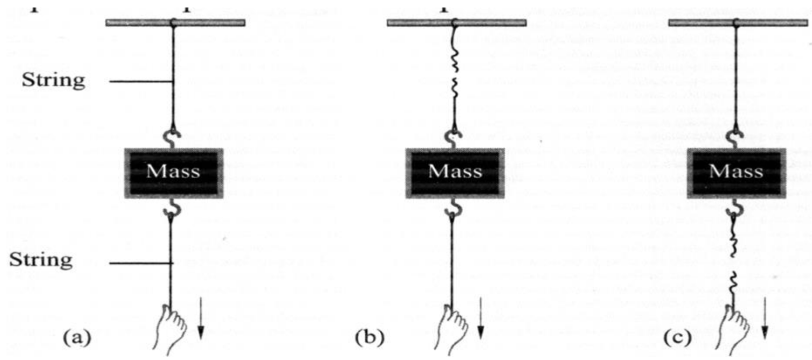
Whem the card is moved suddenly the coin resist motion and does not move with the card and hence drops vertically into the beaker because it lacks support.

DEMONSTRATION OF INERTIA ON BLOCKS OF WOOD
Piles of wooden blocks are placed on a table and the lower block is pulled suddenly.



The lower block moves leaving the other blocks at the same position and settles down excactly on where the lower block was.

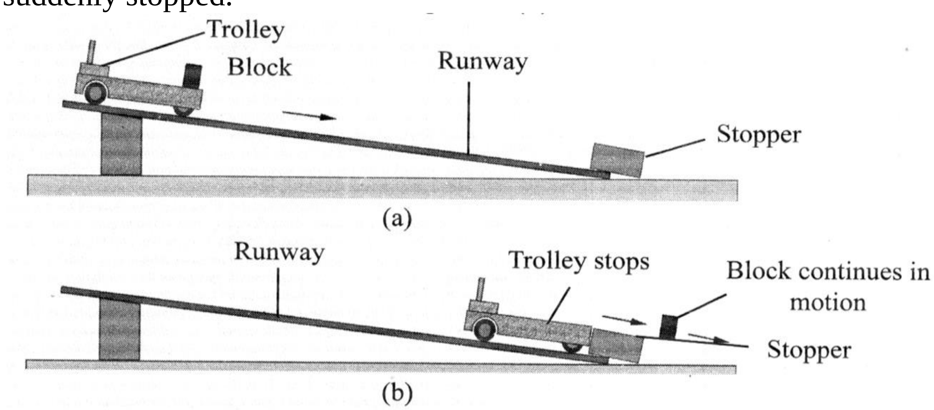
DEMONSTRATION OF INERTIA ON STRINGS SUPPORTING LOAD
A mass is hang on a string and another string attached to the lower part of the mass is pulled slowly/suddenly.



When pulled slowly, the upper string breaks but when pulled suddenly the lower string breaks. From these experiments one can conclude that a body tends to remain in its state of rst unless acted upon by an external force. A body at rest has a reluctance to move.

DEMONSTRATION TO SHOW BODIES CONTINUE THEIR STATE OF MOTION UNLESS ACTED BY AN EXTERNAL FORCE

A wooden block is placed on a trolley and the trolley moves down a runway. The trolley is suddenly stopped.



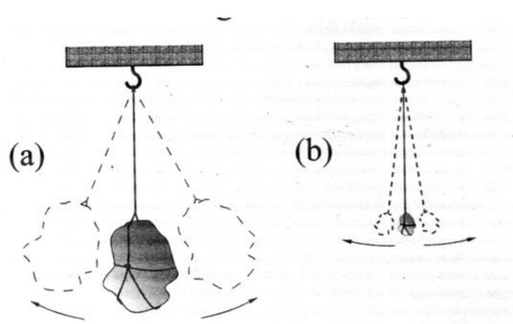
The wooden block slides of the trolley and continues moving in the same direction the trolley was moving i.e. the wooden block is reluctant to stop moving.

MASS AND INERTIA

Mass is the amount of matter in a substance while inertia is the reluctance of a body to change its state of motion.

INVESTIGATING RELATIONSHIP BETWEEN MASS AND INERTIA

Heavy stone and a light stones are suspended using strings as shown in the diagram. The stones are pushed to one side and released to swing and thentry to stop from swinging.



The lighter stone is easier to start moving and to stop moving. The heavier stone is more difficult to start or stop moving i.e. it requires a larger force. This shows that mass of a body is a measure of its inertia i.e. a body with a large mass has a large inertia than that with a small mass.

MOMENTUM

Momentum of an object is the product of mass and velocity of the object.

P = mass (m) x velocity (v)

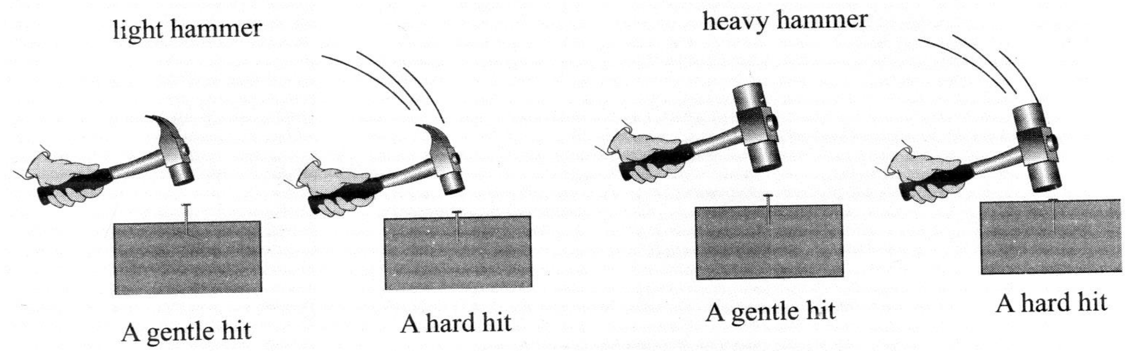
= m x v

Momentum is a quantity involving both motion and mass of the body.

Example

When one drives a nail into the wood, a certain rate of motion (velocity) and mass of the hammer are required.

A hard hit using a heavy hammer drives the nail deepest into the wood.



The SI unit of momentum is kgm/s. momentum is a vector quantity as the direction of the momentum is the same as that of the velocity.

Example 1

A car of mass 600kg moves with a velocity of 40m/s. calculate the momentum of the car.

Solution

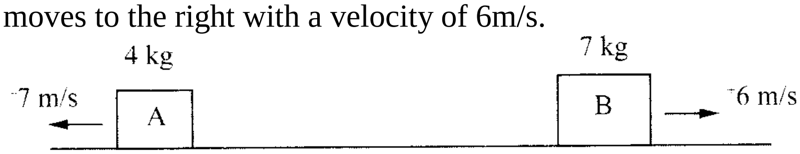
Momentum = mass x velocity

= 600kg x 40m/s

= ***<u>24,000kgm/s</u>*** in the direction of velocity

Example 2

A body A of a mass 4kg moves to the left with a velocity of 7m/s. another body B of mass 7kg moves to the right with a velocity of 6m/s.



Calculate

a. The momentum of A
b. The momentum of B
c. The total momentum of A and B

Solution

a. Momentum of A = 4kg x 7m/s = 28kgm/s
b. Momentum of B = 7kg x 6m/s = 42kgm/s
c. Total momentum = momentum of A + momentum of B

   Negative for motion to the left and positive for motion to the right.

   = - 28kgm/s + 42kgm/s

   <u>= 14kgm/s</u>

IMPULSE

Impulse is the product of force and time.

Impulse = force (F) x time (t)

= Ft

SI unit of impulse is the Newton-second (Ns). When a force (F) acts on an object for a short time (t) it produces an impact called impulse on the object.
When an impulsive force acts on an object it produces a change in momentum of that object. The velocity of that object changes from initial value (u) to final value (v) but its mass (m) remains constant.
Impulse acting on the body is equal to the change in momentum it produces on the body.

Impulse = change in momentum

$$Ft = mv - mu$$

Example 1
A hammer strikes a metal rod with a force of 20N. if the impact lasts 0.4s, calculate the impulse due to this force.

Impulse = force x time
= 20N x 0.4s
= 8Ns

B. NEWTON'S SECOND LAW OF MOTION
This law states that the rate of change of momentum is directly proportional to the resultant force and it takes place in the direction in which the force acts.
Mathematically

$$\text{Force (F)} \ \alpha \ \frac{change\ in\ momentum}{time\ taken}$$

$$\text{Force (F)} \ \alpha \frac{final\ momentum - initial\ momentum}{time\ taken}$$

If 'm' is mass of the body and taking "u" and "v" to represent initial and final velocities respectively;

Final momentum = mass x final velocity (mv)
Initial momentum = mass x initial velocity (mu)
Change in momentum = final momentum – initial momentum
= mv – mu

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

$$= m\left(\frac{v-u}{t}\right)$$

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

Thus F α ma
Therefore F = ma which shows that the greater the force applied on an object the more acceleration it causes on the object.
Newton can therefore be defined as a force which when it acts on a mass of 1kg, it gives an acceleration of $1m/s^2$.

Example 1
A truck of mass 2.5 tonnes accelerates at $7.5m/s^2$. Calculate the force generated by the truck's engine to attain this acceleration.
Solution

F = ma
= 2.5 x 1000kg x $7.5m/s^2$
= 18 750N

Example 2

An object of mass 4kg accelerates to $5m/s^2$. Calculate the resultant force .

Solution

$$F = ma$$
$$= 4kg \times 5m/s^2$$
$$\underline{\boldsymbol{= 20N}}$$

Example 3

Calculate the acceleration produced by a force of 20N on an object of mass 300kg.

Solution

$$F = ma$$

$$a = \frac{F}{m} = \frac{20N}{300kg}$$
$$= 0.0667m/^2.$$

Example 4

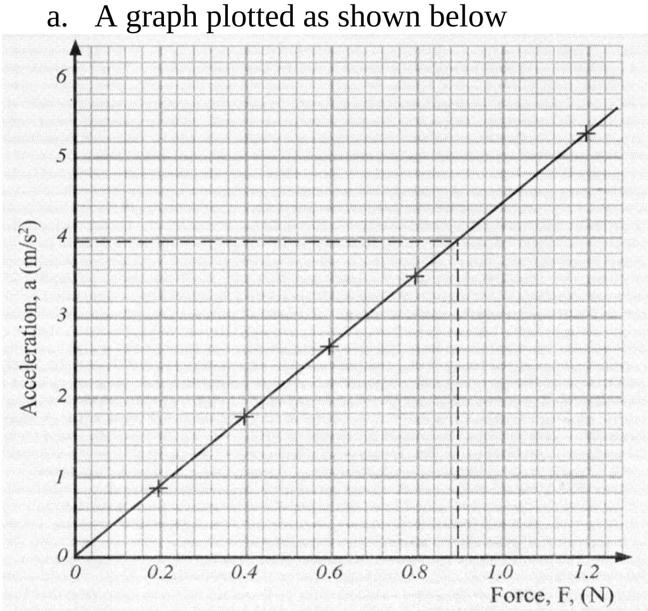
Table shows the values of force (F) and the acceleration (a) for the motion of a trolley on a runway.

Force (N)	0.2	0.4	0.6	0.8	1.2
Acceleration (m/s^2)	0.90	1.8	2.7	3.5	5.3

a. Plot a graph of acceleration force (F)
b. Use your graph to determine the force when the acceleration is $4.0m/s^2$
c. Calculate the mass of the trolley, in grams, from your answer in (b)

Solution

a. A graph plotted as shown below



Graph of acceleration against force

b. By extrapolation, force, F = 0.9N, when acceleration a = $4.0m/s^2$.
c. Since F = ma, $m = \frac{F}{a}$

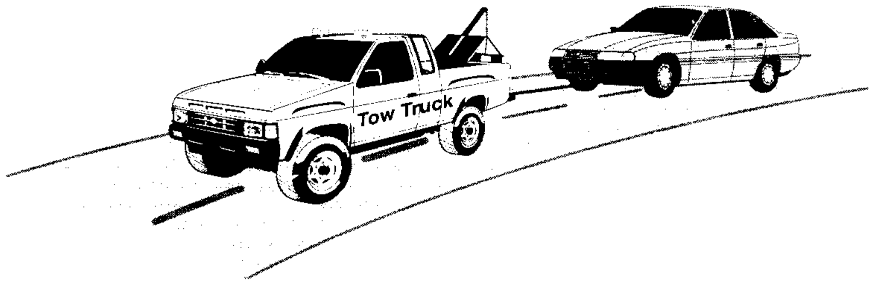
$$= \frac{0.9N}{4.0m/s^2}$$

= 0.225kg x 1000g/kg

= 225g

Example 5

A car of mass 900kg is towed by a breakdown truck along a level road. They accelerates at $0.6m/s^2$. Calculate the tension in the rope.



Solution

Tension = resultant force using acceleration

Resultant force (F) = ma

$= 900kg \times 0.6m/s^2$

=540N

Tension ***= 540N***

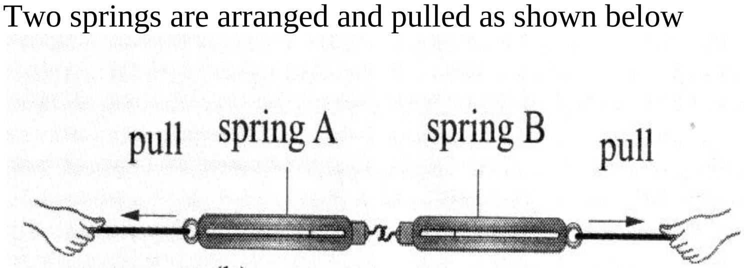
C. NEWTON'S THIRD LAW OF MOTION

It states that whenever a body exerts a force on another body, the other body exerts an equal but opposite force on the first body.

It states that to every action there is an equal and opposite reaction.

DEMONSTRATION OF ACTION REACTION FORCES USING TWO SPRINGS

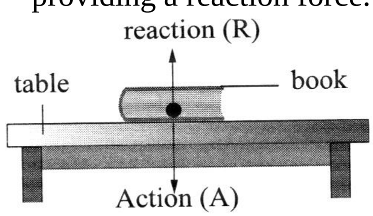
Two springs are arranged and pulled as shown below



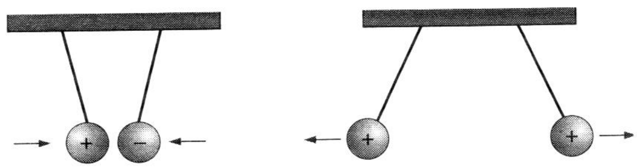
When two springs were pulled they had the same reading. The reading in spring B is the same as in spring A. the two forces are equal in size but are in opposite direction.

EXAMPLES OF ACTION REACTION FORCES

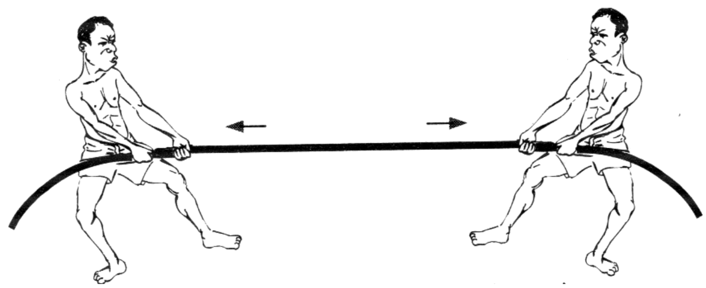
a. When one pushes a rigid wall (exert action), the wall pushes back (exerts a reaction).
b. A book placed on a table provides the action, while the table supports the book by providing a reaction force.



c. Charged bodies show two equal but opposite forces.



d. Tug of war



SOME COMMON EXPERIENCES DUE TO NEWTON'S THIRD LAW OF MOTION

a. When running or walking a person exerts a backward force on the ground. The ground exerts a forward push on the person making walking possible.
b. When a gun is fired, the bullet travels in one direction while the gun recoils backwards. Although the two forces are equal and opposite, the bullet's velocity is greater than that of the gun

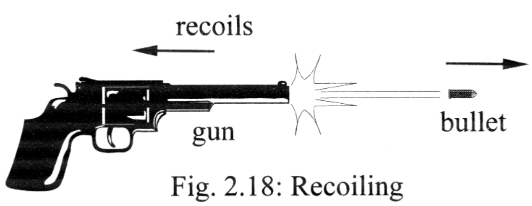
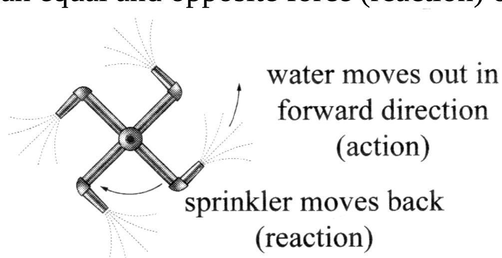


Fig. 2.18: Recoiling

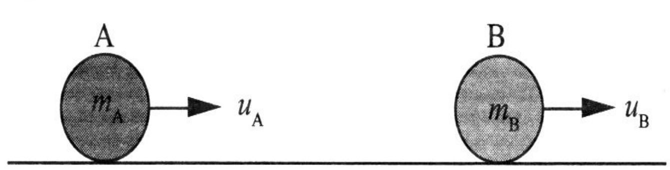
c. A balloon will always move in the opposite direction when the air inside it is released i.e. a principle that rockets and jet engines use. The force (action) of the air coming out exerts an equal and opposite force (reaction) on the balloon making it move.



d. The water sprinkler works on action and reaction principle. The sprinkler rotates in the direction opposite to that of the water jet.

CONSERVATION OF LINEAR MOMENTUM

Two objects A and B of masses m_A and m_B are moving in the same direction with different velocities



On collision, A pushes B with a force F_A and B reacts by pushing A with an equal and opposite force F_B

i.e. $F_A = F_B$

Since time spent in colliding is the same, A experiences an impulse F_Bt from B while B also experience an impulse F_At from A.

Therefore, $F_Bt = F_At$

Impulse = change in momentum = mv - mu

Total momentum before collision = total momentum after collision

Letting the final velocities of A and B be v_A and v_B respectively

Then, $-F_Bt = m_Av_A - m_Au_A$ ……(ii)

$F_At = m_Bv_B - m_Bu_B$……(iii)

Equating (ii) and (iii)

$$-(m_Av_A - m_Au_A) = m_Bv_B - m_Bu_B$$

$$-m_Av_A + m_Au_A = m_Bv_B - m_Bu_B$$

$$m_Au_A + m_Bu_B = m_Av_A + m_Bv_B$$

But $m_Au_A + m_Bu_B$ = total momentum before collision

and $m_Av_A + m_Bv_B$ = total momentum after collision

The momentum has been conserved.

The law of conservation of momentum states that two or more bodies collide, their total momentum remains constant provided no external forces are acting.

COLLISIONS

Collision occurs when one object strikes another. It is an event when two or more bodies exert forces on each other

TYPES OF COLLISIONS

Two types of collisions are:

a. Elastic collisions
b. Inelastic collisions

A. ELASTIC COLLISIONS

The collision is elastic when the total kinetic energy is conserved after collision i.e. total kinetic energy of the bodies before collision is equal to the total kinetic energy of the bodies after the collision.This is possible only within atoms. Collision between two smooth marble balls is elastic. If no other forces are acting, the total momentum and the total energy before and after collisions are found to be the same.

These types of collisions are not common because in every collision, some energy is always converted to other forms.

Example

Cannon of mass 800kg fired a cannon ball of mass 3kg at a velocity of 120m/s. find the recoil velocity of the cannon.

Solution

m_1 = 3kg, u = 0m/s, v_1 = 120m/s, m_2 = 800kg, u_2 = 0m/s, v_2= ? (to be found)

$m_1u_1 + m_2u_2 = m_1v_1 + m_2 + v_2$

$3 \times 0 + 800 \times 0 = 3 \times 120 + 800 \times v_2$

$0 = 360 + 800v_2$

$-800v_2 = 360$

$V_2 = -\frac{360}{800}$m/s

= - 0.45m/s

The cannon recoiled backwards at a velocity of o.45m/s. the negative value in the velocity shows that the cannon moved (recoiled) in the opposite direction.

B. INELASTIC COLLISION

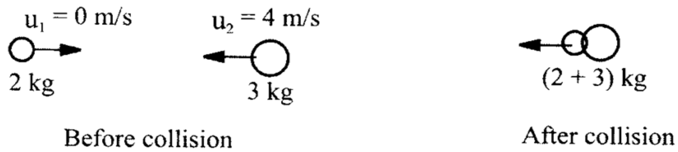
Inelastic collisions are thosecollisions where total energy is not conserved after collision. Some energy is converted into sound and heat.

A completely inelastic collision is the one in which two bodies stick together after collisions.

Example 1

A mass of 3kg moving with a velocity of 4m/s collides with another mass of 2kg which is stationary. After collision the two masses stick together. Calculate the common velocity for the two masses.

Solution



Momentum before collision $= m_1u_1 + m_2u_2 = (2 \times 0) + (3 \times 4)$

$= 12$ kgm/s

Momentum after collision $= (m_1 + m_2)v = (3 + 2)v = 5v$

Momentum before collision = momentum after collision

12 kgm/s = 5v

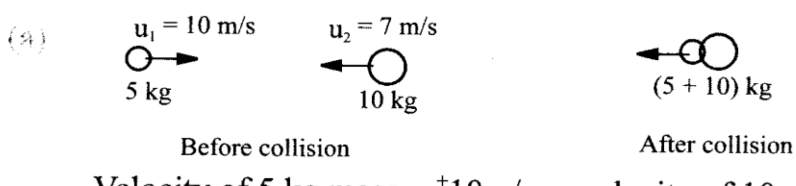
$\therefore$ Common velocity, v = 2.4 m/s

Example 2

A mass of 5kg moving with a velocity of 10m/s collides with a 10kg mass moving with a velocity of 7.0m/s along the same line. If the two masses join together on impact, find their common velocity if they were moving.

a. In opposite direction
b. In the same direction

Solution



Velocity of 5 kg mass = $^+$10m/s ; velocity of 10 mass = -7 m/s

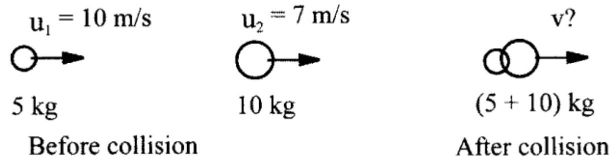
Momentum before collision = momentum after collision

$(5 \times 10) + (10 \times -7) = (5 + 10)$ v

$50 + (-70) = 15$v

v $= -1.33$ m/s

The minus sign means that the joined mass moves to the left.



Momentum before collision = momentum after collision

$$(5 \times 10) + (10 \times 7) = 15 \times v$$

$$50 + 70 = 15\ v$$

$$v = +8.0 \text{ m/s}$$

The plus sign means that the joined mass move to the right.

Chapter 3

FRICTIONAL FORCE

Friction is the force that opposes the relative motion of two surfaces that are in contact. Two factors that affect friction between two surfaces are the nature of the surfaces and the normal reaction (R)

COEFFICIENCT OF SOLID FRICTION

When a solid is being pulled over a horizontal surface by an applied force, F, frictional force (F) acts in the opposite direction to oppose the movement of the block.

When the block is just about to move, the solid friction is called static friction.

Static friction is the force opposing motion between surfaces when the surfaces are just about to move.

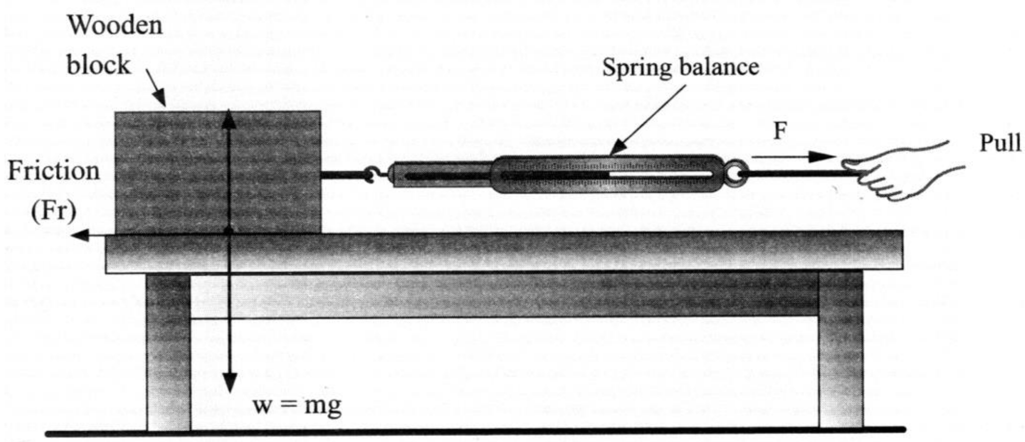
When the block is moving, friction force is reduced and is called dynamic friction.

Dynamic friction is the force opposing to the motion when there is relative motion

RELATIONSHIP BETWEEN FRICTIONAL FORCE AND NORMAL REACTION

HOW TO ESTABLISH THERELATIONSHIP BETWEEN FRICTIONAL FORCE AND NORMAL REACTION

An apparatus is set up as shown



The spring balance is pulled until the block is just about to move and record the reading on the spring balance.

Note that the spring balance reads the value of frictional force which is acting in the opposite direction

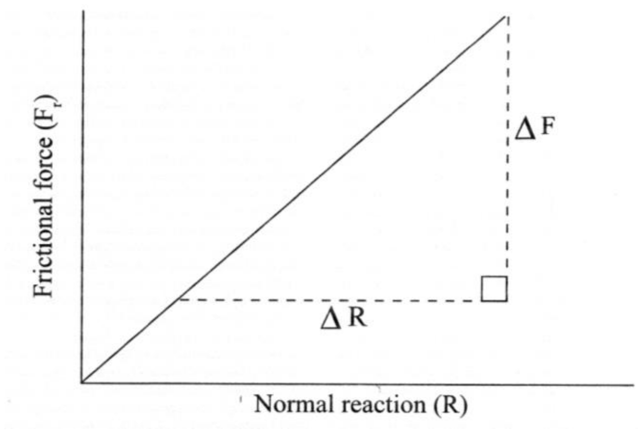
F is the frictional force between the surfaces

Frictional force = applied force F

The experiment is repeated using masses of 50g, 100g, 150g and 200g instead of the wooden block. The reading on the spring balance is recorded in each case.

It can be observed that the readings on the spring balance increase with increase of the mass.

When a graph of F against reaction (R) is plotted, a straight line that is passing through the origin is obtained.



The gradient of the line gives

$$\text{Gradient} = \frac{change\ of\ F}{change\ in\ N} = \frac{\Delta F}{\Delta R}$$

From the graph it can be concluded that frictional force in solid is direclty proportional to the weight of the solid

$$F \propto W$$

From Newton's third law of motion;
Weight (W) of an object placed on the bench is equal and opposite to the normal reaction (R) between the surface of the bench and the block in contact.

Frictional force, $F \propto W$

Therefore, $F \propto$ Normal reaction (R)

$F = \mu_s R$, where μ_s is a constant called the coefficient of static friction.

The coefficient of static friction μ_s, is the ratio of static frictional force to thre normal reaction R

$$\mu_s = \frac{F}{R}$$

Coefficient of static friction, μ_s has no units since it is the ratio of forces.
One has to apply a force largerthan the limiting static frictional force (F) for a body to move.
When a body is sliding along a bench with a constant velocity, the frictional force is now called kinetic or dynamic friction (F) and it is calculated as

$$F_k = \mu_k R$$

Where R is the normal force and μ_k is the coefficient of kinetic friction.

Example 1

A force of 25N limits the motion of a block of mass 50kg which is being dragged on the horizontal ground. Calculate the coefficient of static friction force.

Solution

$F_s = \mu_s R$ where μ_s is the coefficient of static friction

Weight of the block = Normal force = 50 kg × 10 N/kg = 500 N

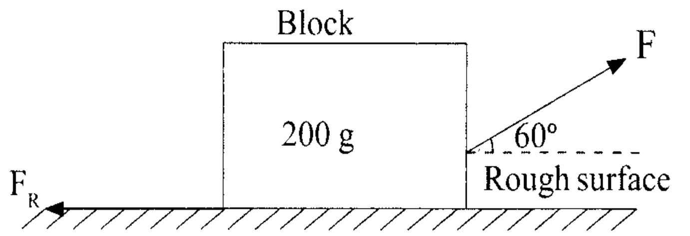
$$\therefore \quad 25 = \mu_s \times 500$$

$$\mu = \frac{25}{500} = 0.05$$

$$\mu_s = 0.05$$

Example 2

Figure shows a block of mass 200kg being dragged at a constant velocity with a force of 40N at an angle 60^o to the horizontal.



Determine the coefficient of the kinetic friction (μ_k)

Solution

$F = \mu_k R$

Since F is acting at an angle, we find its horizontal component.

$F_H = F\cos\theta$

$= 40 \times \cos 60 = 40 \times 0.5 = 20$ N

Substituting this in, $F = \mu_k R$, we get:

$$20 \text{ N} = \mu_k \times 200 \text{ kg} \times 10 \text{ N/kg}$$

$$\mu_k = \frac{20}{2000} = 0.01$$

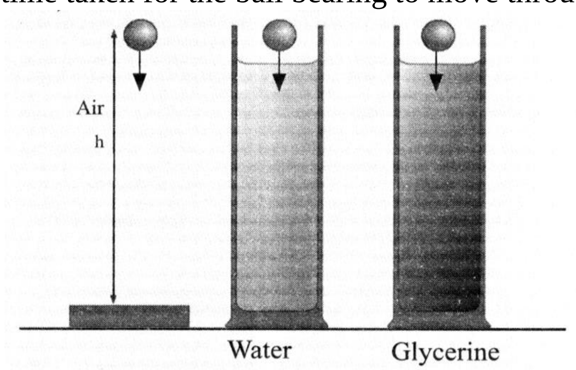
The coefficient of kinetic friction is 0.01

FRICTION IN FLUIDS
VISCOSITY

Fluids particles offer opposition to the motion of a body through the fluid.

HOW TO SHOW THAT FLUIDS OFFER RESISTANCE TO MOTION OF OBJECTS THROUGH THEM

Identical ball bearings are allowed to fall through a certain height in air, water and glycerine. The time taken for the ball bearing to move through this heigh, h.



Time taken by the ball bearing to fall in air is shorter than time ittakes to fall in water. The time taken for the ball to fall in water is shorter than in glycerine.

The experiment shows that liquids offer resistance to the movement of objects in them. The resistance differs from fluid to fluid.

Frictional force in liquids is due to the viscosity of the liquid.

Viscosity is the measure of how easily a fluid flows.

If fricttional force is comparatively low, as in water, the viscosity of the liquid is low. If frictional force is large as in glycerine, the viscosity of the liquid is high.

Air has very low visosity

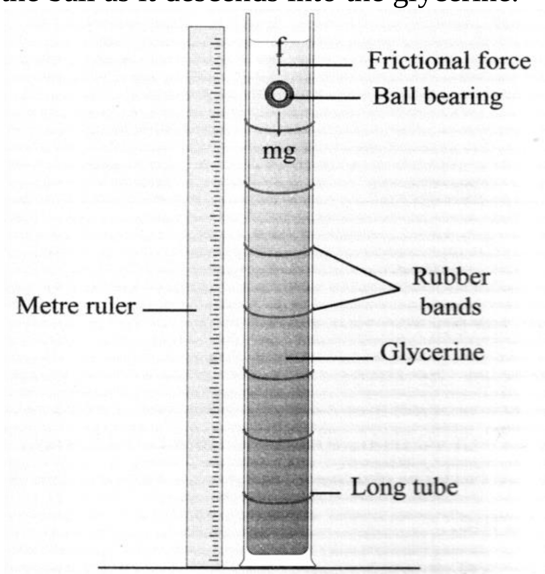
Resistance due to fluids is called viscous drag.

TERMINAL VELOCITY

HOW TO DETERMINE TERMINAL VELOCITY

Rubber bands are fixed along a long tube at equal distances. A small steel ball bearing isdropped into the long tube containing glycerine.

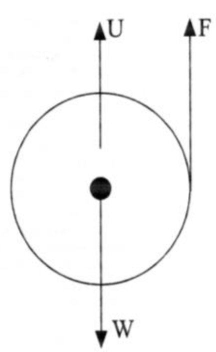
Time taken by the ball to move through the equal intervals is taken and determine the velocity of the ball as it descends into the glycerine.



It can be observed that the velocity of the ball starts from zero and accelerates to a maximum value and then remains constant at this value, as the ball continues falling.

When a body is falling in a fluid, three forces act on it. These forces are

a. Weight of the body (W)
b. The upthrust (U)
c. Viscous drag (fluid friction F)



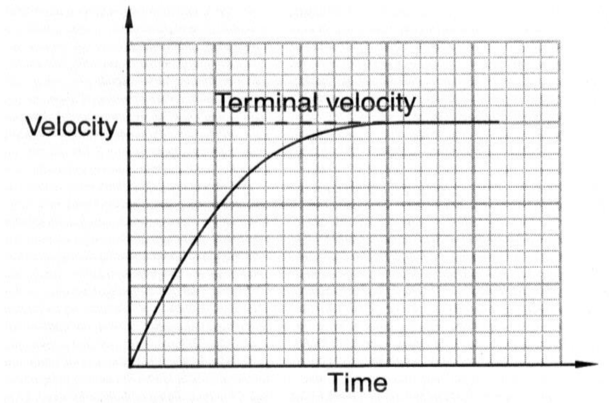
The fluid friction increases with increase in speed of the falling body.

Initially, W > (U + F) hence the body accelerates downwards.

As fluid friction (F) increases, it reaches a point where U = F = W. there being no resultant force, the body moves at uniform (constant)velocity called terminal velocity.(V_t)

Terminal velocity is the mximum downward velocity possible for a particular object falling through a fluid.

If the velocity of an object is plotted againsttime, the following graph is obtained.



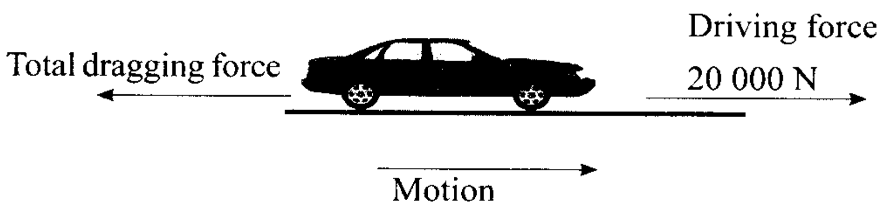
AIR RESISTANCE

Air offers resistance to movement e.g. when one is running he experiences backward pushing by air. Air resistance (air friction) is friction opposing a moving body in air. It is a form of dynamic friction.

Moving objects waste a lot of energy in overcoming air resistance e.g. a moving vehicle results in high fuel consumption. To reduce air resistance, bodies of cars and planes are streamlined i.e. they have smoothened, rounded and pointed bodies.

Example

A car of mass 1000kg is travelling under the action of forces as shown.



a. State the size of the drag force when the car is travelling at a constant speed.
b. If the car accelerates at $5m/s^2$, work out the total dragging force
c. The car continues accelerating at $5m/s^2$ but eventually reaches a constant speed. Explain.

(a) At constant speed, Resultant force = 0 N.

$\therefore$ Total dragging force = Driving force = 20 000N

(b) According to Newton's second law,

Resultannt force = mass × acceleration

Driving force – total drag force = ma

$$20\ 000 - F = 1\ 000\ kg \times 5\ m/s^2$$

$$F = 20\ 000\ N - 5000\ N$$

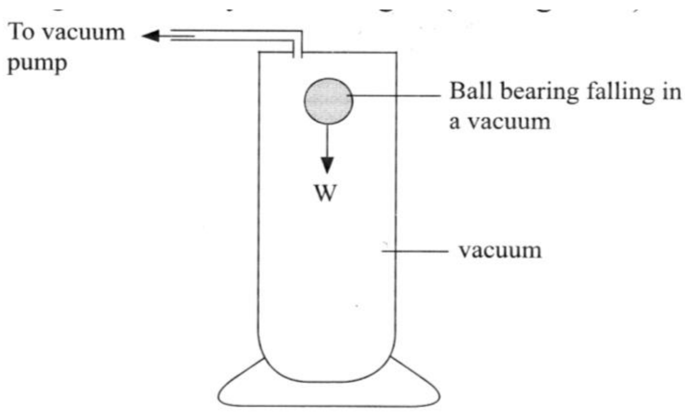
$$= 15\ 000\ N$$

(c) As the speed of the car increases, air resistance increases. At some point the total drag equals the highest driving force, hence the car cannot accelerate any further.

FALLING IN VACUUM

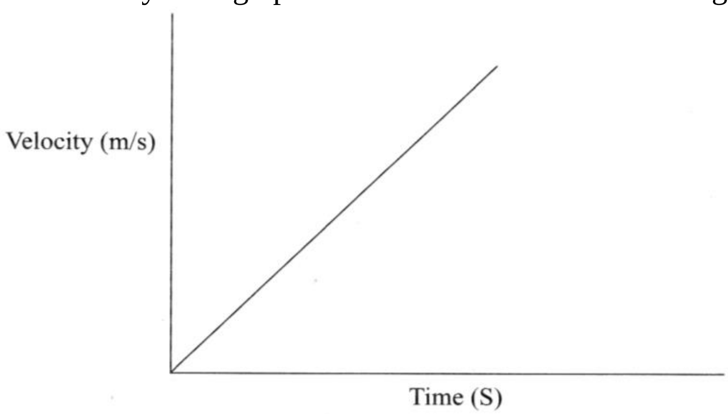
An object falling in a vacuum does not experience air resistance and upthrust force opposing its motion.

The body accelerates downwards due to its weight i.e. accelerates due to gravity . the only force acting on the body is its own weight



Since weight is the only force acting on the ball bearing, the acceleration of the ball bearing is equal to the acceleration dueto gravity i.e. a = g.

The velocity-time graph of the motion of the ball bearing is a straight line as shown below



APLICATIONS OF FRICTION FORCE

a. The brakes in a car use pads made of material that offer a lot of friction.
b. The friction between the soles of shoes andtyres of cars provides a grip on the ground
c. The conveyor belts in factories do ot slip because of friction between them.
d. Nails are able to hold the pieces of wood.
e. Writing on paper, chalkboard etc utilises friction.

DISADVANTAGES OF FRICTION

As parts rub against each other in machines, they tear and wear.

To reduce friction lubricants such as oil and ball bearings between the parts are used in machines.

Chapter 4

HOOKE'S LAW

EFFECTS OF FORCES ON BODIES

A force causes changes in motion, change in shape, size and direction. Forces may cause stretching and compressing effects on some materials. The stretching of materials when forces are applied is important for engineers to determine the strength of the materials to be used for specific works.

When elastic materials e.g. rubber band are compressed by a force, their sizes reduce and when acted upon by tensional forces, their sizes increase i.e. they stretch.

STRETCHING OF MATERIALS

Robert Hooke performed different experiments on stretching of materials e.g.

- Stretching of spiral springs
- Stretching of wires
- Loading horizontal beams fixed at one end.

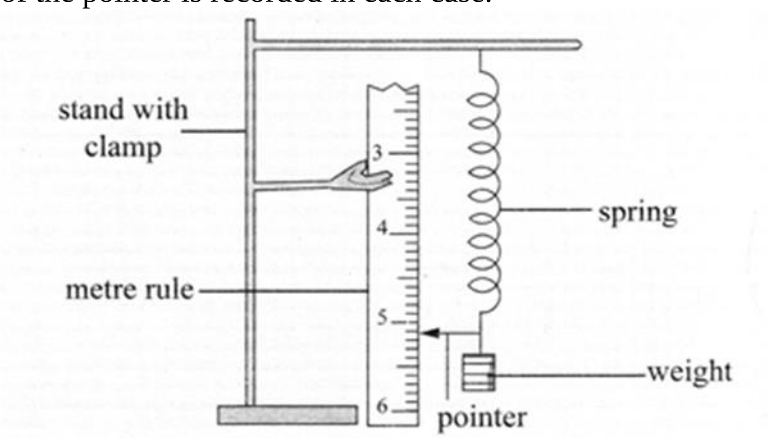
It was discovered from these experiments that there is a relationship between the applied force and the extension of the material used i.e. Hooke's Law.

INVESTIGATING RELATIONSHIP BETWEEN THE EXTENSION PRODUCED IN A SPRING AND THE FORCE APPLIED.

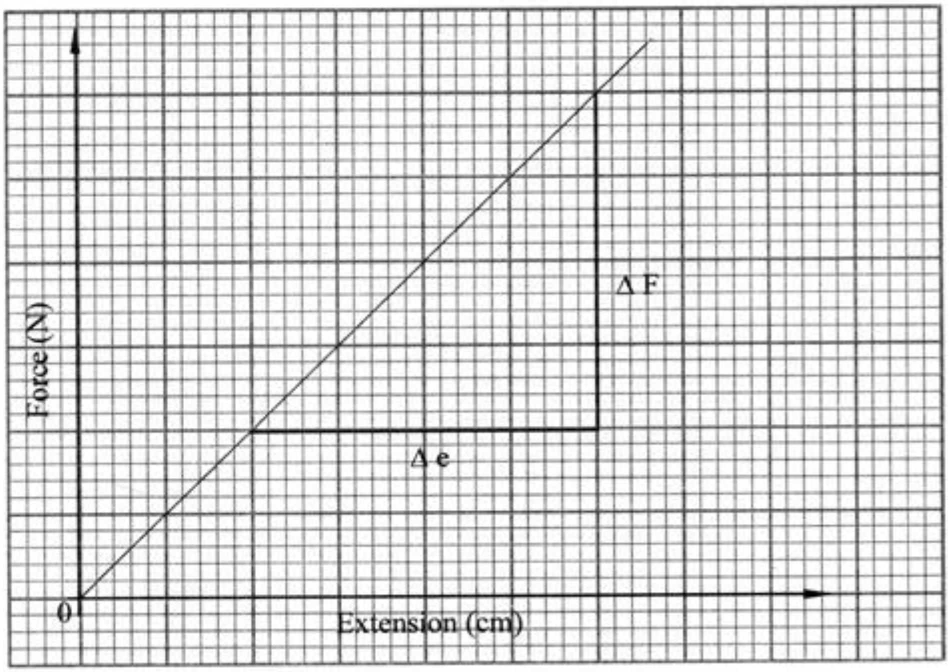
The apparatus is set up as shown in the figure and record the initial position of the pointer before the weight is loaded.

The spring is loaded with a 50g mass and the new position of the pointer is recorded.

The experiment is repeated with masses of 100g, 150g, 200g, 250g, 300g, 350g and the readings of the pointer is recorded in each case.



A graph of applied force against extension is produced as shown below



Force – extension graph

The graph of force against extension is a straight line graph passing through the origin. The $\frac{\Delta F}{\Delta e}$ gradient of a graph of force against extension.

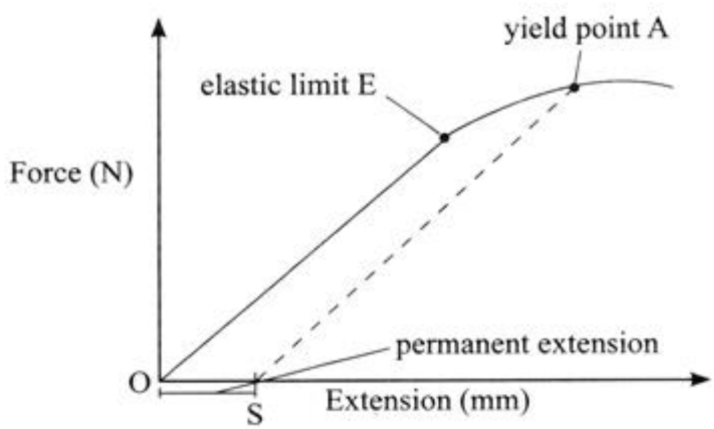
It can be seen from the graph that extension produced is directly proportional to the force applied.

Each time the spring is unloaded the pointer returns to its original position.

Materials that are able to recover their original shape and size after unloading are said to be elastic. If more weights are added to the spring in the experiment, a point is reached where the extension is ***no longer proportional to the applied force***. The point is called ***elastic limit i.e. point E.***

The pointer does not return to the original position when the load is removed once the elastic limit is exceeded; then the spring is said to have been permanently deformed i.e. acquires permanent extension.

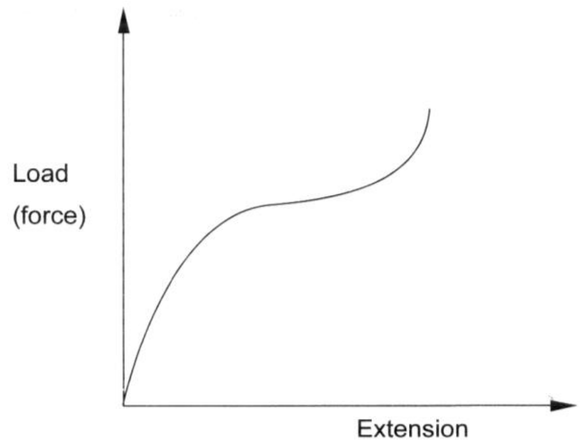
The figure shows a graph of force against extension after the spring has been permanently deformed.



The spring is said to undergo elastic deformation along OE. When a material is undergoing elastic deformation it is said to be obeying Hooke's law (shown by straight line OE)

The spring is said to undergo plastic deformation along EA i.e. Hooke's law is no longer obeyed (beyond point E).

If the weight are further added, a point is reached beyond which the material loses its elasticity and this point is called yield point i.e. point A.
If the experiment is repeated using a rubber band instead of a spring a graph as shown below is obtained. The graph is not a straight line showing that the rubber does not obey Hooke's law.



Hooke's law states that provided the elastic limit is not exceeded, the extension of the spring is directly proportional to the load applied on the spring.
Mathematically
The applied force, F, is directly proportional to the extension, e, i.e. $F \propto e$
Therefore

F = ke

Where k is a constant of proportionality called the spring constant.
Hence k = $\frac{F}{e}$.
The SI unit of the spring constant, k , is the newton/metre (N/m)

Example 1

A sack containing drugs and narcotic substances intercepted by the police was weighed on the spring balance and the spring balance stretched by 3cm. the owner was arrested and finally jailed after a court case. If the sack had a mass of 200g, calculate the spring constant of the spring balance.

Solution

F = ke
k = $\frac{F}{e}$
= $\frac{mg}{e}$
=(200 ÷ 1000) x 10
3÷100)
= ***66.7N/m***

Example 2
a long, slinky spring has a spring constant of k = 1.20N/m. if the spring is stretched 1.50m, what is the restoring force exerted by the spring?

Solution

F = ke
= 1.20N/m x 1.50m
= 2.4N

Example 3

A spring has a spring constant of 200N/m. if it is compressed by 0.06m, calculate the compressing force.

Solution

k = 200N/m, e = 0.06m

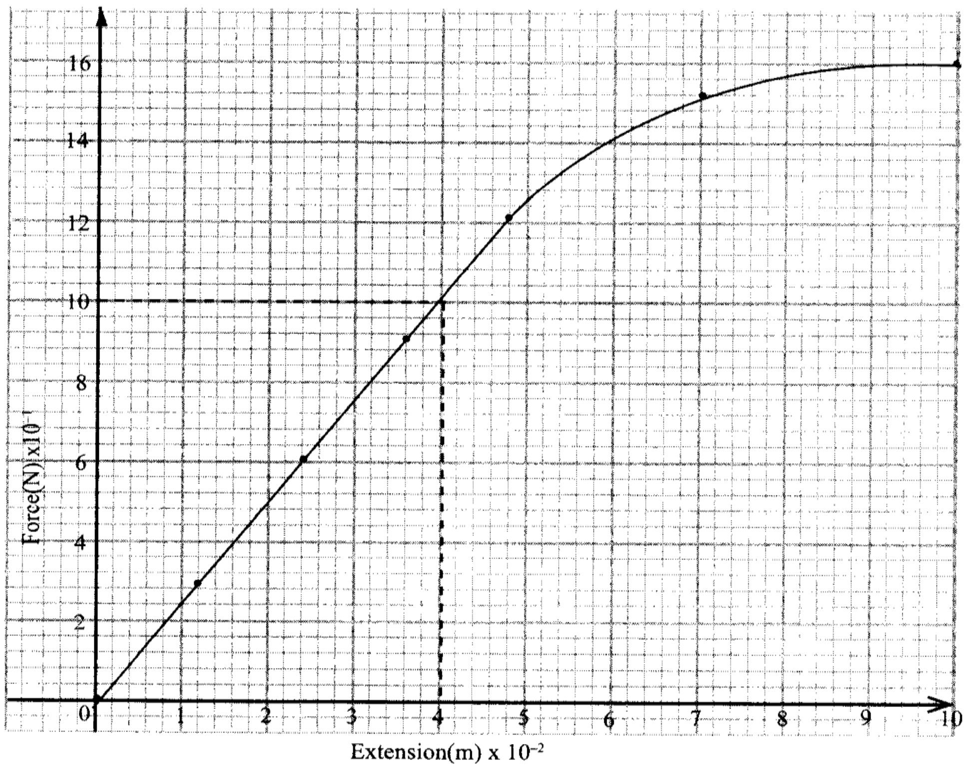
F = ke

= 200N/m x 0.06m

= 12N

Example 4

Figure is a graph of force against extension **drawn from an experiment to verify Hooke's law.**



a. Use the graph to determine the spring constant

Solution

From Hooke's law, k = $\frac{F}{e}$

Thus in a graph of F against e,

Spring constant = gradient of the graph

$= \frac{(10 - 0) \times 10^{-1}\text{N}}{(4 - 0) \times 10^{-2}\text{N}}$

= 25N/m

b. Use the graph to find the length of the spring when a mass of 0.05kg is hung from it.

Solution

Extension for 0.05kg = 2mm

Length of the spring = 80mm + (0.02 x 1000)

= 100mm

c. State with a reason whether or not Hooke's law is obeyed.

Solution

Hooke's law is obeyed up to 12N force because the graph is a straight line from the origin. It is not obeyed beyond 12N

Example 4

A force of 12N extends a spring by 8mm. Calculate the extension that is produced by the same spring if a force of 25N is hanged on it. (assume the elastic limit is not exceeded)

Solution

$$K = \frac{F}{e}$$
$$= \frac{12N}{8mm}$$
$$= 1.5\text{N/mm}$$

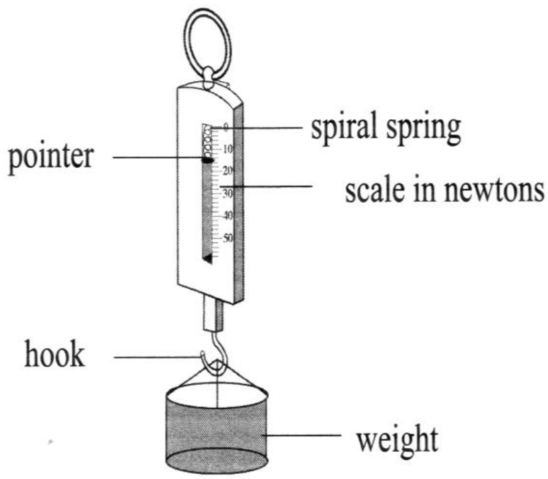
$$\text{Extension, } e = \frac{F}{k}$$
$$= \frac{25N}{1.5N/mm}$$

<u>= 16.67mm</u>

APPLICATIONS OF HOOKES LAW

CALIBRATION OF SPRING BALANCES

Hooke’s law is applied in the making of spring balances which are used to measure weights of various substances.



OTHER APPLICATIONS OF HOOKE’S LAWS

a. Elasticty in materials e.g. springs is applied in making spring beds, driving boards etc.
b. Stretching and compressing of sprirakl springs helps in designing spring shock absorbers or shock breakers used in car suspensions.
c. Elastic materials are used in making rubber bands, rubber shoes, etc
d. Elastic materials are used in making catapult used for hunting birds.

Chapter 5

UNIFORM CIRCULAR MOTION

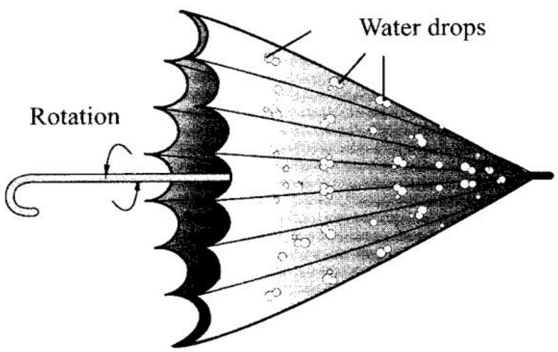
Observations have shown that

- An athlete running in a circular path leans inwards towards the centre.
- A bucket of water is swung round in a horizontal circle without water spilling out.
- As children play on a merry-go-round, the machine rotates fast making circular motion.
-

ILLUSTRATING CIRCULAR MOTION

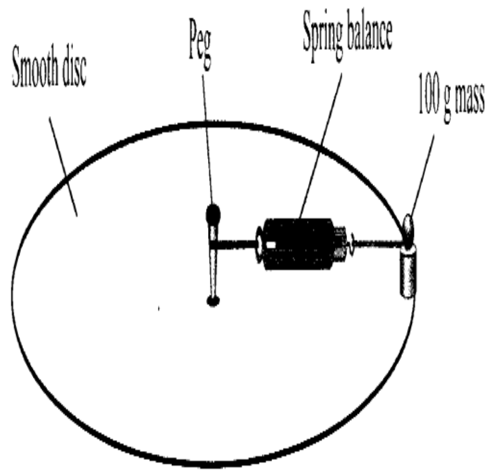
a. MOTION OF MUD ON A ROTATING BICYCLE WHEEL
A bicycle is ridden on muddy road and put on its stand and rotate the pedals.
The mud stuck to the tyre moves in a circular motion along with the wheel because of the force of adhesion between the mud and the tyre. As the speed of the wheel increases, the adhesive force of mud gives up and the mud breaks off and flies away along a tangent of the rim of the tyre.

b. MOTION OF DROPS OF WATER ON A ROTATING UMBRELLA
Wet umbrella is open and its handle horizontal, rotate the handle in a circular manner as shown below



The water drops move in a circular path with the cloth of the umbrella. The force of adhesion between the drops of water and the cloth makes the cloth and the drops of water to move together in a circular path. As the speed of the handle increases, the adhesive force of the drops of water gives up and the drops of water break off from the cloth and fly off.

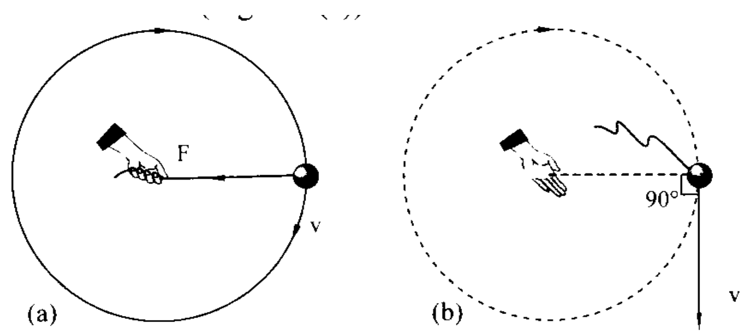
c. MOTION OF A ROTATING MASS ATTACHED TO A SPRING BALANCE
A disc with a smooth surface is mounted horizontally with a peg through its centre so that it can be rotated about a vertical axis. One end of the spring is attached to the peg and the other end to a spring balance.



It can be observed that the mass moves outwards and the spring tighten. The spring balance reads the force exerted by the string on the mass. When the speed increases, the reading increases. The balance reading is a measure of the force directed towards the centre.

d. MOTION OF A ROTATING BALL ATTACHED TO A SPRING

A small ball is tied to one end of a string and grip the free end of the string with one hand and rotate it in a circular manner above the head so that the ball moves in a horizontal circle.
The hand is rotated faster and then release the string.

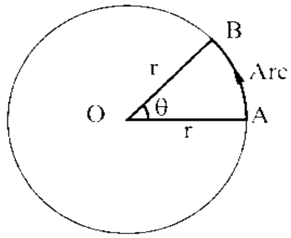


As the hand is rotated faster, the ball moves in a circular motion with a higher speed, along with the hand. The pull of the hand on the string provides a force directed towards the centre and the ball is kept in a circular path of constant radius. When the string is released, suddenly there is no tension in the string and the ball having uniform velocity flies off along the tangent, at a point of release.
Uniform circular motion is the motion along circular path in which there is no change in speed only a change in direction.

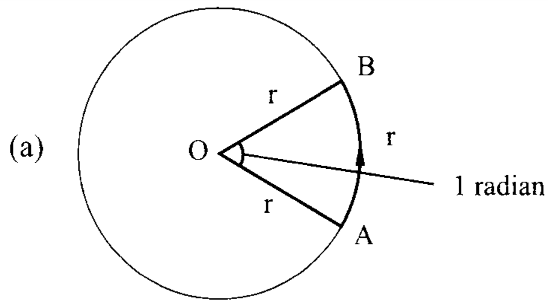
ANGULAR DISPLACEMENT AND ANGULAR VELOCITY

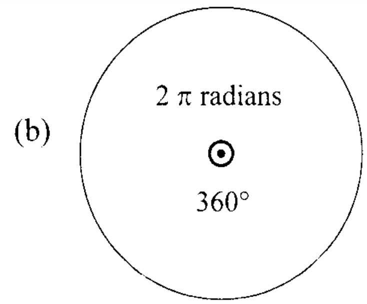
When a particle moving along a circular path moves along the arc of the circle from A to B, the line OA (radius r) joining the particle to the centre of the circle sweeps through an angle θ.
The angle swept is called angular displacement and it is measured in radians.
When the length of the arc AB is equal to the radius r of the circle, the angle subtended by this arc at the centre of the circle is equal to one radian.
One radian is the angle subtended at the centre of a circle by an arc of length equal to the radius of the circle.

Radians is also denoted as rad.



If the length of the arc is 2 times the radius, then the angular displacement is 2 radians. For the whole circle, the length of the arc is its circumference, i.e. 2πr and the angular displacement is 2π radians.





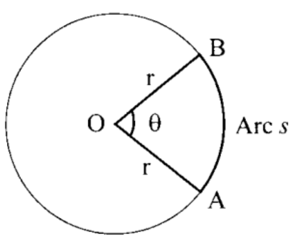
The angle at the centre of the circle is 2π radians i.e. 360°, therefore 2π radians = 360°.

1 radian = $\frac{360}{2\pi}$ = 57.3°

If the angle at the centre of a circle is 1 radian, then the length of thearch is r units. If the angle at the centre is θ radians, the length s of the arc AB of the circle is given by

S = $\frac{r}{1\,rad}$ x no of radians = rθ

Arc length s = rθ



Example 1

The radius of a particle moving along a circular path sweeps through an angle of 60° at the centre of the circle. Calculate angular displacement of the particle.

Solution

360° = 2π rad

1° =$\frac{2\pi}{360}$ rad

Therefore 60° =$\frac{2\pi}{360}$ x 60° rad

= $\frac{\pi}{3}$ radians

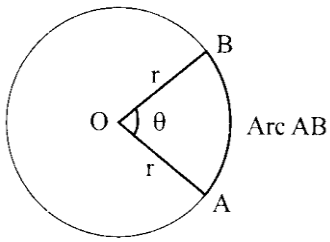
Angular displacement of the particle = $\frac{\pi}{3}$

= $\frac{22}{7\ x\ 3}$ rad

= 1.05 rad

ANGULAR VELOCITY

A particle moving along a circular path covering an arc of length AB in a time ‘t’, the angular displacement of the radius OA is in the same time “t”.



Angular velocity is defined as the rate of change of angular displacement.

Angular velocity (ω) =$\frac{angular displacement}{time}$

RELATIONSHIP BETWEEN ANGULAR VELOCITY AND FREQUENCY.

For one complete circular motion, ϑ = 360° = 2π radians and time taken “t” = T (periodic time)

Therefore v = $\frac{\theta}{t}$ = $\frac{2\pi}{T}$

Since frequency of revolution f = $\frac{1}{T}$

ω= 2πf

Angular velocity (ω)= 2π x frequency (f)

ω = 2πf

RELATIONSHIP BETWEEN THE ANGULAR VELOCITY AND LINEAR VELOCITY

When a body is whirled around it moves with an angular velocity but when suddenly releasedit flies off along a tangential velocity or with linear velocity.

Arc length, s = rθ

Dividing both sides by “t” one gets $\frac{s}{t}$ = $\frac{r\theta}{t}$

But $\frac{s}{t}$ is the linear velocity or tangential velocity of the rotating particle and $\frac{r\theta}{t}$is its angular velocity

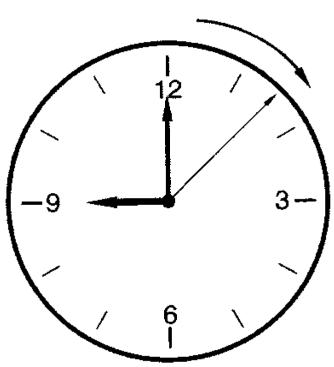
Therefore

Line = radius ® x angular velocity (ω)

V = rω

Example 1

Figure shows the motion of the second hand of a clock. Calculate its angular velocity



Solution

Angular velocity $\omega = \frac{2\pi}{t}$

$= \frac{2\pi}{60}$

$= 0.105$ rad/s

Example 2

A bicycle wheel makes 300 revolutions per minute (rpm). Calculate the angular velocity of the wheel

Solution

The wheel makes 300 revolutions in 1 minute.

In each second it makes $\frac{360}{60}$ = 5 revolutions

1 revolution = 2π rad

5 revolutions = 5 x 2π rad

= 10π rad

Angular velocity (ω) = $\frac{\theta}{t} = \frac{2\pi}{T} = \frac{10\pi}{1}$

= 31.4 rad/s

Example 2

Calculate the angular velocity of the earth when it is rotating about its own axis. Time period of the earth about its own axis is 24 hours.

Solution

The earth takes 24 hours to rotate once about its own axis.

Hence angular velocity (ω) is given by

$\omega = \frac{\theta}{t} = \frac{2\pi}{24 \; x \; 60 \; x \; 60}$

$= \frac{2\pi}{86400}$

$= 7.3 \times 10^{-5}$ rad/s

Example 3

A ball tied to a string is rotated at a uniform speed in a circle of radius 10cm. it takes 1.5 seconds to describe an arc of length 6cm. calculate its

a. Tangential velocity
b. Angular velocity
c. Periodic time

Solution

a. Linear velocity, v = $\frac{x}{t} = \frac{6}{1.5}$ = 4.0cm/s
b. Since linear speed, v = ω r,
   angular velocity, $\omega = \frac{v}{r} = \frac{4.0}{10} = 0.40$
c. $\omega = \frac{2\pi}{T}$, hence T = $\frac{2\pi}{0.4}$ = 15.7s

Example 4

The wheel of a car of radius 20cm is rotating at a frequency of 20Hz. Calculate the linear speed of the car.

Solution

Angular velocity of the wheel

$\omega = \frac{\theta}{t} = \frac{2\pi}{T} = 2\pi f$

Therefore $\omega = 2\ x\ \pi\ x\ 20 = 40\pi$ rad/s

Linear speed (v) = radius (r) x angular velocity (ω),

Hence = 0.20 x 40π

= 25.14 m/s

the speed of the car is 25.14m/s

CIRCULAR MOTION AND CENTRIPETAL FORCE

When a force acts on the body from a fixed point, then the body describes a circular motion

.

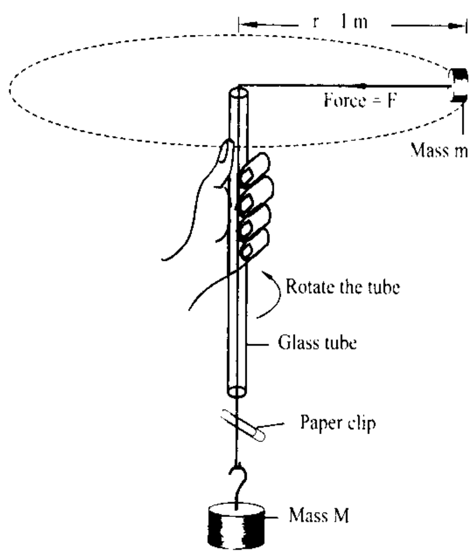
INVESTIGATING RELATIONSHIP BETWEEN THE FORCE (F) AND THE SPEED OF REVOLUTION (V) OF A BODY UNDERGOING CIRCULAR MOTION.

A body of mass(m) is tied to the end of a thick string of 1.5m long and pass the free end of the string through a tube and attach a hanger of known mass (M)

Attach a long paper clip or crocodile clip to the vertical portion of the string which acts as an indicator to keep the radius of the circular path constant and to check that the motion is steady.

Adjust the position of the paper clip so that the radius of the circular path is 1m i.e. the length of the horizontal portion of the string is 1m.

Grip the tube with one hand and swing the hand above the head, so that the mass (m) moves in a horizontal radius of 1m.



Number of revolutions made by the mass (m) in a certain time is noted and frequency of revolutions (f) (i.e. number of revolutions made by mass (m) in 1 second) is calculated.

Periodic time (T) = $\frac{1}{f}$

The linear speed (v) of revolution of the mass (m) is calculated i.e. v = $\frac{2\pi r}{T}$

It can be observed that when the frequency is doubled (i.e. time period is halved) the speed of revolution (v) of mass m is doubled and the force (F) needed to maintain the same radius as before is 4 times more.The force needed is 9 times more, when the speed is trebled (3 times).

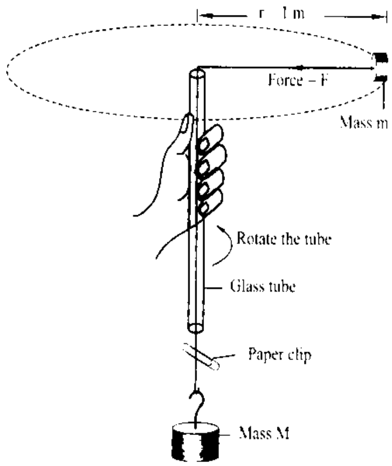
Therefore

The force F required to keep the body in a circular path of constant radius is directly proportional to the square of the speed of revolution.

$$F \alpha v^2$$

INVESTIGATING THE RELATIONSHIP BETWEEN THE FORCE (F) AND THE RADIUS (R) OF THE CIRCULAR PATH

Keep the mass (m) constant but add slotted masses (M) in turn to the hanger and measure radius (r) of the circular motion.



It can be noted that when the mass (M) is doubled, the radius of the circular path is halved (i.e. the mass(M) required to keep mass (m) in a circular path of radius $\frac{r}{2}$ is 2M

When mass is 3M, the radius is $\frac{r}{3}$.

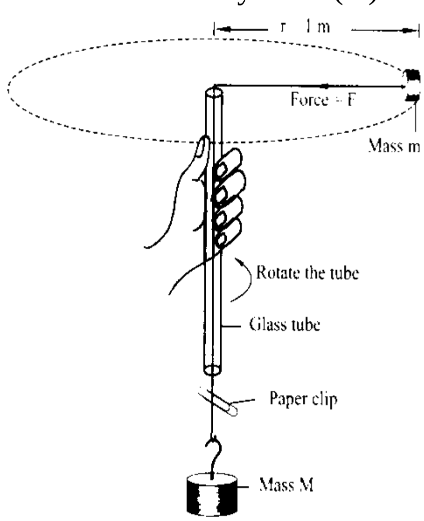
Therefore

The force F needed is inversely proportional to the radius (r) of the circular path, when speed of revolution of the body is constant

$$F \alpha \frac{1}{r}$$

INVESTIGATING THE RELATIONSHIP BETWEEN THE FORCE (F) AND MASS (m) OF A BODY UNDERGOING CIRCULAR MOTION.

Attach a mass (m) to the string when the radius of the circular path is 1m and find the number of revolutions made by mass (m) in a certain time and find frequency of revolutions.



Tie two masses (2m) to the end of the string and put 2 masses (2M) to the hanger and find the frequency of revolution.
Repeat adding masses but keeping the radius of the circular path constant
It can be noted that as mass (m) of the body undergoing circular motion increases, the hanging mass (M) also increases in the same ratio and the frequency of revolution of the mass (m) is the same each time.
Therefore
The force (F) required is directly proportional to the mass undergoing motion.

$$F \alpha m$$

Force (F) required to keep a body in a circular path depends upon three factors

- The speed of revolution of the body (v), i.e. $\boldsymbol{F \alpha v^2}$
- The radius of the circular path (r) i.e. $\boldsymbol{F \alpha \frac{1}{r}}$
- The mass of the body undergoing circular motion (m) i.e. $\boldsymbol{F \alpha m}$

CENTRIPETAL FORCE

It is a force that constrains an object in motion to move in a circular motion. Centripetal is a Greek word meaning "seeking centre". Centripetal force is the centre seeking force. An external force acts towards the centre of the circle and keeps the body circulating at a fixed distance from the centre.Centripetal force F α v^2, F $\alpha \frac{1}{r}$ and F α m combined together and gives

$$F = \frac{kmv^2}{r}$$ where k is the constant proportionality

But k = 1 as shown in experiments.

Therefore

Centripetal force = $\frac{mv^2}{r}$where ,***m*** is the mass of the object
v is the linear speed along the circular path in m/s
r is the radius of the circular path

CENTRIPETAL FORCE IN TERMS OF ANGULAR VELOCITY

From experiments, centripetal force F is given by: $F = \frac{mv^2}{r}$

But v = rω, where ω is the angular velocity.

Substituting for $F = \frac{mv^2}{r}$

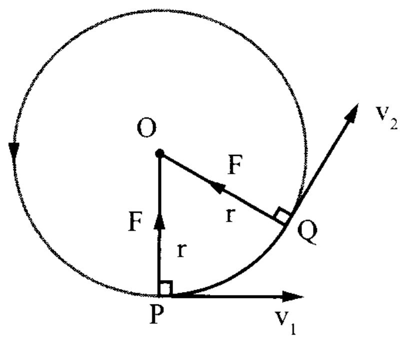
$$F = \frac{m(r\omega)(r\omega)}{r}$$

$$= mr\omega^2$$

Therefore centripetal force in terms of angular velocity
<u>F = mr</u>$\boldsymbol{\omega^2}$
For any circular motion, there should be a centripetal force towards the centre of the circle provided by an external agent i.e. no centripetal force no circular motion.

CENTRIPETAL ACCELERATION

When a body executes uniform circular motion, though the speed is uniform, its direction of motion is continuously changing. The direction of motion of the body at a point P is along the tangent drawn at P but when the body is at Q, it is along the tangent drawn at Q etc



For a body in uniform circular motion, the linear velocity changes continuously since only direction changes continuously.
Change of velocity with time is the acceleration and so during circular motion, the body accelerating due to continuous change in direction though the speed remains uniform

$$\text{Acceleration} = \frac{change\ in\ velocity}{time\ taken}$$
$$= \frac{v_2 - v_1}{t}$$

From Newton's Second Law of motionF = ma

But centripetal force $F = \frac{mv^2}{r}$

$$a = \frac{F}{m}$$
$$\text{But } F = \frac{mv^2}{r}$$

Therefore $a = \frac{mv^2}{rm}$

$$= \frac{v^2}{r}$$

Therefore centripetal acceleration, a, of a body towards the centre is given by $a = \frac{v^2}{r}$

Where $v_2 = v_1 = v$ (in magnitude) and r is the radius of the circular path.
Centripetal acceleration acts towards the centre of the circle and is at 90^o to the tangent at each point of motion.

Example 1

A 5kg mass moves at uniform speed of 18m/s in a circular path of radius 0.5m. Calculate the centripetal force acting on the mass

Solution

Centripetal force, $F = m\frac{v^2}{r}$

$= 5 \text{ x } \frac{18^2}{0.5}$

= ***3240N***

Example 2

A car of mass 1,200kg has to make a circular turn of radius 30m. if it is moving with uniform speed of 10m/s, calculate the centripetal force acting on the car.

Solution

Centripetal force, $F = m\ \frac{v^2}{r}$

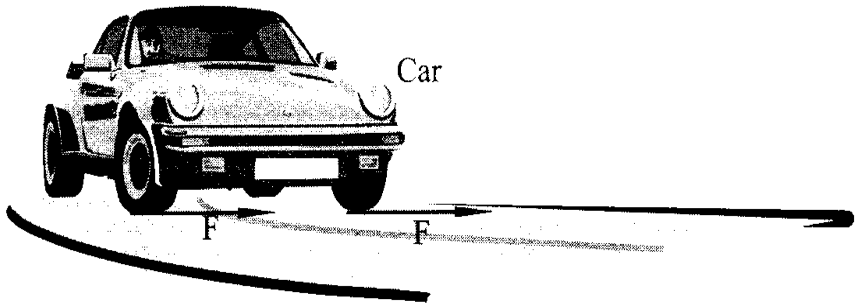
$= 1\ 200 \text{ x } \frac{10^2}{30}$

= 4000N

APPLICATIONS OF UNIFORM CIRCULAR MOTION

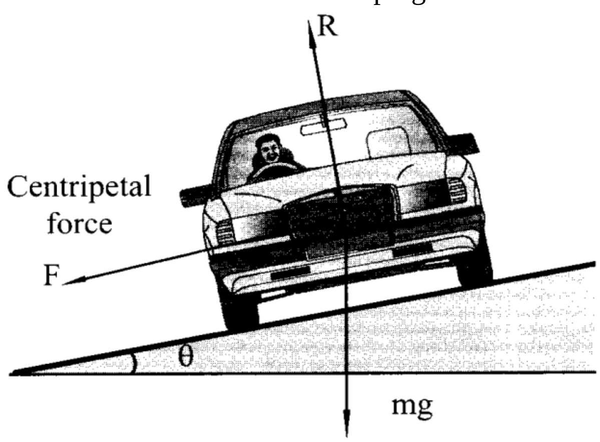
a. A CAR NEGOTIATING A CIRCULAR PATH ON A HORIZONTAL ROAD

When a car is going round a circular path on a horizontal road, the centripetal force required for circular motion is provided by the frictional force F, between the tyres and the road.



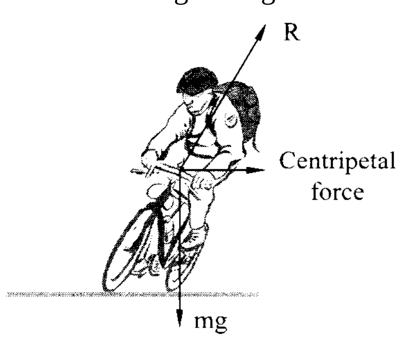
Centripetal force F = $\frac{mv^2}{r}$, where m is the mass of the car, v is its uniform speed and r is the radius of the circular path taken by the car.
Hence
$v_{maximum} = \sqrt{F\ x\ \frac{r}{m}}$ i.e. this is the maximum safe speed for the motorist not to skid off the track

b. BANKED TRACKS
For motorists not to fully depend on the frictional force between the tyres and the road, circular paths are given a small banking angle, i.e. the outer edge of the road is raised a little above the inner side so that the track is sloping towards the centre of the curve.



Part of the contact force R (the normal reaction force) acting towards the centre of the circle providing the required centripetal force.

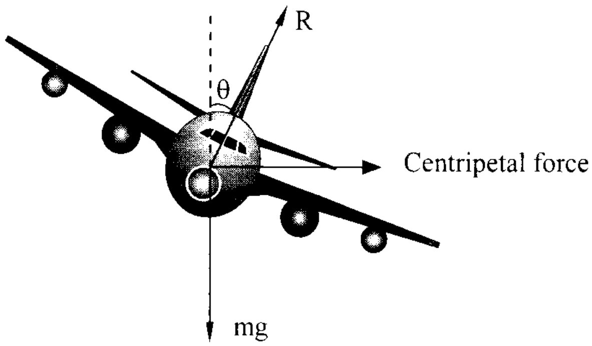
c. LEANING INWARD OF A CYCLIST
A cyclist going round a curve leans inwards to provide the necessary centripetal force, so as to be able to go along the curved track.



The part of the contact force or the reaction force provides the required centripetal force acting towards the centre of the track.

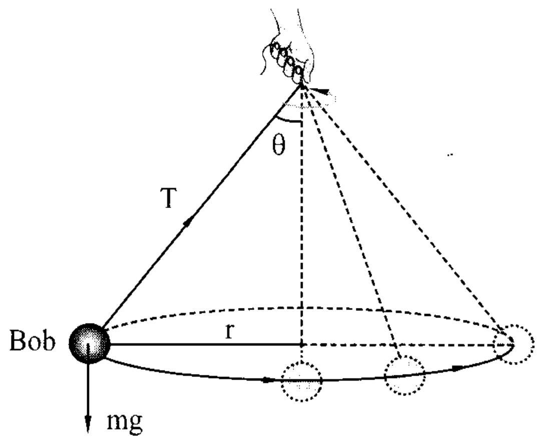
d. AIRCRAFT TAKING A CIRCULAR TURN

When an aircraft takes a turn in a horizontal plane, it must make a correct banking angle in mid air in order to successfully negotiate the curved path



e. CONICAL PENDULUM

If the hand is swung in a circular pattern, the bob of the pendulum starts revolving in a horizontal circle of radius r. if the speed of the bob is increased gradually, the radius of the circle in which the bob revolves also increases.



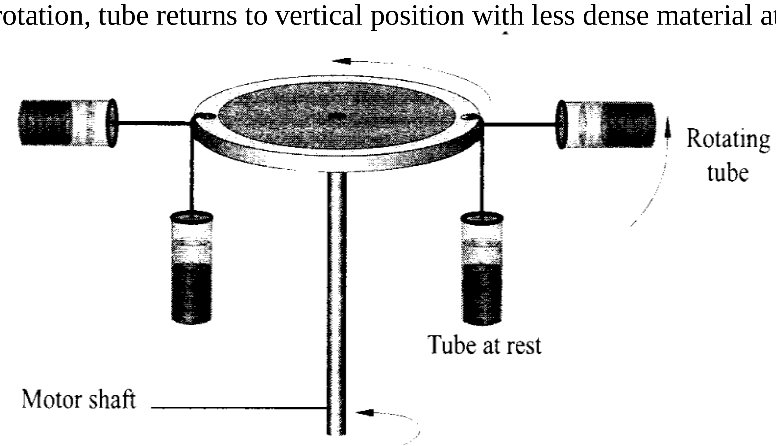
Part of the tension developed in the string provides the centripetal force for the bob to execute circular motion.

f. CENTRIFUGE

Centrifuge is a device that separates liquids of different densities or solids suspended in liquids. The mixture is poured into a tube in the centrifuge, which is then rotated at high speeds in a horizontal circle.

The tube is initially in vertical position and takes up horizontal position when the centrifuge rotates.

The matter of low density moves inwards towards the centre of rotation and on stopping the rotation, tube returns to vertical position with less dense material at the top



Centrifuge can be used in

- Cream separator,
  when milk is churned rapidly, cream being lighter comes towards the top of the tube and can be removed.
- Blood screening,
  When blood is rotate at high speeds in a centrifuge, red blood cells and blood fluids are separated. Viruses and germs can be separated in the same manner and used in the study of viruses such as HIV virus which causes AIDS.

g. DRYING MACHINE
Wet clothes are rotated in a cylindrical drum containing a lot of perforations. Initially the wet clothes move in a circular motion along with the drum. As the speed of the drum increases, the adhesive force of the water in the clothes "gives up" and water breaks off from the clothes and flies off through the perforations.

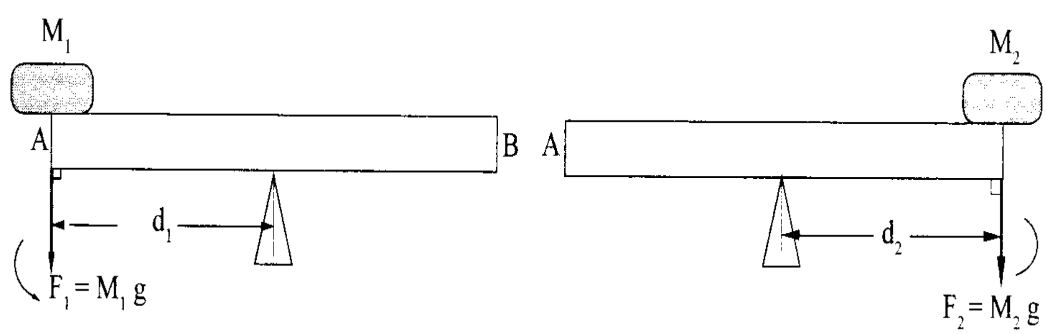
Chapter 6

MOMENT OF A FORCE

Simple machines like levers, pliers, spanners do work when a force produces a turning effect on some of their parts. The force has to be applied at a particular position for the machine to be more efficiently in doing work.

TO INVESTIGATE THE TURNING EFFECT O A FORCE OF A FORCE

A metre rule is balanced on an edge (fulcrum) and a force applied at a point A at a distance d_1 from the edge. This is repeated by applying another force at a distance d_2 from the edge (fulcrum).



(a) Anticlockwise turning *(b) Clockwise turning*

In both cases the metre rule turns about the edge. When the force F_1 is applied at A, the metre rule turns in an anticlockwise direction about the edge. When F_2 is applied at B, the metre rule turns in clockwise direction.

The turning effect of a force about a point is called the moment of the force about that point. The moment depends on the force applied and its distance from that point.

The moment of a force about a point is the product of the force and the perpendicular distance from the point to the line of action of the force.

Moment of a force about a point = Force x perpendicular distance from the point to the line of action of the force.

$= F \times d$

Moment of a force is a vector since it has both magnitude and direction

In the figure (a) above, the anticlockwise moment about the edge is $F_1 \times d_1$ and in (b) the clockwise moment about the edge is $F_2 \times d_2$.

SI UNIT OF A MOMENT OF A FORCE

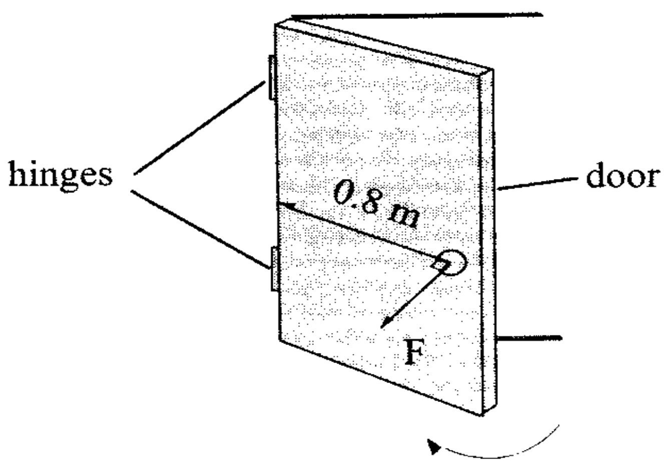
Moment of a force = Force (Newton) x perpendicular distance (metre)

= Newton metre

= **Nm**

Example 1

A student applies a force of 10N to a handle of a door, which is o.8m from the hinges of the door. Calculate the moment of the force.



Solution

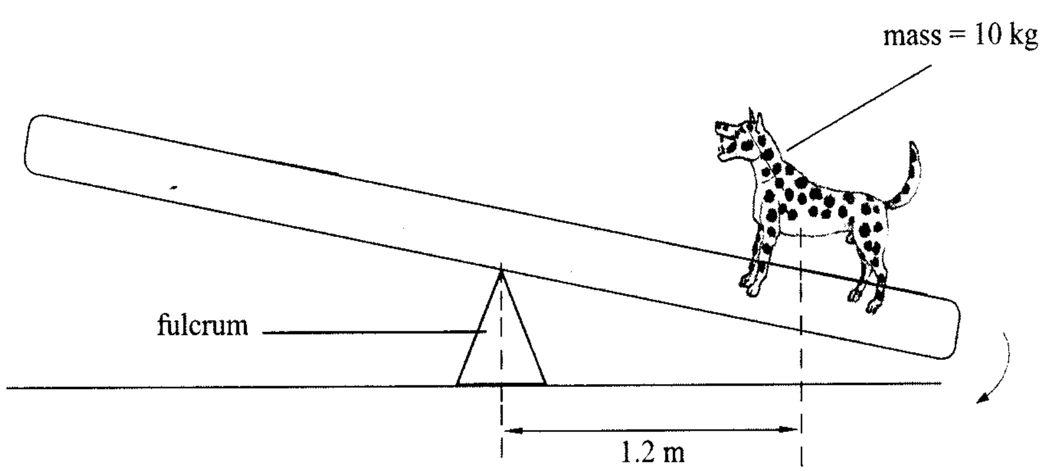
Moment of a force about a point = Force x perpendicular distance from the point to the force.

= 10N x 0.8m

= 8Nm in the clockwise direction.

Example 2

Calculate the moment of the force about the fulcrum when a pet dog of mass 10kg is at a distance of 1.2m from the fulcrum of the seesaw as shown in the figure.



Solution

Force = weight of the dog = mg = 10kg x 10N/kg

= 100N

Moment of the force about the fulcrum = Force x perpendicular distance from the fulcrum

= 100N x 1.2m

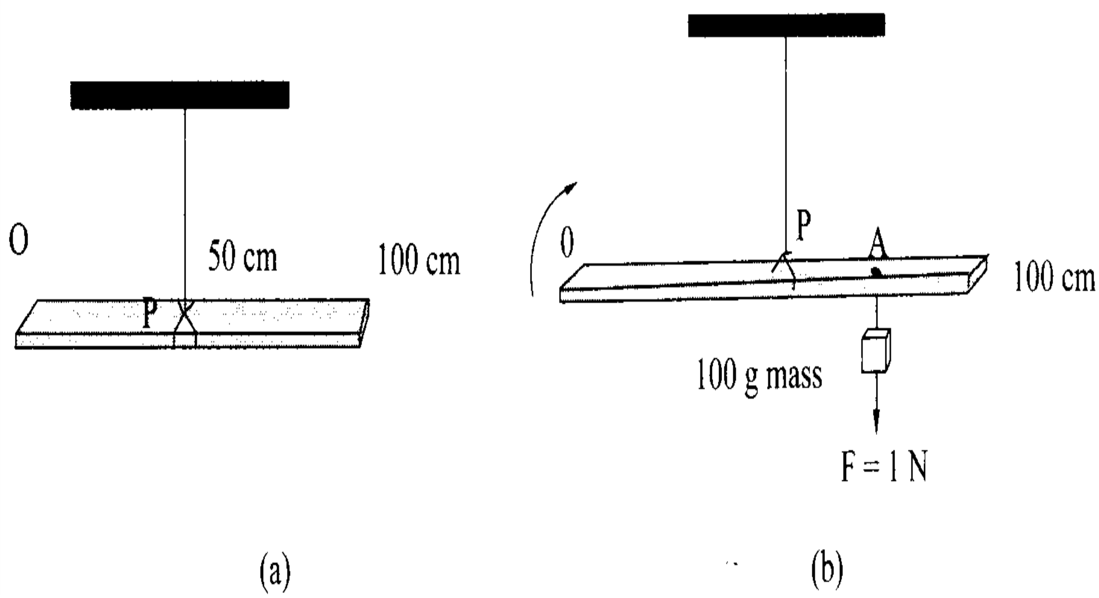
<u>= 120N</u> in the clockwise direction

PRINCIPLE OF MOMENTS

The principle of moments gives the relationship between two moments that are at the same turning point (fulcrum).

INVESTIGATING THE PRINCIPLE OF MOMENTS

A metre rule is suspended from a firm support at mid point P using a string as shown in (a). A 100g mass is suspended at a point A as shown in (b)

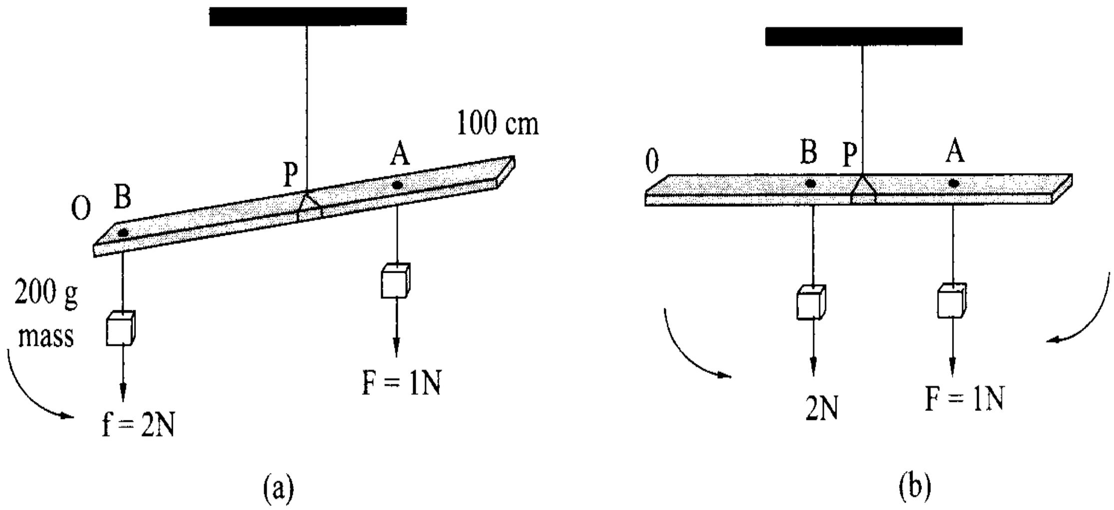


It can be observed that the metre rule turns in the clockwise direction. There is a moment of a force in the clockwise direction due to the force acting vertically downwards at point A.

Moment of the force in the clockwise direction = Force x perpendicular distance

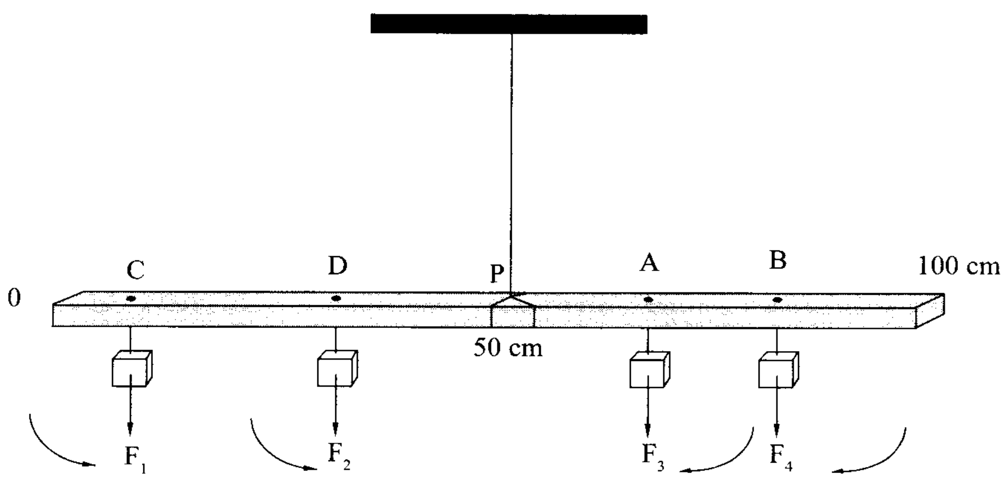
= 1.0 x PA

When a 200g mass is suspended at point B near the o cm mark, the system turns in the anticlockwise direction. The position of B is adjusted till the system balances horizontally.



Moment due to the 2N force about P is 2N x PB in the anticlockwise direction.
It can be noted that the two moments are equal in magnitude and opposite in direction i.e. the clockwise moment of the 1N force about point P is equal to the anticlockwise moment of the 2N force about point P.

INVESTIGATING PRINCIPLE OF MOMENTS WITH MORE THAN TWO FORCES.
As shown below four masses are suspended, two on each side of P

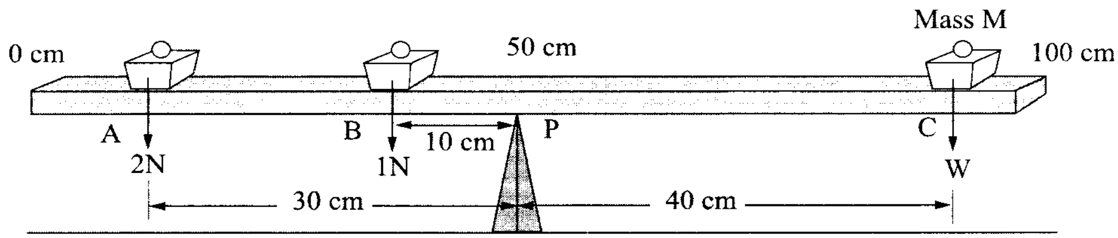


Moments about point P:
The sum of clockwise moments = F_3 x PA + F_4 x PB
The sum of anticlockwise moments = F_1 x PC + F_2 x PD
It follows that F_3 x PA + F_4 x PB = F_1 x PC + F_2 x PD
From this experiment it can be concluded that the sum of the clockwise moments about a point is equal to the sum of the anticlockwise moments about the same point when the metre rule is balanced.
When the body is balanced under the action of a number of forces, it is said to be in equilibrium.

Principle of moments states that, when a body is in equilibrium under the action of forces, the sum of the clockwise moments about any point is equal to the sum of anticlockwise moments about the same point.

Example 1

A uniform metre rule is pivoted at its centre P, and 3 masses are placed at A, B and C as shown in the figure. Find the value for the weight W of the mass M placed at C so that the metre rule is balanced horizontally.



Solution

Taking moments about P, when the metre rule is in equilibrium.

Sum of the clockwise moments = sum of the anticlockwise moments

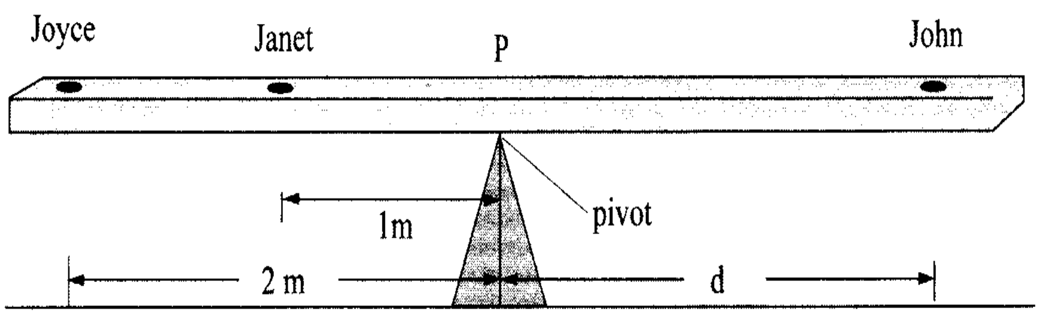
W x 0.4 = (2.0 x 0.3) + (1.0 x 0.1)

$$W = \frac{(2.0 \, x \, 0.3) + (1.0 \, x \, 0.1)}{0.4}$$

= 1.75N

Example 2

John, Joyce and Janet sat on a seesaw as shown in the figure. Where is John whose mass is 60kg seated so that the seesaw is balanced horizontally if the masses of the Joyce and Janet are 50kg and 20kg respectively.



Solution

John's weight =600N, Joyce's weight = 500N, Janet's weight = 200N

Taking moments about the pivot;

Sum of clockwise moments about a pivot = sum of anticlockwise moments about a pivot

600N x d = (500N x 2m) +(200N x 1m)

600d = 1000 + 200Nm

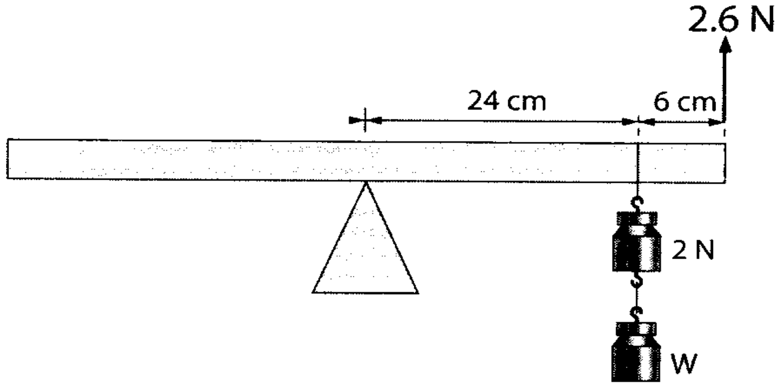
$$d = \frac{1200Nm}{600N}$$

= 2m

John should sit at a distance of 2m from the pivot

Example 3

The uniform plank of wood in the figure is balanced at its centre by the forces shown. Determine the value of W in kg.



Solution

Note that 2.6N produces anticlockwise moment.

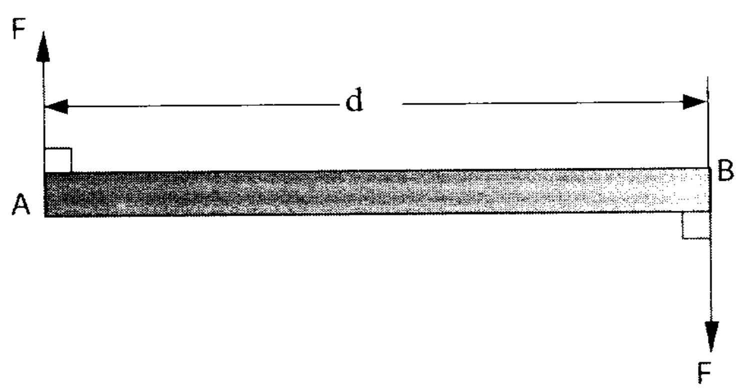
Sum of clockwise moments = sum of anticlockwise moments

$$0.24 \text{ x } (2 + W) = 2.6 \text{ x } 0.3$$
$$0.48 + 0.24W = 0.78$$
$$W = \frac{0.78Nm - 0.48Nm}{0.24m}$$
$$= 1.25N$$
$$= 0.125kg$$

COUPLE

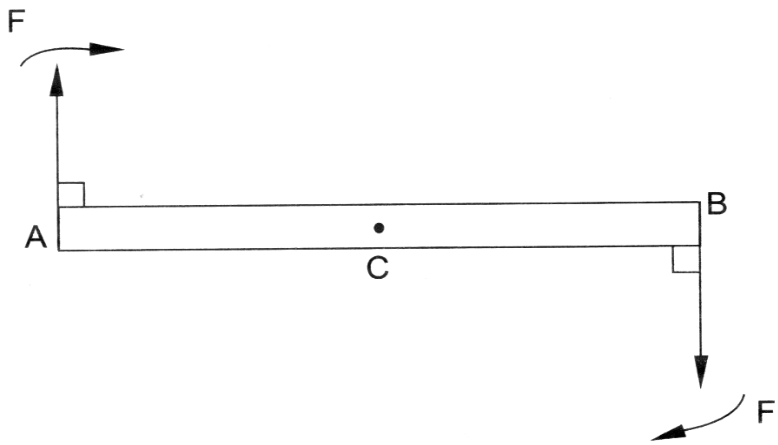
Parallel forces which act in the same direction are called like parallel forces while parallel forces which act in opposite directions are called unlike parallel forces.

A couple are two equal and unlike parallel forces acting on a body at different points.



MOMENT OF A COUPLE

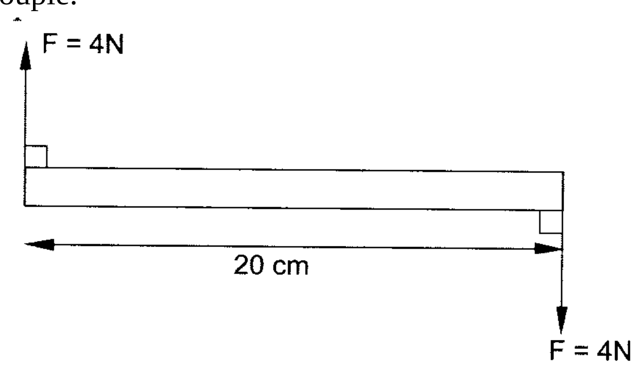
A couple produces a turning effect on a body as shown in the figure.



Since the pivot is at C, the moment of the force F acting at a point A = F x AC, in the clockwise direction.
Similarly, the moment of the force, F acting at a point B = F x BC also in clockwise direction.
The moment of the couple = (F x AC) + (F x BC)
= F(AC+BC)
But AB = BC + AC
F x AB = F x Arm of the couple
The moment of the couple is called a TORQUE i.e. the total rotating effect of a couple and is given by the product of one of the forces and the perpendicular distance between the forces.
Torque = F x perpendicular distance AB
SI unit of torque is the Newton-metre (Nm)

Example 1

In the figure, each force is 4N and the arm of the couple is 20cm. calculate the moment of the couple.



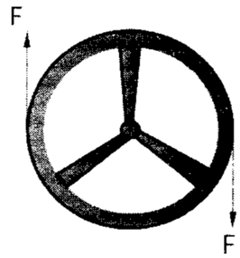
Solution

The moment of the couple = F x perpendicular distance
= 4Nx 0.20m

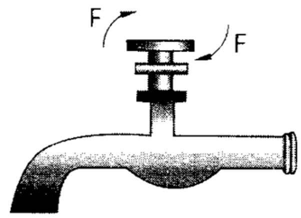
= 0.80Nm

COMMON EXAMPLES OF A COUPLE

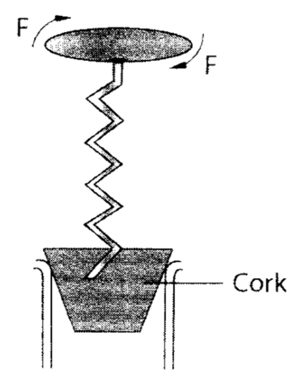
a. Forces are applied by hands to turn a steering wheel of a motor car or handle bars of a bicycle as shown in (a)
b. A water tap is opened or closed as shown in (b)
c. A cork is removed from the mouth of the bottle using a cork-screw as shown in (c).



(a) Steering wheel



(b) Water tap



(c) Cork-screw

CENTRE OF MASS OF A BODY

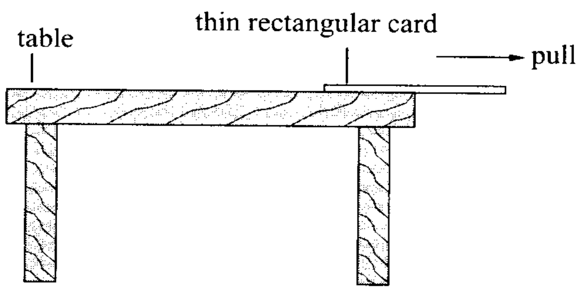
Bodies experience a force of gravity exerted on them by the earth and this force is directed towards the earth’s centre and is called weight of the body.

INVESTIGATING WHERE THE WEIGHT OF A BODY ACTS FROM

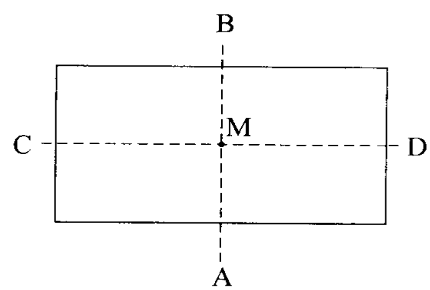
A thin rectangular cardboard is placed near the edge of a bench top and pulled slowly away from the bench until it is just about to topple over when released as shown in the figure.

Mark and draw a line AB along which the card balances. Repeat the experiment using the other side of the card, mark and draw CD along which the card balances.

Lines AB and CD intersect at a point M



(a)

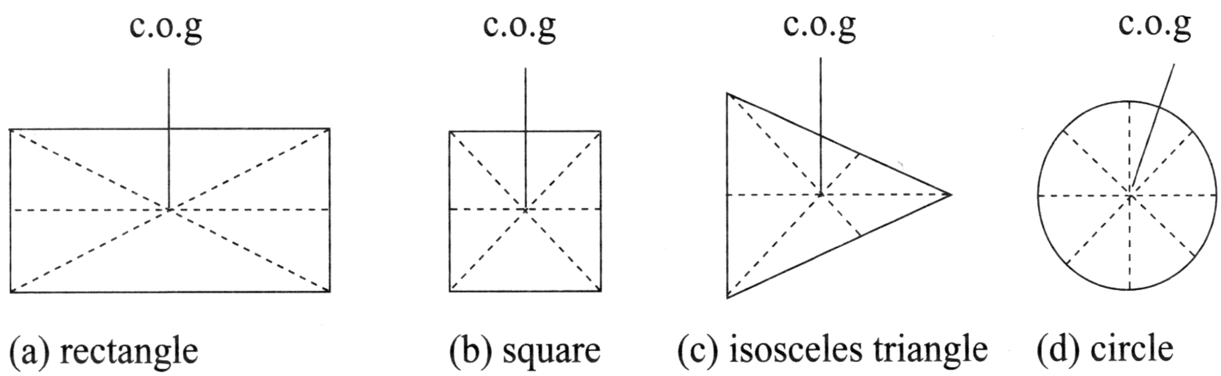


(b)

Although the mass of the cardboard is distributed over the whole body, there is a particular point M where the whole mass of the cardboard appears to be concentrated. When pivoted at this point the cardboard balances horizontally. Point M is the centre of mass of the cardboard

The centre of mass of a body is the point where the whole mass of the body appears to be concentrated.

Bodies with uniform cross section area and density have their centre of mass located at their geometrical centre.



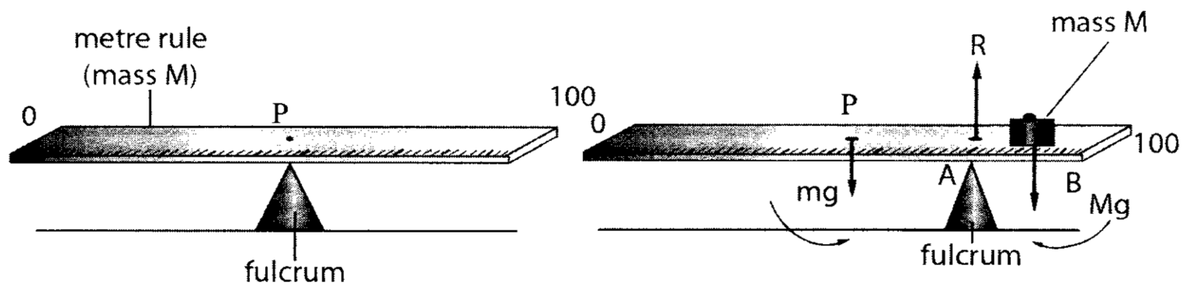
CENTRE OF MASS OF LAMINA

A lamina is a body whose thickness is very small compared with other dimensions of the body e.g. a thin cardboard, cook cover, etc

DETERMINING THE CENTRE OF MASS OF AN REGULAR OBJECTS

Balance a uniform metre rule of mass EM on a fulcrum and adjust its position until the metre rule is horizontal and note position of P as shown in (a).

Displace fulcrum to point A to the right of P and place a mass M between A and 100cm mark and adjust its position B until the metre rule is horizontal ad in figure (b)



(a) (b)

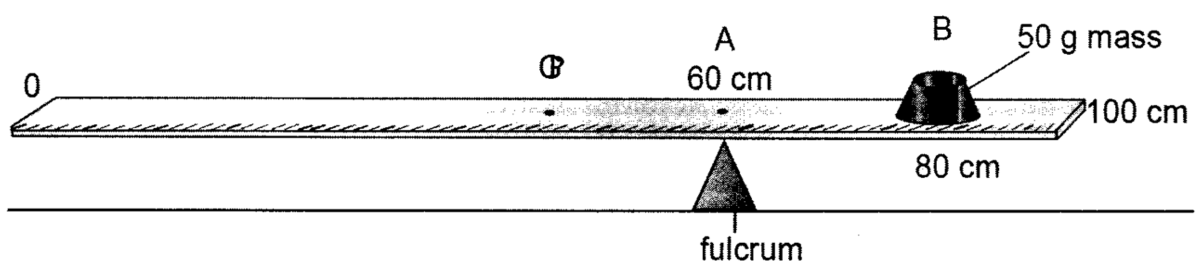
Taking moments about A

mg x PA = Mg x BA

m $= \frac{MxBA}{PA}$

Example 1

A uniform metre rule pivoted at the 6ocm mark is kept horizontal by placing a 50g mass on the 80cm mark. Calculate the mass of the centre of the metre rule.



Let the mass of the metre rule be m

Force due to m = m x g where g = 10N/kg

= 10m newtons

Force due to 50g mass = $\frac{50g x\ 10N}{1000g}$ = 0.50N

PA = 10cm = 0.1m

AB = 20cm = 0.2m

By principle of moments, taking moments A

$$10m \times 0.1 = 0.50 \times 0.2$$

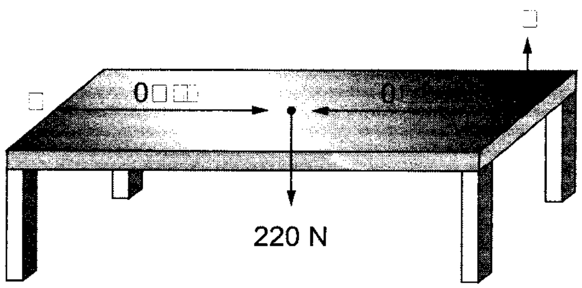
$$M = \frac{0.50\ x\ 0.2}{x\ 0.1}$$

$$= 0.10kg$$

= 100g

Example 2

A coffee table of mass 22kg and a length of 1.6m is to be lifted off the floor on one of its shorter sides to slip a carpet underneath. Calculate the maximum force needed to lift the table.



Taking moment about a point A

Sum of clockwise moments = sum of anticlockwise moments

$$220N \times 0.8m = F \times 1.6m$$

$$F \quad = \frac{220\ x\ 0.8}{1.6}$$

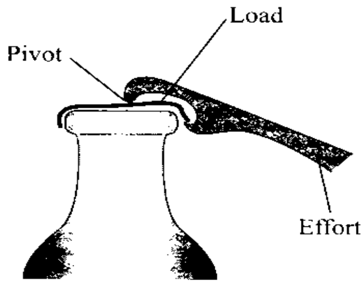
= 110N

The minimum force required is 110N

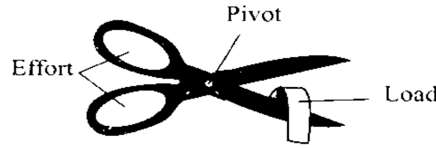
APPLICATIONS OF MOMENT OF A FORCE

Common examples illustrating the turning effect of a force i.e. moment of a force are

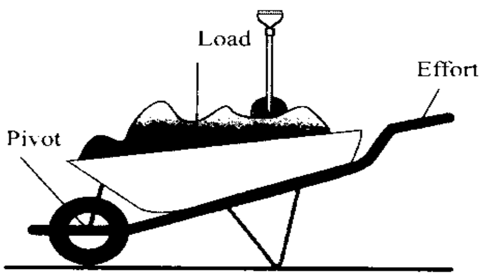
a. Opening or closing a door.
b. Opening a bottle using a bottle opener
c. A pair of scissors or garden shears in use
d. Children playing on a seesaw.
e. Wheelbarrow being used to lift a load
f. A screw driver being used to tightening or loosening a screw
g. A crowbar being used to move a large object.



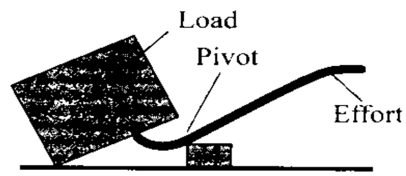
(a) Bottle opener



(b) Scissors



(c) Wheelbarrow



(d) Crowbar

INVESTIGATING THE EFFECT OF LENGTH TO THE EFFORT NEEDED IN USING A TOOL

Remove a bottle top using a bottle opener with a short handle and then use an opener with a long handle

Open a classroom door with hand near the door hinge and then open same door with hand away from the door hinge.

It can be noted that less effort is used when using an opener with a longer handle to remove a bottle top and when hands are far away from hinge to open a door.

Therefore

- The longer the handle, the lesser the effort used when using machines
- The shorter the handle, the more the effort used while working with the tools and machines.

Chapter 7

MAGNETISM

Magnets are ferrous materials that attract metallic objects. Magnetic materials include iron, nickel and cobalt.

Magnet has two poles: North and South poles where magnetic force is concentrated.

Law of magnetism states that like poles repel while unlike poles attract.

MAGNETIZATION

Magnets are made by the following methods

- Stroking method
- Touching method
- Electric method

- Hammering method
- Induction method

a. STROKING METHOD

A piece of steel e.g. steel needle placed near a magnet becomes magnetized though the magnetism acquired disappears quickly when the magnet is removed.

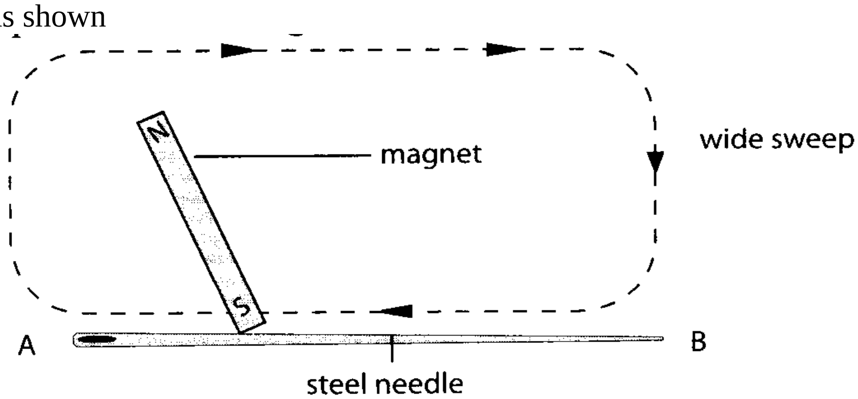
There are two ways of magnetizing an object by stroking method

- Single stroke method
- Double stroke method

(i) SINGLE STROKE METHOD

HOW TO MAKE A MAGNET BY SINGLE STROKING METHOD

A needle is placed on a bench and it is stroke with the south pole of a bar magnet along the whole length. Once at the end, lift the magnet well away from the steel needle (i.e. make a wide sweep) as shown

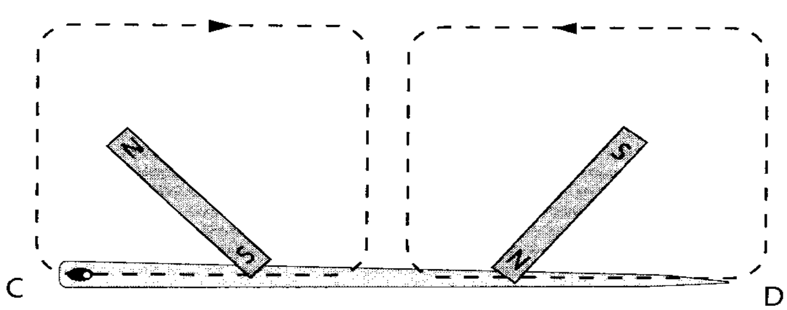


The process is repeated several times and the needle is tested for polarity by repulsion method.
It is observed that the steel needle becomes magnetized with one end B becoming S-pole and end A becoming a N-pole.
The end of the magnetic material last touched by the magnet acquires a polarity opposite to the one touching.

(ii) DOUBLE STROKING

HOW TO MAKE A MAGNET BY DOUBLE STROKING METHOD

A needle is stroke by two magnets and stroking begin at the middle of the steel needle making sure that the two bar magnets are lifted away from the steel needle once the ends are reached.
Test for the polarity at the ends of the steel needle.



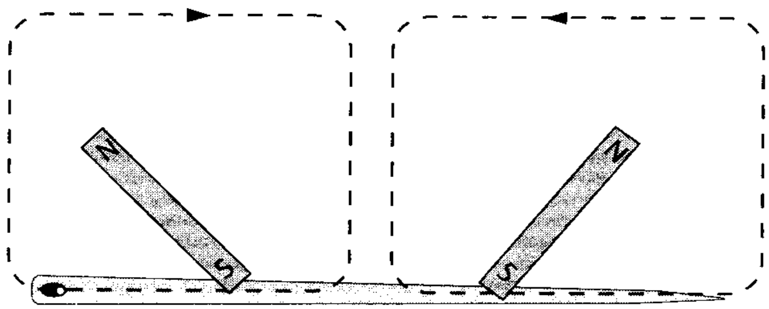
It is observed that the end C becomes a N-pole while end D becomes a S-pole. This double stroke method is also called the divided stroke method.

MAKING CONSEQUENT POLES

Consequent poles are poles of a magnet that are alike on both ends of a magnet

HOW TO MAKE MAGNET WITH CONSEQUENT POLES

Double stroking method is performed using similar poles in stroking.

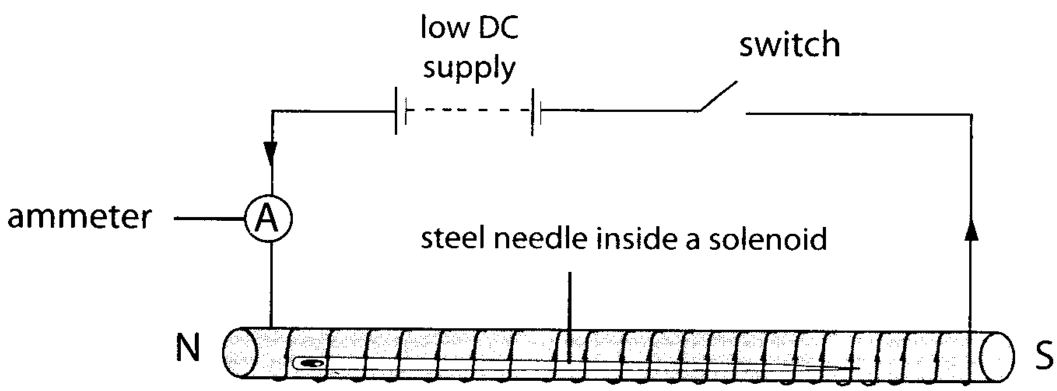


When tested for polarity, it is observed that similar poles appear at each end of the steel needle. The middle of the steel becomes a South Pole or north pole depending on the pole used for stroking

b. ELECTRICAL METHOD

HOW TO MAKE A MAGNET BY ELECTRICAL METHOD

A wire is wound a number of turns around a hollow tube (i.e. solenoid) and an iron needle is placed inside the tube and pass a direct current (DC) through the turns of the solenoid as shown



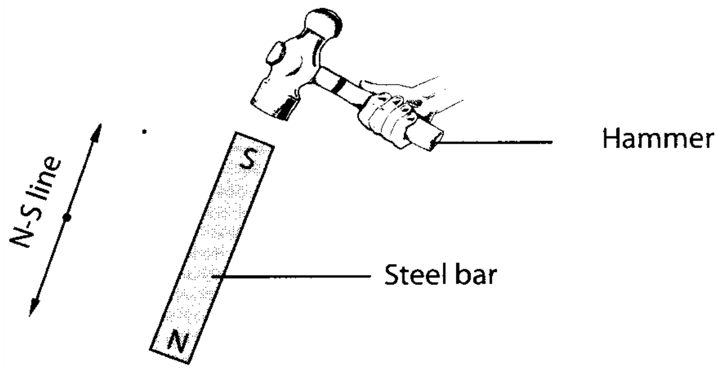
The current is switched off and iron needle removed and tested for polarity by using a magnet of known polarity.

The polarity of the magnet produced depends on the direction of the electric current.

The current flowing in a coil has a magnetic effect and it induces magnetism to the iron needle i.e. an electromagnet.

c. HAMMERING

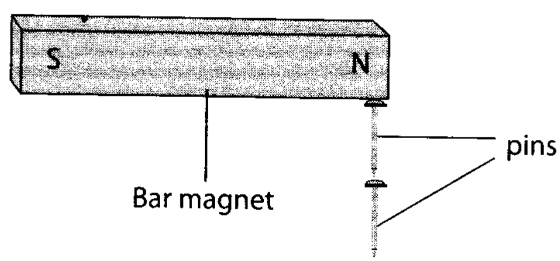
A steel bar is hammered while fixed in the north-south direction several times and test for polarity.



The steel bar becomes a weak magnet. In this case the lower end becomes a weak north pole. In this method the influence of the earth's magnetic field is used to magnetise the steel bar being hammered.

d. INDUCTION METHOD

When a bar of magnet is pleased near unmagnetised steel pin the pin is attracted by the bar magnet and if a second pin is placed near the first pin, it is also attracted.



The first pin becomes magnetized by the magnet through a process called induction and gets attracted to the magnet. The induced pole nearest the magnet is of opposite polarity to that of the inducing magnet. The second pin gets magnetized by the first pin through the same process.

DEMAGNETIZATION

Demagnetization is the process through which magnets lose their magnetism. The process may be achieved through the following methods.

- Hammering

Hammering a magnetized material placed in the East-West direction or dropping it violently on a hard floor several times disorganizes the alignment of dipoles hence loses most of its magnetism.

- Heating

Heating a magnetized material red hot and cooling it suddenly when resting in East-West direction makes it lose its magnetism by disorganizing the alignment of dipoles.

- Electrical method

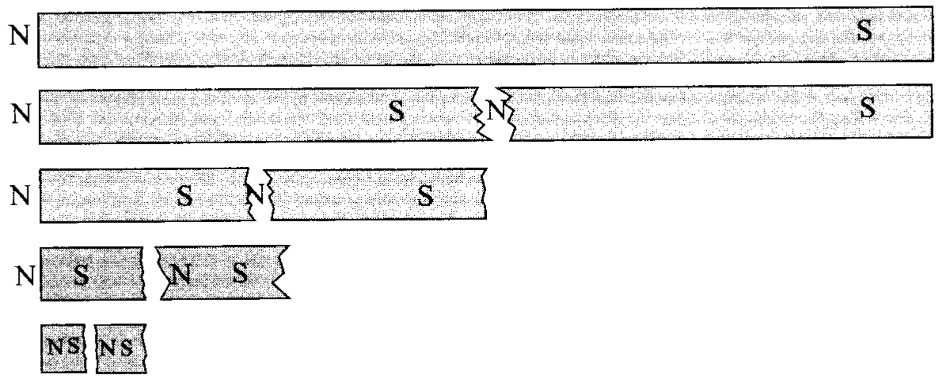
Placing a magnet in a coil placed in East-West direction and passing alternating current (AC) demagnetizes the magnet.

DOMAIN THEORY OF MAGNETS

Domain theory of magnetism was developed and helps to explain the phenomenon of magnetism.

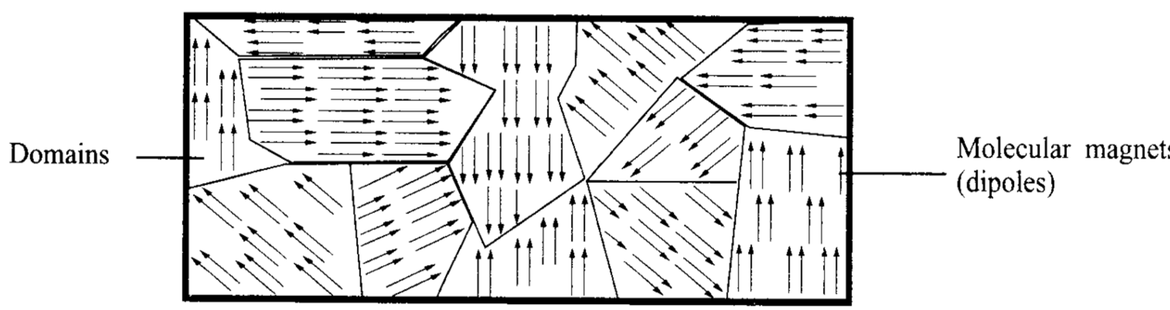
HOW TO SHOW THE EXISTENCE OF MOLECULAR MAGNETS

A magnetized steel bar is cut into two halves and tested for polarity, cut one of the halves into two halves and again test polarity. The cutting continues until one is not able to cut any more.

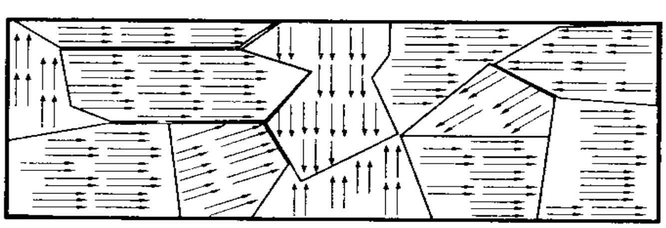


Polarity test for the halves show that each piece is a magnet in its own. Cutting the magnets further would see that the smallest magnet would be a molecule.
In ferromagnetic materials these molecular magnets or dipoles (with two poles) occupy tiny regions called domains. Magnetism in each domain is aligned but the domain points in different directions.
Domain theory of magnetism states that inside a magnet there are small regions in which magnetic direction of all dipoles are aligned in the same direction.
A dipole is the smallest particle of a magnetic material i.e. equal to an atom in a conductor.
Domain theory is used to explain the process of magnetization and demagnetization.
MAGNETISATION is the process of making a magnet from a magnetic material.

- Since the domains are aligned in all possible directions in an unmagnetised material, the net magnetism in the material is zero

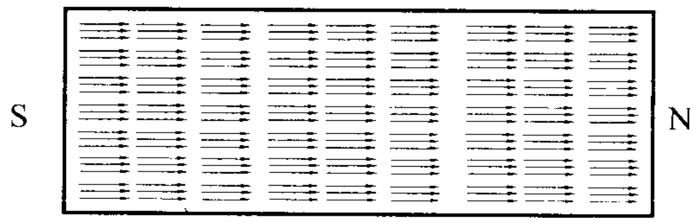


- In partially magnetized material, the domains align themselves as shown in the figure. Note that the domains are not all aligned in the same direction.



Partially magnetised

- When the material is fully magnetized, the domain walls and the molecular magnets align themselves in one particular direction as shown in the figure.



Fully magnetised

A ferromagnetic material is said to be magnetically saturated when the walls are swept out and molecular magnets point in the same direction.
A resultant north pole is produced at one end and a south pole at the other end.

DEMAGNETISATION

Self demagnetization is when the walls of domain slowly return to their original state as this is a more stable state. This is due to the poles at the end which tend to reverse the direction of the molecular magnets.
Demagnetization process can also be influenced externally by giving the molecular magnets enough energy to overcome the forces holding them in a particular direction. This energy may be provided by heating, hammering or dropping on a hard surface or by using an alternating current.

Chapter 8

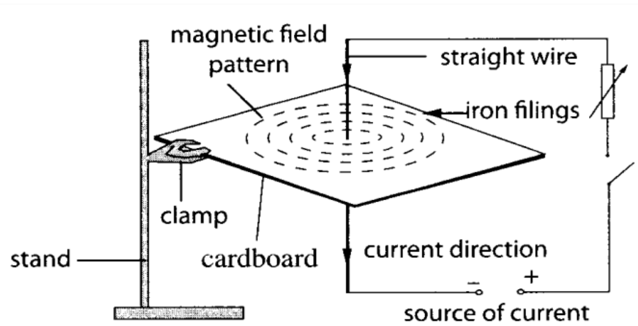
ELECTROMAGNETISM

There is a relationship between electric current and magnetism and the interaction between these two fields is known as electromagnetism.

MAGNETIC FIELD DUE TO A STRAIGHT CURRENT-CARRYING CONDUCTOR

HOW TO SHOW MAGNETIC FIELD PATTERN DUE TO A STRAIGHT CURRENT-CARRYING CPONDUCTOR.

The experiment is set up as follows and sprinkle iron filings on the card and switch on the current and observe the pattern formed by iron filings.

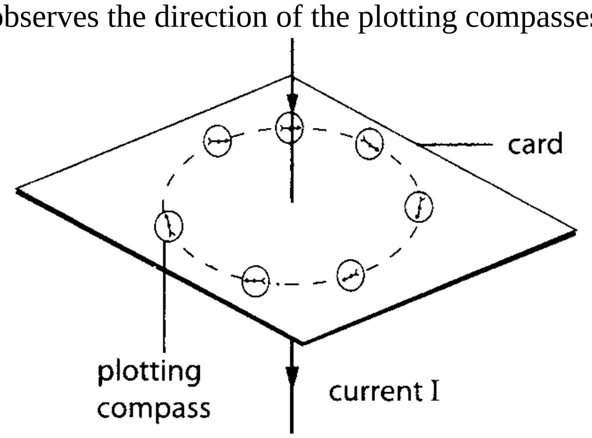


The iron filings settle in a particular pattern depending on the magnetic field present. The iron filings settle in concentric circles round the wire suggesting that there is magnetic field around the wire. Current in the conductor has produced a magnetic field around it.
Magnetic field around a straight current-carrying conductor is a pattern of concentric circles around the conductor.
The field has three features:

a. Magnetic lines are circular
b. The field is strongest close to the wire
c. Increasing the current increases the strength of the field.

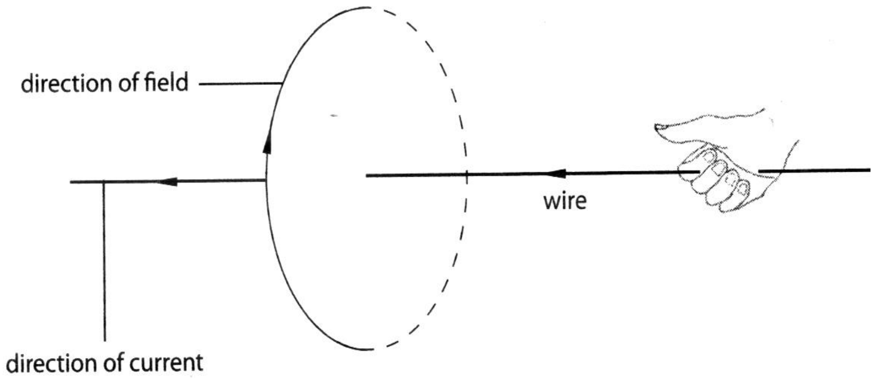
HOW TO DETERMINE THE DIRECTION OF MAGNETIC FIELD FOR CURRENT-CARRYING CONDUCTOR

The experiment above is repeated but using plotting compass instead of iron filings and observes the direction of the plotting compasses.

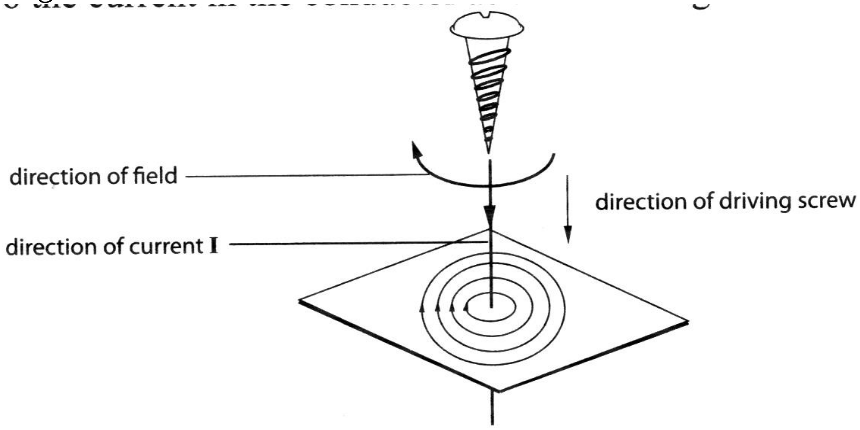


RULES FOR DETERMINING THE DIRECTION OF MAGNETIC FIELD

a. RIGHT HAND GRIP RULE
   Assuming you are holding a conductor in your right hand with the thumb pointing in the direction of the current, the other fingers will point in the direction of the magnetic field due to the current in the wire.

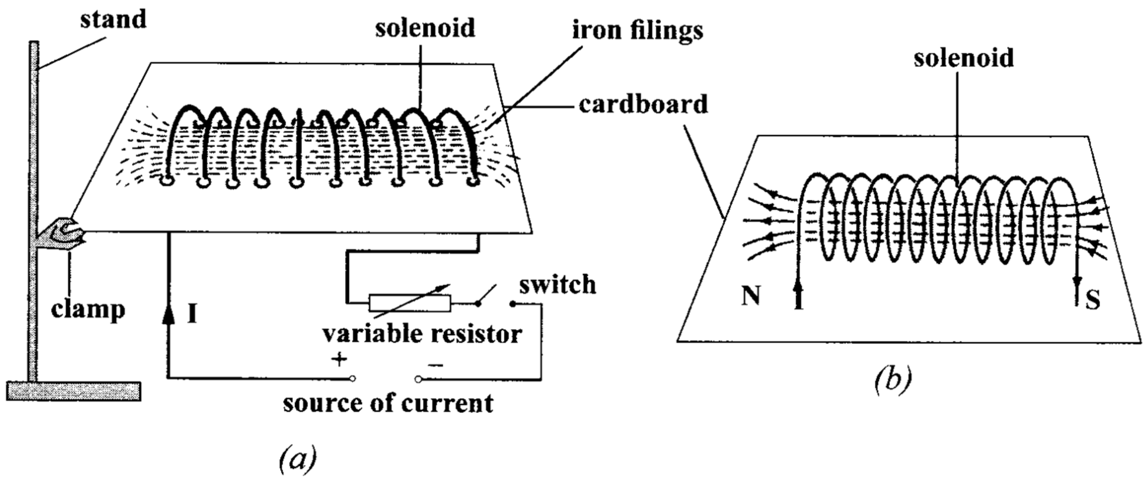


b. RIGHT HANDED CORK SCREW RULE
   Imagine you are holding and turning a screw in your right hand with the screw pointing in the direction of the current, and turning the screw clockwise so that it advances in the direction of the current. The clockwise rotation of the screw gives the direction of the magnetic field due to the current in the conductor



MAGNETIC FIELD DUE TO A CURRENT CARRYING SOLENOID
A solenoid is a long cylindrical coil made of a number of turns of a closely packed wire.

HOW TO SHOW THE MAGNETIC FIELD PATTERN DUE TO A CURRENT CARRYING SOLENOID
A solenoid is mounted on a rectangular piece of cardboard and iron filings are sprinkled on the cardboard. The switch is closed, observe and draw field patterns shown by the iron filings.
Repeat the experiment by placing a number of magnetic plotting compassesinstead of iron filings both inside and outside the solenoid.



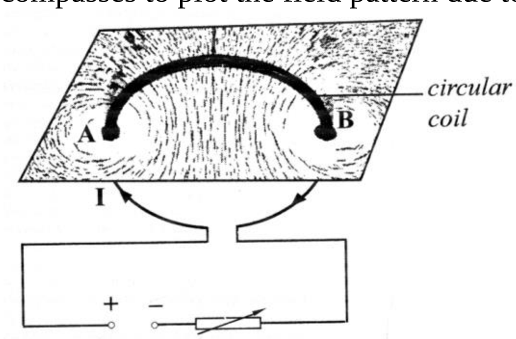
It is observed that iron filings arrange themselves as shown figure (a) and that the plotting compasses show direction of field pattern.
The solenoid behaves like a magnet with the N and S poles as shown in figure (b).

POLARITY OF A COIL (SOLENOID) CARRYING AN ELECTRIC CURRENT

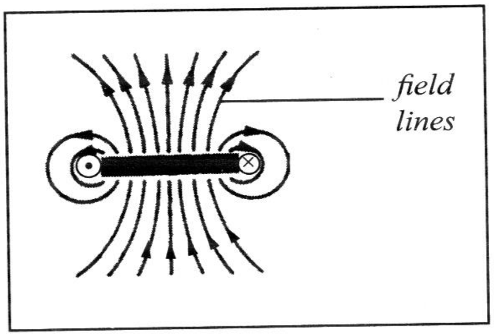
If the direction of the current through the end being viewed is clockwise, then that end is found to be the south (S) pole as shown in figure (b) and if the direction is anticlockwise the end is found to be a north (N) pole.

HOW TO SHOW THE MAGNETIC FIELD PATTERN AROUND A SHORT CIRCULAR CURRENT-CARRYING COIL

Mount a short circular coil on a cardboard and sprinkle iron filings on it. Use plotting compasses to plot the field pattern due to the electric current flowing in the coil.

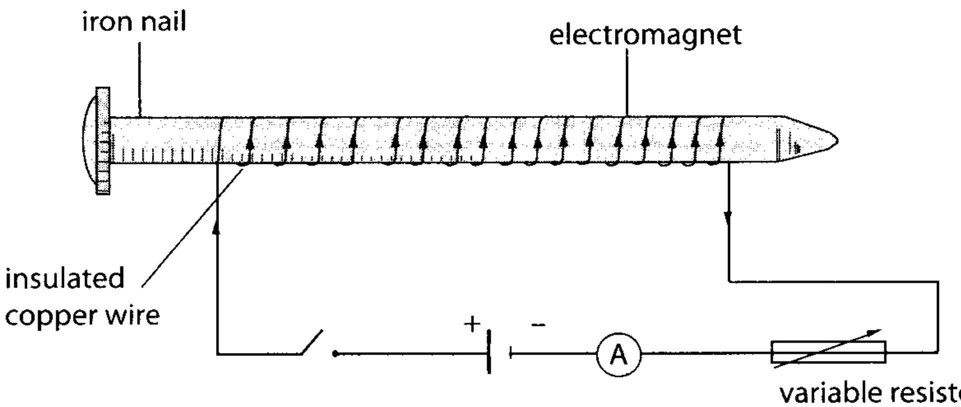


At point A the current is coming out of the cardboard and at B the current is going into the cardboard
Applying the right hand screw rule or the right hand grip rule at points A and B, the direction of the field can be determined.



SIMPLE ELECTROMAGNETS

An electromagnet is a device made by coils of an insulated wire wound on a magnetic material and then current passed through the coils.



HOW TO DETERMINE THE STRENGTH OF AN ELECTROMAGNET

An insulated copper wire is wound round the long iron nail and connect the circuit as shown.

- All the windings are in a single layer i.e. all are touching the nail,
- the windings should be close together
- All windings are in the same direction.

Close the switch and adjust the variable resistor so that a suitable current flows in the circuit. Place steel drawing pins at the base of the nail, one after another and note maximum number of pins the electromagnet can keep attracted to it. Repeat the experiment by varying the current and noting new maximum number of pins attracted.

It can be noted that the strength of an electromagnet increases with

a. Increasing current when the number of windings per length is constant
b. The number of turns per length when the current is kept constant.

Strength of an electromagnet also depends on the material the nail is made of. Soft magnetic alloys will make strong electromagnets.

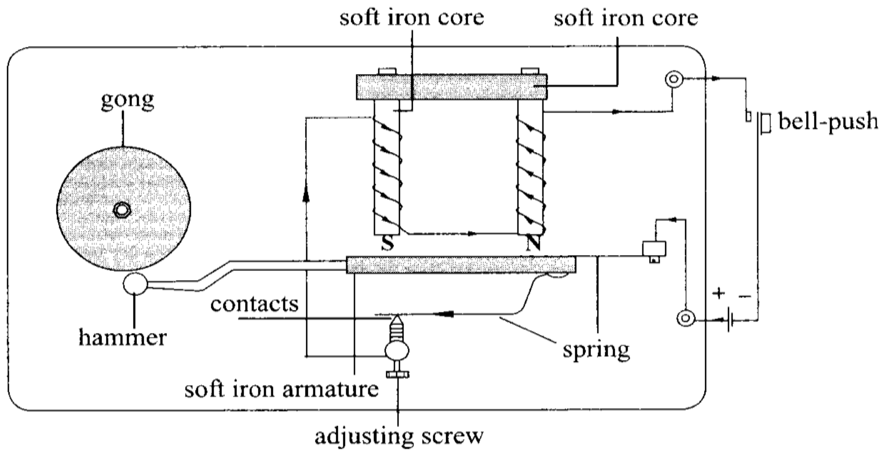
APPLICATIONS OF ELECTROMAGNETS

There are many devices that make use of electromagnets including

- Electric bell
- Telephone receiver

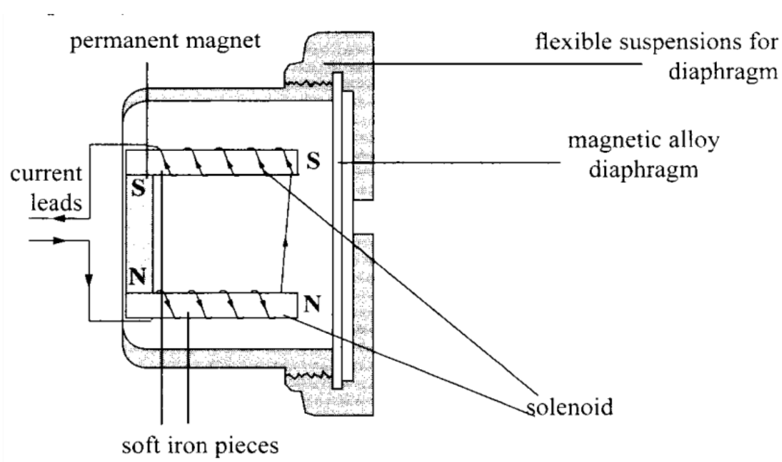
a. THE ELECTRIC BELL

The electric bell consists of two soft iron cores connected by a soft iron core. An insulated wire is wound in an opposite directions round the two cores.



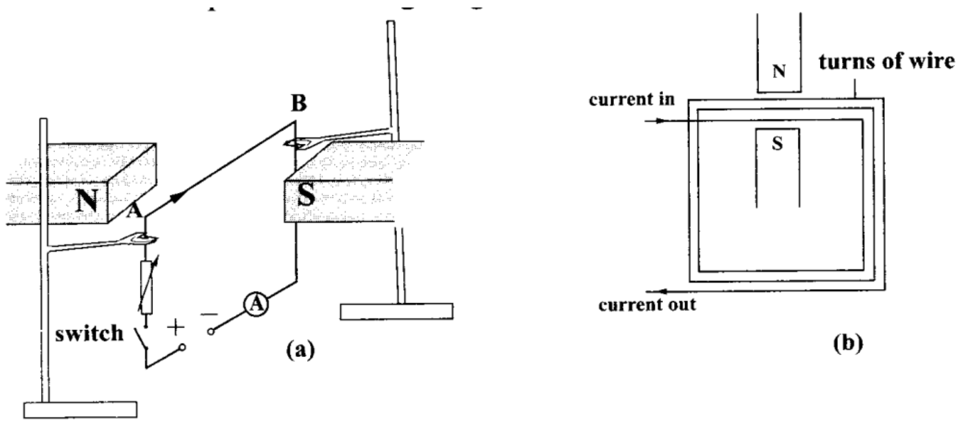
When the switch is closed (by pushing a button switch) a current flows through the circuit and the cores become magnetized. The cores then attract the soft iron armature which creates a gap between the contacts thus breaking the circuit and stopping the flow of current.
As a result the cores lose their magnetism and the armature returns to its original position resulting in contacts closing so that current flows. The cycle is repeated as long as the switch is closed. A hammer which is attached to the end of the armature keeps hitting the gong every time contact is made resulting in familiar continuous sound of ringing bell. When push switch is released the current flow stops and the bell stops ringing.

b. THE TELEPHONE RECEIVER
Commonly referred to as earpiece works on the same principle as the electric bell. When a person speaks in the microphone on the other end of the line an electric current is set up in the earpiece receiver having the same frequency as that of sound waves in the microphone.
As current in the earpiece is varying the diaphragm made of springs of magnetic alloy vibrates accordingly. A similar sound to the one in the microphone is reproduced in the receiver (earpiece)



FORCE ON A CURRENT-CARRYING CONDUCTOR IN A MAGNETIC FIELD (MOTOR EFFECT)

HOW TO DEMONSTRATE A FORCE ON A CURRENT-CARRYING CONDUCTOR (MOTOR EFFECT)
An apparatus is arranged as shown with AB being a flexible wire loosely held between the poles of strong magnets.



The switch is closed and observe what happens to the wire.
The experiment is repeated with

- a larger current
- stronger magnets but with the same initial current
- two or more turns of wire in the magnetic field but carrying the same current
- the battery interchanged

The results show that the wire in the magnetic field experiences a force. The force of the wire increases when

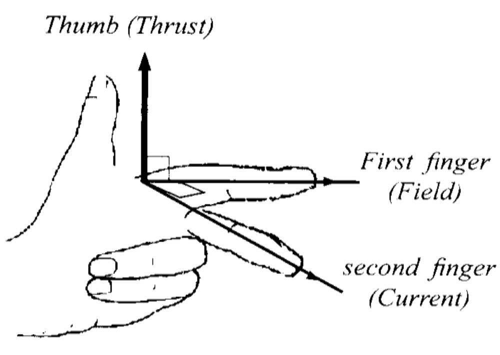
a. the current is increased
b. the stronger magnets are used
c. the number of turns of the wire in the magnetic field is increased.

Current-carrying conductor placed in a magnetic field experiences a force i.e. motor effect.

FLEMING LEFT HAND RULE

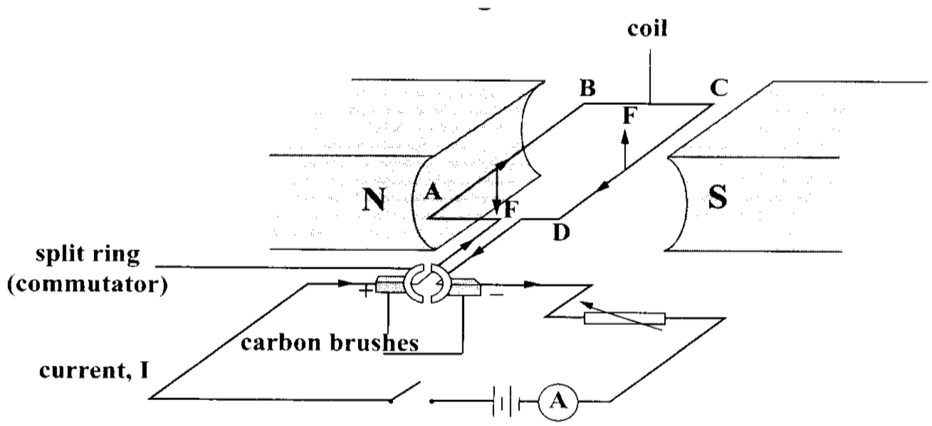
The method of determining the direction of force on a current-carrying conductor was proposed by a physicist Fleming using three fingers of the left hand.
When the thumb sand the first two fingers are held at right angles to each other,

- the First finger points in the direction of the Field,
- the seCond finger points in the direction of the Current
- the Thumb points in the direction of the Thrust (force) on the conductor.



APPLICATIONS OF ELECTRIC MOTOR EFFECT

a. SIMPLE D.C. ELECTRIC MOTOR
An electric motor is a device which converts electrical energy to mechanical energy. Examples of devices which use electric motors include electric drill, vacuum cleaner, electric shaving machine, electric fan, electric bell, etc.
A simple electric motor consists of a rectangular coil of wire placed between the poles of a strong magnet

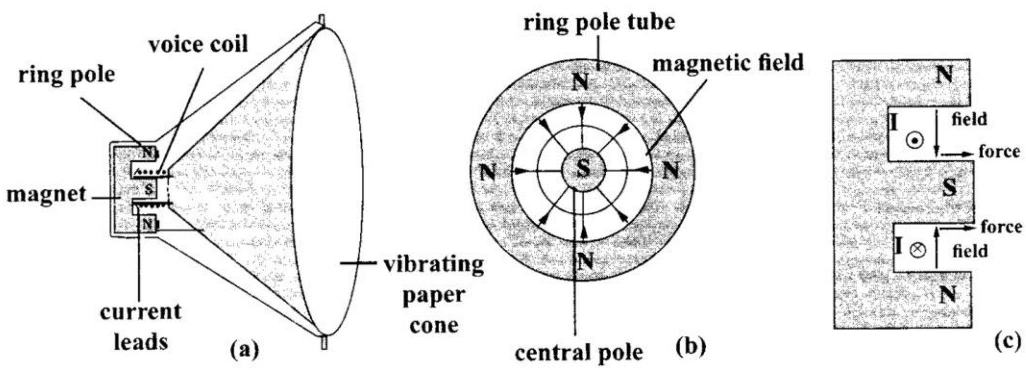


The end of each wire is connected to a section of a split ring called commutator. The commutator rotates with the coil. Two carbon brushes are fixed just by touching the commutators. Current enters the coil through the brushes.
According to Fleming's left hand rule, wire AB experiences a force downwards while wire CD experiences an upward force. These two equal forces in opposite directions cause the loop ABCD to rotate in anticlockwise direction.
The commutator reverses the current flow in the coil every half-cycle. This ensures that the coil continues to rotate in the same direction.
The motor is found to work faster and strongly when

a. The current in the coil is increased
b. A stronger magnet is used
c. More turns of the coil of the wire is increased
d. The area of the coil in magnetic field is increased.
e. Many coils are used with more split ring parts in many planes

MOVING COIL LOUDSPEAKER

Moving coil loudspeaker works on the same principle as the earpiece. It converts electrical energy to sound energy.



The turns of the cylindrical coil (voice coil) are at right angles to the magnetic field between the ring pole and the central pole. The coil experiences a force in accordance with Fleming's left hand rule, when a current flows through it. A varying force on the coil (in response to the varying current) causes the paper cone connected to it to move thus producing sound waves which travel through the surrounding air to the ear of the listener.

Chapter 9

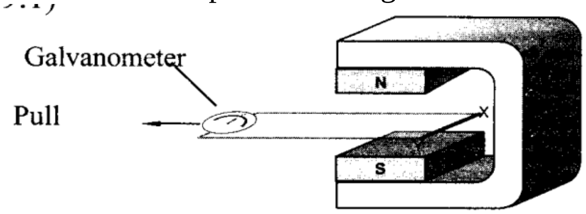
Electromagnetic induction

Electromagnetic or magnetic induction is the production of an `
(i.e., voltage) across an ` in a changing
.

DEMONSTRATION OF ELECTROMAGNETIC INDUCTION.

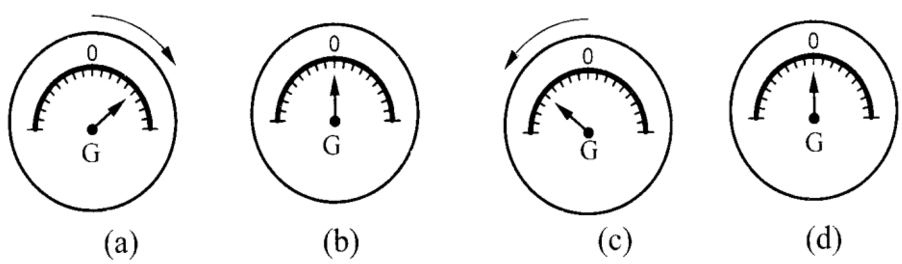
HOW TO INDUCE AN ELECTROMOTIVE FORCE IN A CONDUCTOR (WIRE)

A copper wire XY is connected to a sensitive centre zero galvometer and place the wire between the poles of a magnet as shown.



The wire is pulled quickly horizontally away from the two poles and quickly re-introduced in between the two poles.

When the wire is stationary, the pointer does not move. When the wire is moved out, the pointer shows a deflection in one side as in (a) but returns to zero when wire stops as in (b).

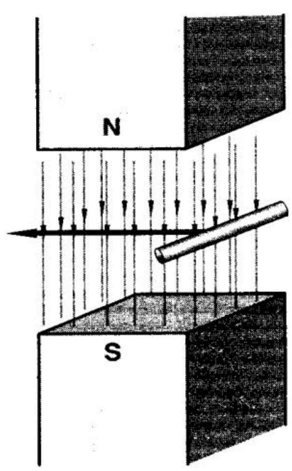


When the wire is re-introduced in between the poles, the pointer deflects in the opposite direction as in (c) but when the wire stops, the pointer returns to the zero position again.

Similar effects can be observed when the magnet is moved instead of the conductor.

No deflection is observed when the wire or the magnet is moved vertically.

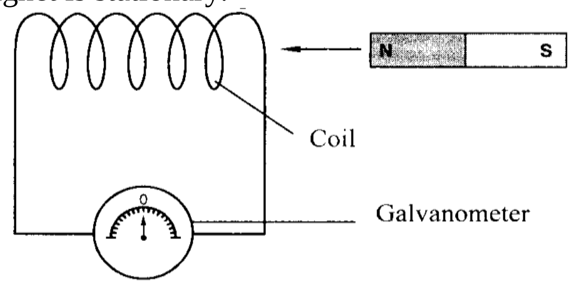
Whenever there is relative motion between the wire and the magnet, electromotive force is induced in the wire and hence current flows in the circuit. This motion is such that the wire cuts the magnetic field lines of the force as shown below



HOW TO INDUCE AN ELECTROMOTIVE FORCE IN A COIL USING A MAGNET

A coil is made using insulated copper wire and the ends of the coil connected to a sensitive centre zero galvanometer.

A bar magnet is introduced into the coil and withdraw quickly or the coil is moved while the bar magnet is stationary.



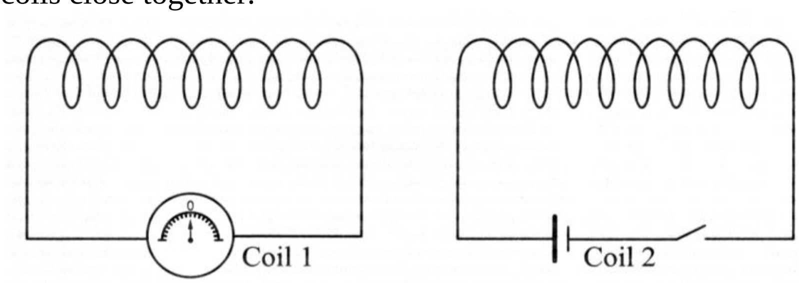
When the magnet is introduced into the coil, the pointer of the galvanometer shows a deflection in one side but returns to zero position when the magnet is brought to rest.

When the magnet is withdrawn from the coil, the pointer deflects but in opposite direction.

Similar effects are observed when the coil moves instead of the magnet.

HOW TO INDUCE AN ELECTROMOTIVE FORCE IN A COIL USING ANOTHER COIL

Two coils are made using insulated copper wire and connect the coils as shown below. Keep the coils close together.



When the switch is closed, the pointer of the galvanometer momentarily deflects to one side but returns to zero position when the switch is left closed.

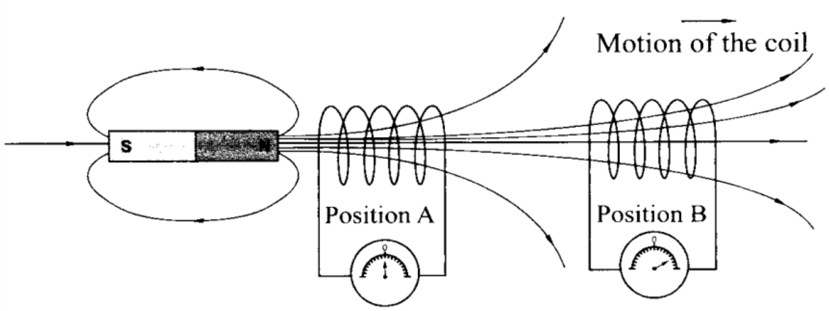
When the switch is opened, the pointer momentarily deflects but in the opposite direction and whenthe switch is left open, the pointer once again returns to zero.

It can therefore be concluded that an e.m.f is induced in coil 1 the moment the switch in coil 2 is closed or opened.

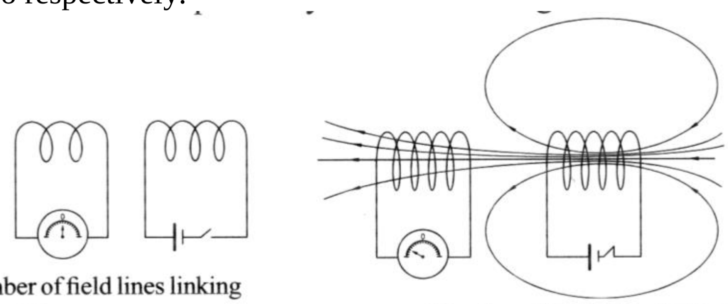
EXPLANATION OF ELECTROMAGNETIC INDUCTION

Electromagnetic induction is as a result of one of those actions at a distance effects.

Faraday explained that an electromotive force is induced in a conductor when there is a change in the number of magnetic field lines linking (passing through) it or the conductor “cuts” the field lines.



The number of magnetic field lines linking or threading the coil decreases from 6 to 4 as the coil ins moved from position A to position B i.e. the coil cuts two lines as it moves from position A to position B
In case of switching on and off of the current, the fields build up to a certain strength and reduces to zero respectively.

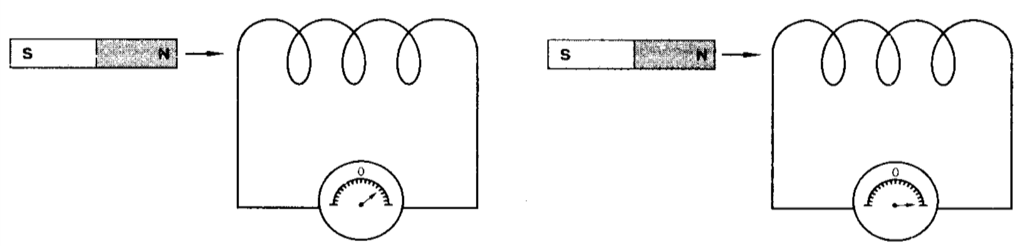


Number of field lines linking the coil is zero

Number of field lines linking the coil is 4

FACTORS AFFECTING THE MAGNITUDE OF THE INDUCED ELECTROMOTIVE FORCE.

HOW TO INVESTIGATE THE MAGNITUDE OF THE INDUCED ELECTROMOTIVE FORCE
A coil is made of a few turns using insulated copper wire and connect the circuit as shown.



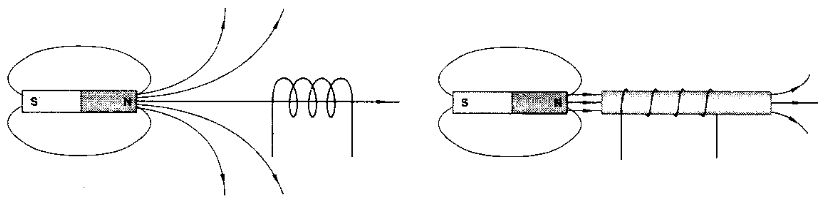
(a) Magnet moving slowly

(b) Magnet moving fast

A magnet is slowly plunged into the coil and then repeated by plunging it quickly and observe the pointer of a sensitive centre-zero galvanometer in each case.
The experiment is repeated by

- Using stronger magnet e.g. ceramic magnets
- Using coil with more turns
- Winding the coil around a soft iron rod

When a magnet is slowly plunged into the coil, the induced e.m.f is less than when the magnet is moved quickly. Same effect is observed when the coil is moved slowly or quickly towards the magnet.
When stronger magnet is used, the induced electromotive force increases. When a coil has more turns the induced e.m.f increases.
Electromotive force also increases when a soft iron core is used. Figure (a) shows one line of force linking the coils while in (b) there are three lines of force.



(a) (b)

The soft iron core concentrates the flux lines onto the coil producing a higher rate of flux when there is relative movement.
It can be concluded that, the magnitude of the induced electromotive force is directly proportional to:

a. The rate of change of the magnetic flux linked to the coil.
b. The strength of the magnetic field, i.e. the stronger the magnet the higher the induced e.m.f
c. The number of turns in the coil i.e. the more turns the higher the induced e.m.f
d. The induced e.m.f is much higher in the presence of a soft iron core.

LAWS OF ELECTROMAGNETIC INDUCTION

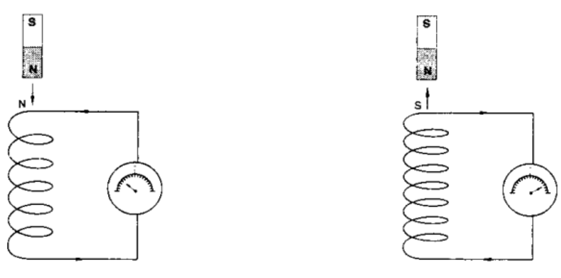
a. FARADAY' LAW OF ELECTROMAGNETIC INDUCTION

Michael Faraday summarized the factors affecting the magnitude of the induced electromotive force

The law states that

The electromotive force induced in a conductor is directly proportional to the rate of change of the magnetic flux linked to the conductor.

THE DIRECTION OF INDUCED ELECTROMOTIVE FORCE (LENZ'S LAW)



(a) (b)

When the North Pole is moved towards the coil, the current flows in such a way as to oppose the introduction of the North Pole. A north pole is therefore induced at the top end of the coil to repel the incoming north pole of the magnet. Similarly South Pole is induced at the top end of the coil to resist the withdrawal of North Pole of the magnet.

b. LENZ'S LAW

The direction of the induced current has been developed by a German scientist called Lenz.

Lenz's law states that

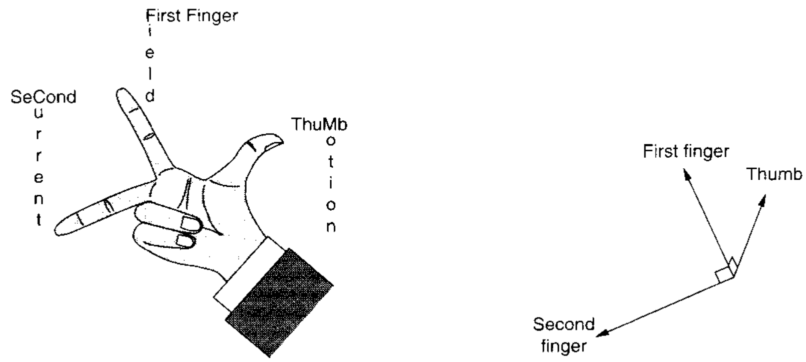
The direction of the induced current is such that it opposes the change producing it.

c. FLEMING'S RIGHT HAND RULE

In straight conductors moving in a magnetic field, Fleming's right hand rule gives the relationship between directions of the field motion and the induced current.

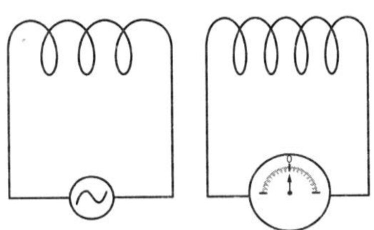
It states that,

If the thumb and the first two fingers of the right hand are mutually perpendicular to each other; the First finger points in the direction of the Field and the thuMb in the direction of Motion of the conductor, then the seCond finger points in the direction of the induced Current



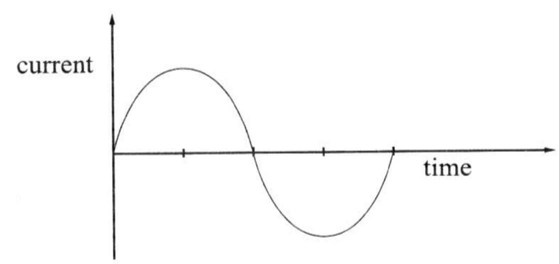
MUTUAL INDUCTION

Switching the current on and off in one coil induces electromotive force in another coil.
The circuit that induces the electromotive force is called the primary circuit
The circuit where the electromotive force is induced is called the secondary circuit. Though the two coils are not connected, changes in current in the primary circuit induces an electromagnetic force in the secondary circuit i.e. mutual induction
Mutual induction occurs on switching the current on and off in the primary circuit. The switching on and off of the circuit can also be achieved by replacing the battery and the switch with an a.c. power supply



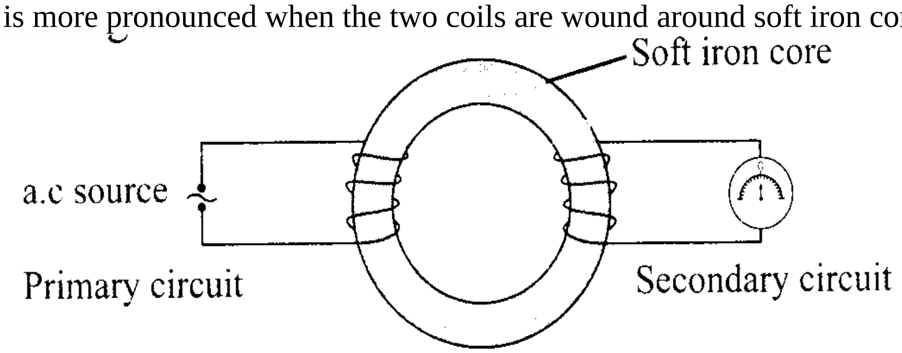
a.c power supply

(a)



(b)

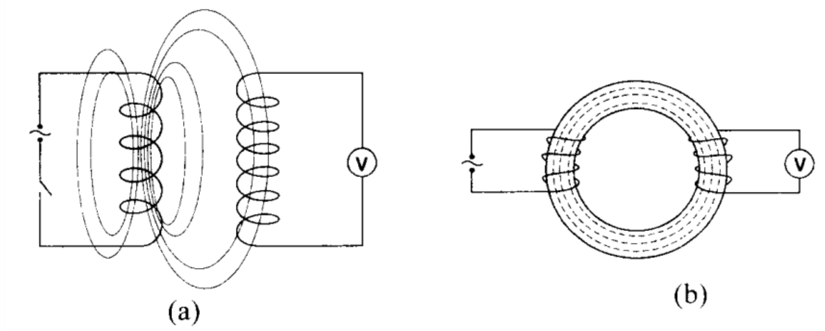
Mutual induction is more pronounced when the two coils are wound around soft iron core.



EXPLAINING MUTUAL INDUCTION

An electric current creates a magnetic field around the conductor through which it flows.
When current is switched on and off in the primary coil, the strength of the field (magnetic flux) keeps changing from zero to maximum and back to zero (alternating current does this automatically without being switched on and off as it fluctuates from zero to maximum).
The change in magnetic flux induces a current in the secondary coil in a way that this current tend to oppose the current in the primary coil and also fluctuates from zero to maximum.

Thus a.c. input in the primary coil induces an a.c. output in the secondary coil. Thus the change in the number of magnetic field lines threading the secondary circuit induces an electromotive force in the secondary circuit in an opposite direction in accordance with Lenz's law.



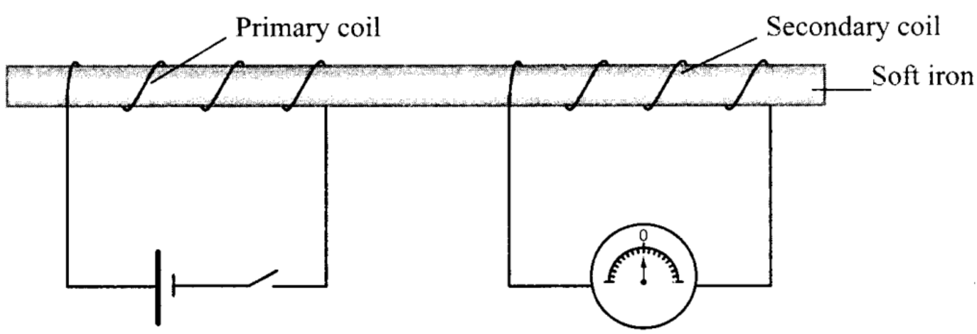
FACTORS AFFECTING THE MAGNITUDE OF THE INDUCED ELECTROMOTIVE FORCE IN THE SECONDARY CIRCUIT

There are several factors that affect the magnitude of the induced e.m.f in the secondary circuit.

INVESTIGATING HOW ELECTROMOTIVE FORCE OF THE PRIMARY CIRCUITS AFFECTS THE ELECTROMOTIVE FORCE OF THE SECONDARY CIRCUIT

Two coils of 4 turns are made using insulated copper wire and ***one*** dry cell connected to the ends of one coil called the primary coil. A sensitive centre-zero galvanometer is connected to the secondary coil.

A soft iron core is introduced inside the two coils as shown in the figure below



The experiment is repeated using ***three*** cells instead of one and not difference in the deflection of the galvanometer.

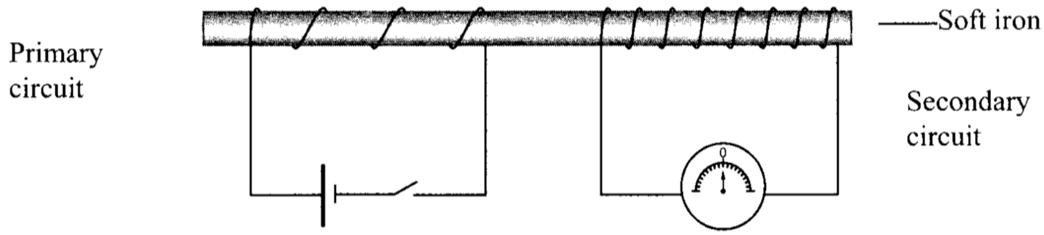
When three dry cells are used, the deflection of the needle of the galvanometer is more than when one dry cell is used. This shows that a higher e.m.f is induced in the secondary circuit.

Induced electromotive force in the secondary coil (ε_s) is directly proportional to the electromotive force in the primary coil (ε_p)

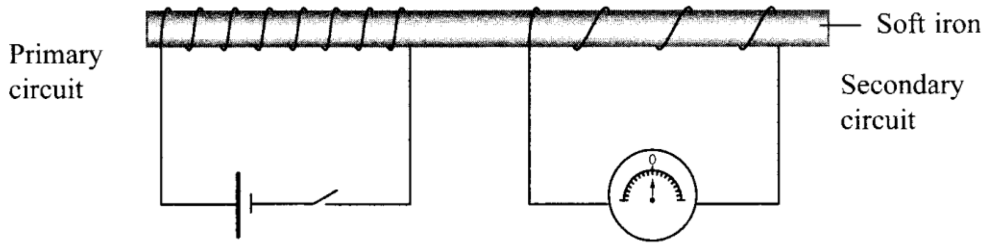
i.e. $\varepsilon_s \propto \varepsilon_p$

INVESTIGATING THE EFFECT OF THE NUMBER OF TURNS IN THE PRIMARY AND SECONDARY CIRCUIT ON INDUCED ELECTROMOTIVE FORCE

The experiment is set as shown in the figure with more turns on the secondary coil than the primary. Close the switch and note the deflection on the galvanometer.



Interchange the primary and the secondary coils so that there are less turns on the secondary coil as shown in the figure and compare the deflections.



When more turns are used in the secondary circuit, a higher electromotive force is induced in the secondary circuit.
It can be noted that the magnitude of the induced electromotive force in the secondary circuit depends on the ration of the number of turns of the coils used.

Electromotive force induced in the secondary circuit (ε_s) $\propto \frac{number\ of\ turns\ in\ secondary\ coil, N_s}{number\ of\ turns\ in\ primary,\ N_p}$

i.e. $\varepsilon \propto \frac{N_s}{N_p}$

When the experiment is done using an a.c. power supply,

$\frac{secondary\ emf\ , V_S}{primary\ emf\ ,\ V_p} = \frac{\text{number of turns in secondary, } \mathrm{N_S}}{\text{number of turns in primary ,} \mathrm{N_p}}$

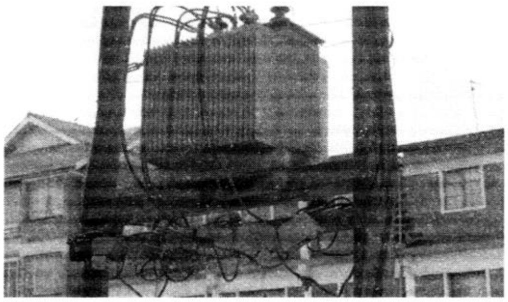
In an ideal case (no power loss), the electric power (P = VI) in the primary is equal to that in the secondary. Thus, when voltage is stepped up, the current is stepped down and vice versa.

Hence $\frac{I_S}{I_p} = \frac{\mathrm{N_s}}{\mathrm{N_p}}$

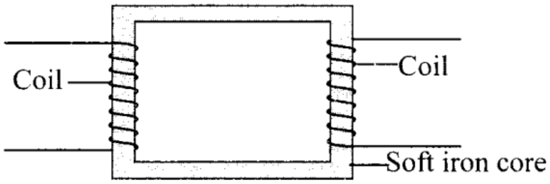
The e.m.f induced in the secondary is maximum when the two coils are close together and when wound on soft iron core.

TRANSFORMERS

A transformer is an electrical device that transfers electrical energy from one circuit to another by electromagnetic induction.
In transferring this energy, a transformer changes voltage or electromotive force to a higher or lower value.



A transformer consists of two coils; the primary and the secondary coils. These two coils are not connected to one another in any way but are wound on the same soft iron core as shown below

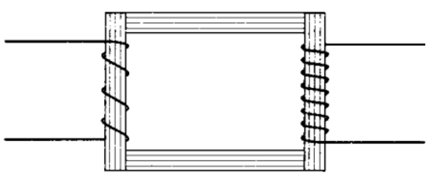


When an alternating electromotive force is applied to the primary coil, a changing magnetic field is produced. The soft iron core links this field to the secondary coil. The alternating field produces an alternating electromotive force in the secondary coil through mutual induction.

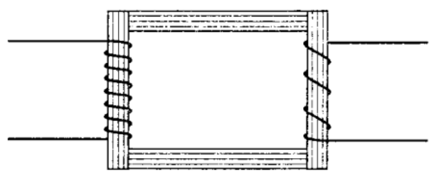
TYPES OF TRANSFORMER

There are two types of transformers

- The step-up transformers where the number of turns in the secondary N_s is more than the number of turns in the primary coil
- Step-down transformers where the number of turns in the secondary coil is less than the number of turns in the primary coil.

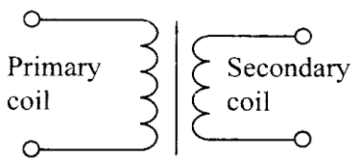


(a) Step-up transformer

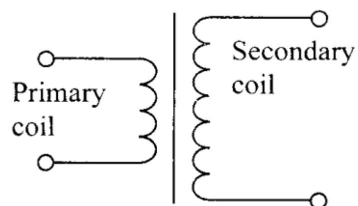


(b) Step-down transformer

The terms step-up and step-down, apply to output voltage of the transformer.
Circuit symbols for step-up and step-down transformers are shown below

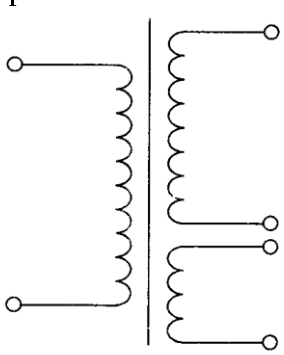


(a) Step-down transformer



(b) Step-up transformer

A transformer may have more than one secondary coils and such transformers can step-up and step-down simultaneously.



EFFICIENCY OF A TRANSFORMER

Transformers transfer electrical energy from one circuit to the other. The energy per second, supplied to the primary coil is called the power input while the energy obtained per second from the secondary coil is called power output.
In an ideal transformer, the power input is equal to power output.

Efficiency of a transformer indicates how effective a transformer is in transferring the input energy to output energy.

Efficiency of the transformer is the ratio of the power output to power input expressed as a percentage.

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

Well designed transformers have efficiency as high as 98%(100% efficiency)

For an ideal transformer power output = power input (100% efficiency)

Power input $V_pI_p = V_sI_s$

$$\frac{V_s}{V_p} = \frac{I_p}{I_s}$$

Example 1

A step-down transformer is connected to a 240V alternating current power supply. The primary coil has 1000 turns. How many turns should the secondary coil have so as to operate a 12V alternating current toy car?

Solution

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$\frac{12}{240} = \frac{N_s}{1000}$$

N_s = ***50 turns***

Example 2

An alternating e.m.f of 240V is applied to a step-up transformer having 200 turns on its primary coil and 4000 turns on its secondary coil. The secondary coil is 0.2A.

Calculate

a. Secondary e.m.f
b. Primary current
c. Power input
d. Efficiency
e. Comment on the answer to (d)

Solution

a. Secondary e.m.f

$$\frac{V_s}{V_p} = \frac{N_s}{N_p}$$

$$V_s = \frac{V_p \times N_s}{N_p}$$

$$= \frac{240 \times 4000}{200}$$

$$= 4\,800V$$

b. Primary current

$$\frac{I_s}{I_p} = \frac{N_p}{N_s}$$

$$I_p = \frac{N_sI_s}{N_p}$$

$$= \frac{4000 \times 0.2}{200}$$

$$= 4.0A$$

c. Power input

$I_p \times V_p = 4 \times 240$

$= 960W$

d. Efficiency $= \frac{\text{power output}}{\text{power input}} \times 100\%$

$= \frac{I_s\ V_s}{960}$ x 100%

$= \frac{0.2 \text{ x } 4\,800}{960}$ x 100%

= 100%

e. This is an ideal transformer.

Example 3

A transformer has an input coil of 60 turns. When this coil is connected to a 240V source, the output voltage is found to be 4 800V. The output power is 3 600W.

a. Calculate the number of turns in the output coil
b. If the efficiency of the transformer is 80%, calculate the
   i. Output current
   ii. Input current

Solution

a. Number of turns

$\frac{V_s}{V_p} = \frac{N_s}{N_p}$

$\frac{4\,800}{240} = \frac{N_s}{60}$

$N_s = \frac{4800 \text{ x } 60}{240}$

=***<u>1 200 turns</u>***

b. (i) Output current

$P_o = V_s\ I_s$

$3\,600 = 4\,800 \text{ x } I_s$

$I_s = \frac{3\,600}{4\,800}$

<u>= 0.75A</u>

(ii) Input power

Efficiency (E) = $\frac{P_o}{P_i}$ x 100%

$= \frac{V_s I_s}{V_p I_p}$ x 100%

$80 = \frac{4\,800 \text{ x } 0.75}{240 \text{ x } I_p}$ x 100%

$I_p = \frac{360000}{240 \text{ x } 80}$

<u>= 18.75A</u>

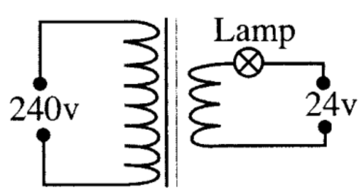
Example 4

An ideal transformer is used to operate a 16V, 48W lamp from a 240V mains supply. Its primary coil has 450 turns.

a. Draw a well labeled sketch of the transformer.
b. How many turns does the transformer have in its secondary coil?

Solution

a.



b. $\frac{V_s}{V_p} = \frac{N_s}{N_p}$

$\frac{16}{240} = \frac{N_s}{450}$

$N_s = \frac{450 \times 16}{240}$

= 30 turns

FACTORS AFFECTING THE EFFICIENCY OF A TRANSFORMER

The energy supplied in the primary circuit of a transformer is lost in a number of ways thereby affecting its efficiency.

a. RESISTANCE OF THE COILS

As the current flows in the coils, the wires heat up and energy is lost in form of heat

$$\text{Energy} = I^2R$$

This method of losing energy is called joule heating.

To minimize energy loss in this way, thick copper wires of low resistance are used where large currents are to be carried.

b. EDDY CURRENTS

When the magnetic field changes, small amount of current called Eddy currents are induced in the core of the transformer. This heats up the core and energy is lost in form of heat.

To minimize this lose of energy, the core is laminated and insulated between the laminations. This reduces the magnitude of the Eddy currents.

c. HYSTERESIS LOSSES

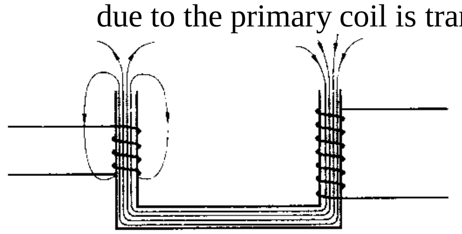
The magnetization and demagnetization of the core by the alternating magnetic field requires energy. This energy heats up the core and is lost as heat energy i.e. hysteresis loss.

To minimize this loss of energy, the core is made of a soft magnetic material that is easy to magnetize and demagnetize e.g. soft iron .

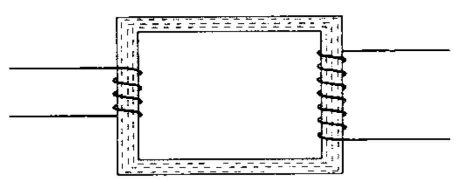
d. FLUX OR MAGNETIC LEAKAGE

Not all magnetic lines of force due to the primary coil may link the secondary coil resulting in what is called flux leakage.

To reduce this loss, the core is designed in such a way that almost all the magnetic effect due to the primary coil is transferred to the secondary coil e.g. using a loop



(a) Incomplete core

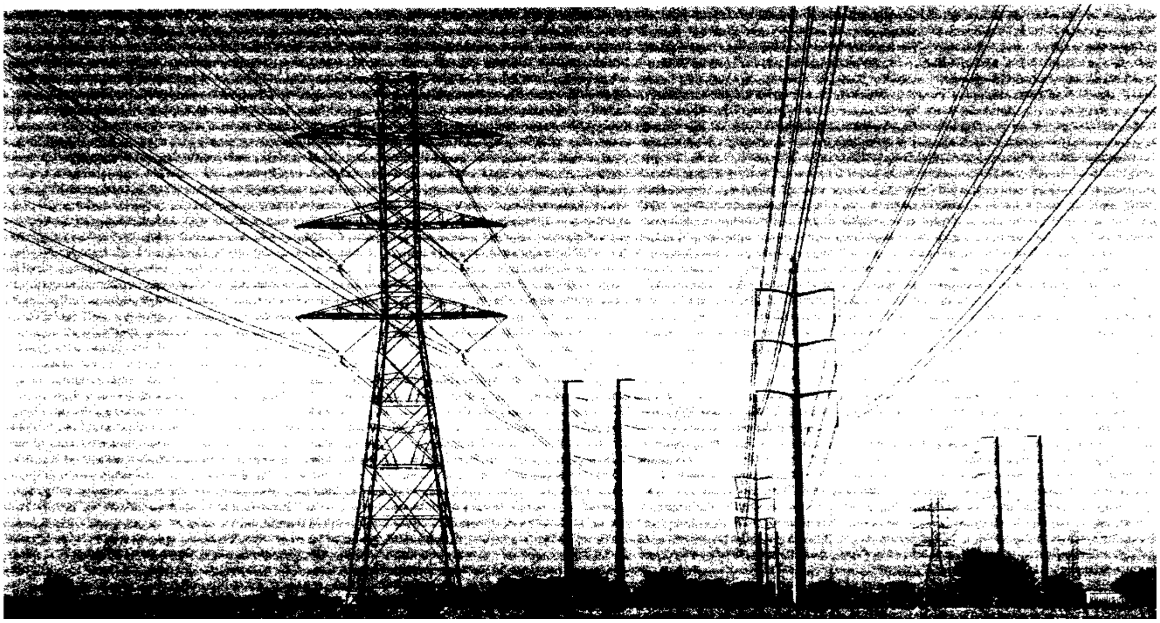


(b) Complete core (loop)

Since it is not possible to completely reduce energy losses in transformers, very large transformers are oil-cooled toreduce overheating.

ELECTRIC POWER TRANSMISSION

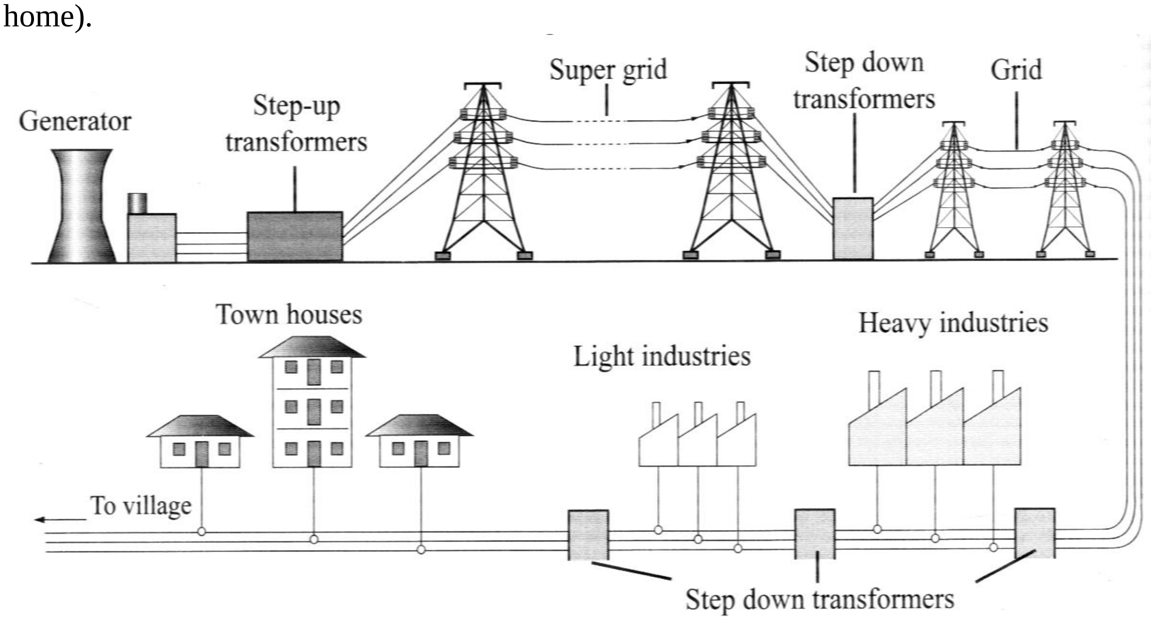
Electrical energy generated at a power station is delivered to consumers through cables i.e. through the National Grid System which consists of a network of transmission cables carried over through structures called the pylons.



Due to electrical resistance (R) of the transmission cables, some electric power ($P = I^2R$) is lost in form of heat in the transmission cables.
Note that electrical resistance of a wire (conductor) is directly proportional to its length.
To reduce power loss in transmission cables

a. Very thick transmission wires are used.
b. Transmission wires are made of metals like copper that are very good conductors of electricity hence have very low electrical resistance.
c. Electrical current is transmitted at very high voltage and at very low current.

EXAMPLE
If electric power is generated at a relatively high current (e.g. at 100A and 25kV), its voltage is immediately stepped up at the generating station, automatically stepping down its current for transmission through the grid (e.g. at 6.25A and 400kV).
On reaching the consumer, the voltage is stepped down to a low value (e.g. 240V for use in a home).



DANGERS OF HIGH VOLTAGE TRANSMISSION

Due to high voltages in the transformation cables, a strong electric field is set up between the cables and the earth. Air, an insulator under normal conditions, may start to conduct electricity especially on rainy days. People or animals in the vicinity may get electrocuted.

To minimize this danger, transmission cables carrying high voltages are supported high above the ground by pylons. When the cables enter towns and cities, they are buried underground.

ENVIRONMENTAL IMPACT OF POWER GENERATION AND TRANSMISSION

Generation and transmission of power have both positive and negative impacts on the environment. The main of environmental pollution is the use of fossil fuels, nuclear, etc.

Power is generated through sources like hydroelectric, nuclear reactions, fossil fuels, solar, geothermal energy and biomass.

HYDROELECTRIC POWER

Hydroelectric power is the type of power generated from generated from gravitational potential energy of water stored in reservoir. This method of power generation is cheaper, has low operating costs and less extensive compared to other methods of generating electricity from fossil fuels or nuclear energy.

Negative impacts of hydroelectric power generation include the following:

a. Dislocation of people living around place where a dam has to be constructed
b. Releasing carbon dioxide during construction and flooding of the reservoir.
c. Can be catastrophic if the dam wall collapses e.g. can cause flooding
d. The dam becomes a breeding site of mosquitoes which carry and transmit malaria.

NUCLEAR ENERGY (POWER)

Nuclear energy is commonly used in developed countries and they produce very high energy. The nuclear plant requires a lot of water to cool. However, it possesses environmental problems. The following are the negative impacts of nuclear power generation

a. Nuclear power plant may reject heat to water bodies e.g. sea. This causes an undesirable increase of the water temperature which affects aquatic life.
b. Emission of radioactivity to the environment to the environment which possess health problems to people around it.
c. Accidental nuclear explosions in nuclear power plants destroy properties and kill many lives e.g. nuclear explosion of the Japan Fukushima plant on March 11th 2011 that killed over 1000 people.
d. Nuclear bombs are used by terrorists and extremist groups to kill innocent people.

FOSSIL FUELS

Another main way of generating electricity today is by burning fossils to producing steam which is then used to drive a steam turbine to produce power in electric generator.

The negative impact of fossil fuels is the emissions of gases like carbon monoxide (CO) and carbon (CO^2). When carbon dioxide is emitted into the atmosphere it can cause greenhouse effect and lead to global warming.

Burning of some fossil fuels lead to production and release of gases like Sulphur dioxide and nitrogen oxide that contribute to smog and acid rain. They can destroy ozone layer hence exposing us to dangerous emissions from the sun e.g. ultra-violet rays which can damage our skins.

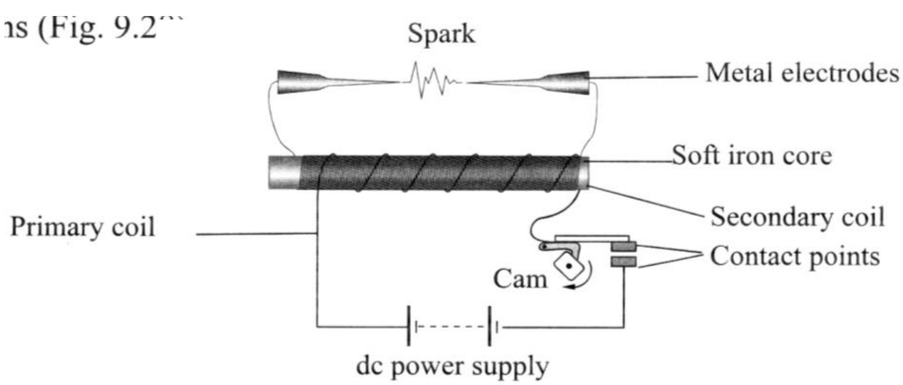
BIOMASS

It is important to note that electrical power can be generated by burning anything that can combust. Some electrical power is generated by burning crops which crops which are grown specifically for the purpose.

Burning biomass also produces some emissions as burning fossil fuels. Biomass captures carbon dioxide out of the air so that the net contribution to global atmospheric carbon dioxide levels lowers.

OTHER USES OF ELECTROMAGNETIC INDUCTION

a. INDUCTION COIL
   Induction coil consists of two coils (secondary and primary coils) with one wound over the other around a soft iron core. The secondary coil has a greater number of turns.



An induction coil works like a step-up transformer but with a d.c. power supply. The direct current in the primary coil is switched on and off by a rotating cam. The current in the primary coil produces a changing magnetic field which in turn induces an electromotive force in the secondary coil.

Due to large amount of turns in the secondary coil and the rapid change of current in the primary coil, a large potential difference is induced between the metal electrodes.

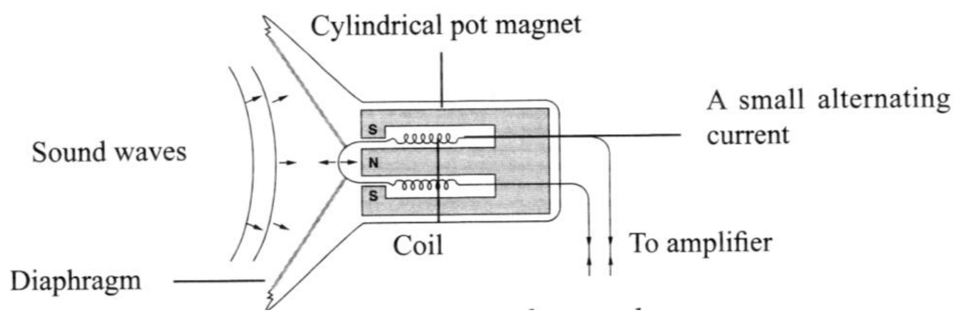
This large potential difference causes a spark between the metal electrodes. This spark may be used in many ways e.g. the spark produced is used in igniting the petrol-air mixture inside the car's engine.

b. MOVING COIL MICROPHONE

A moving coil microphone is a device for changing sound energy into electrical energy. It consists of a diaphragm with a light coil connected to it. This coil is placed in between two poles of a strong cylindrical.

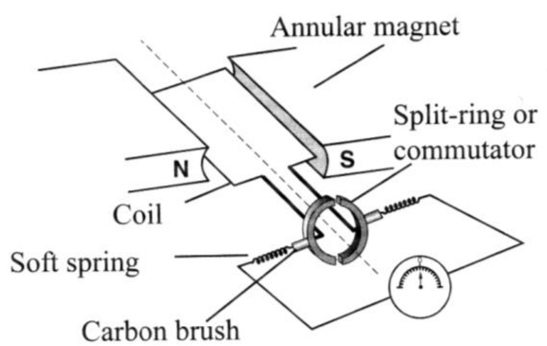
When a person speaks I front of a microphone, the sound energy set the diaphragm into vibration. This moves the coil back and forth between the two poles of the magnet.

A small alternating current is induced in the coil. When this alternating current is made larger (amplified), it operates a loudspeaker.



c. SIMPLE D.C. GENERATOR

A simple d.c. generator has a rectangular coil of a conductor wire whose ends are connected to two halves of a single split-ring called commutator. The split ring makes contact with the carbon brushes which connect them to an external circuit. The two light springs are used to make the carbon brush press lightly on the split-ring. The coil is placed in between two poles of a permanent magnet. The poles are annular in shape so as to concentrate the magnetic field lines to the coil

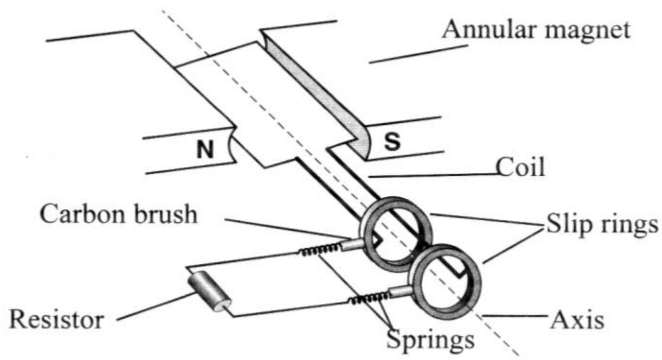


When the coil is rotated about its axis by energy from burning fuel, it "cuts" across the magnetic field of the permanent magnet, causing current to be induced. This induced current causes a deflection of the galvanometer.

When the coil passes through the vertical position, the two halves of the split ring change from one brush to another. This change over between the brushes and the two halves split-ring helps to maintain the flow of the current in the same direction.

d. SIMPLE A.C. GENERATOR

In an a.c. generator, the split-ring are replaced by two slip-rings, thus the direction of the current in the coil changes after every half rotation. This is because each carbon brushes remain on the same ring when the coil is rotating without interchanging positions.



Chapter 10

DIGITAL ELECTRONICS

Electronics is a branch of science that is concerned with the development of tiny electrical circuits designed to process, store or transmit information.
Concepts in electronics are applied in the design of modern communication devices like televisions, calculators, radios, computers, burglar alarms, CD players, digital watches, Automatic Teller Machines, cell phones, etc

CONDUCTORS, SEMI-CONDUCTORS AND INSULATORS

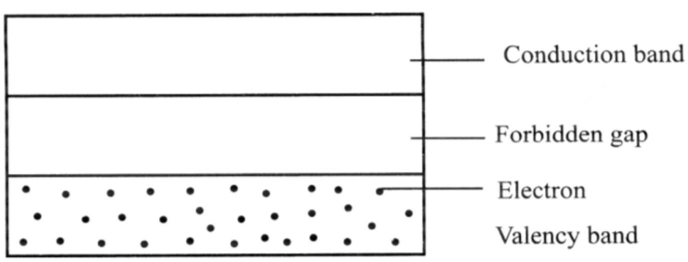
Materials can be grouped according to their electrical conductivity properties as follows:

- Good conductors
  Good conductors are materials that allow an electric current to pass through them easily, e.g. copper, zinc, silver, mercury, etc
- Insulators
  Insulators are materials that do not allow the electric current to flow through them at all, e.g. paper, wood, plastics, etc
- Semi-conductors
  Semi-conductors are those materials whose electrical conductivity lies between good conductors and insulators, e.g. silicon and germanium.

BAND THEORY

In band theory, materials are considered to contain two bands in which electrons may be found. These bands are

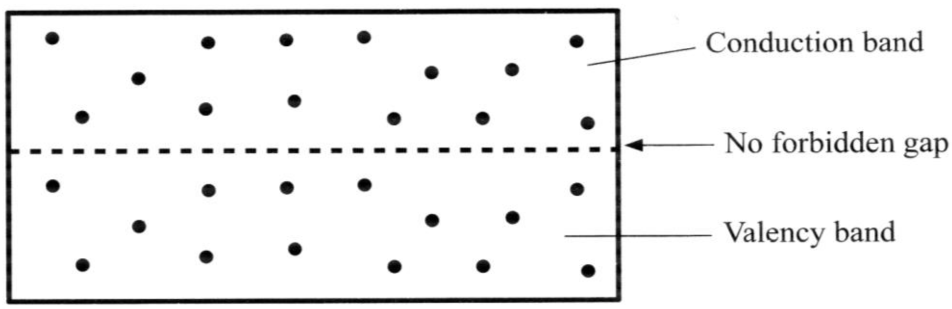
a. Valency band
b. Conduction band.



The two bands are separated by a gap called forbidden gap (no electrons are allowed in this gap). For a material to conduct an electric current, electrons should be in conduction band. However electrons prefer to be in the valency band as this is the lowest energy level. To move the electrons to the conduction band, energy is needed to cross through the forbidden gap. One way of providing energy to cross the forbidden gap is to increase the temperature of the material.

ELECTRICAL CONDUCTION IN CONDUCTORS

In conductors, the valency and conduction bands overlap and hence no energy is needed to overcome the forbidden gap.

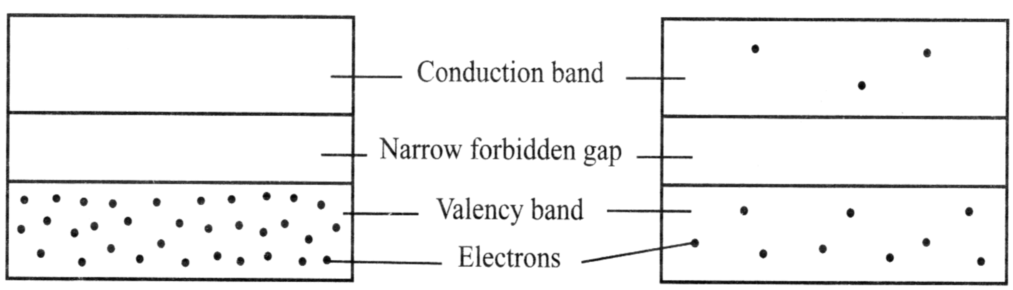


All the electrons are free and mobile to conduct electric current. If conductors are hetated, the internal energy increases and the electrons move in all directions colliding with each other. This explains why metals are poor conductors as temperature increases.

ELECTRICAL CONDUCTION IN SEMICONDUCTORS

In semiconductors the forbidden gap is bigger than in conductors. At low temperatures, all the electrons are in the valency band. However, at room temperature some electrons gain thermal energy and cross the forbidden gap to the conduction band. The material then becomes a fair conductor.

As the temperature increases more electrons move to the conduction band and hence its electrical conductivity is increased. This shows that the resistance of semiconductors decreases with increase in temperature.

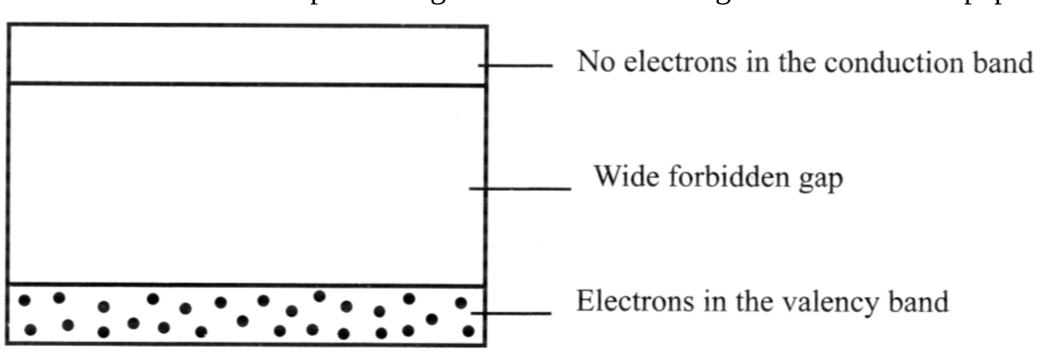


(a) At low temperatures electrons are in the valency band

(b) At high temperatures some electrons move to the conduction band

POOR ELECTRICAL CONDUCTION IN INSULATORS

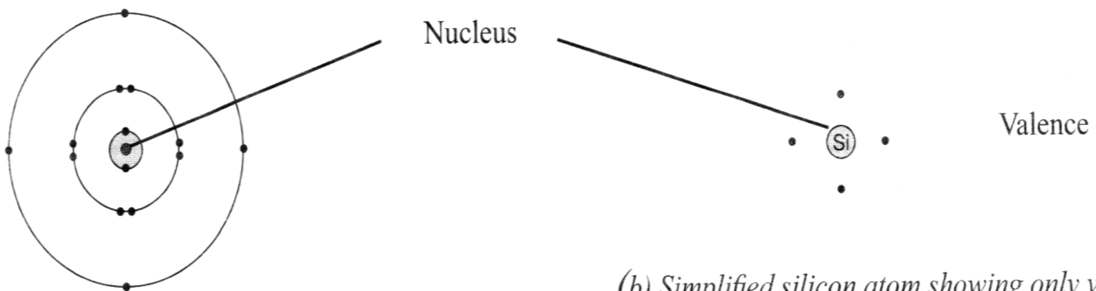
In insulators, the forbidden gap is so wide that any attempt by heating to promote the electrons to the conduction band ends up breaking down the material e.g. if the material is paper it burns off.



TYPES OF SEMICONDUCTORS

INTRINSIC SEMICONDUCTORS

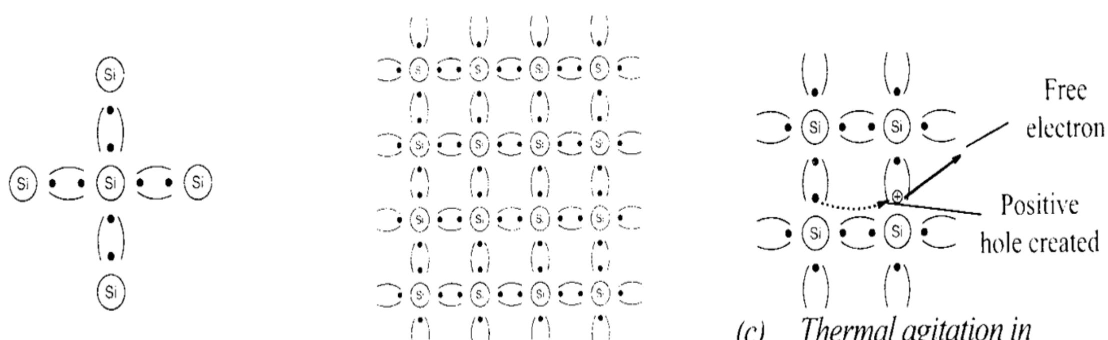
An intrinsic or pure semiconductor is any material which increases its electrical conductivity from within itself (internally).
Silicon and germanium are the most commonly used semiconductors in electronic equipment.



(a) A silicon atom
election configuration: 2.8.4

(b) Simplified silicon atom showing only valence electrons

Silicon has four electrons in its outermost shell (energy level). These electrons are called bonding electrons or valence electrons.
Silicon can be bonded with other silicon atoms through covalent bonding. If the bonding is extended in all directions, the silicon lattice structure is formed.

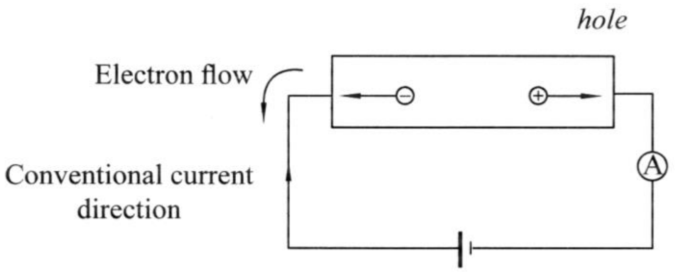


(a) Silicon atom bonded with 4 other silicon atoms

(b) Crystal lattice of pure silicon

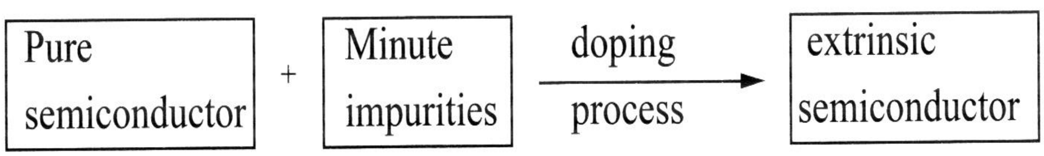
(c) Thermal agitation in a pure semiconductor

At low temperatures, all the electrons are locked up in the covalent bonds i.e. they are in the valency band.
At high temperatures the electrons may gain thermal energy and move to the conduction band, in so doing the bond is broken. These free electrons roam within the lattice and are thus available for conduction. These electrons are called thermal electrons.
A free electron will leave a positive valency in the atom it came from. This vacancy is called a hole. The atom becomes a positive ion and can attract an electron from the neighbouring atom. When this process is repeated from one atom to another, a positive hole seems to drift in the lattice. If the semiconductor is connected in a circuit containing a battery and a milliammeter, a small current is observed.



Two types of charge contribute to the conduction of the current i.e. the negative charge or electrons and the positive charge or holes. The electrons in the conduction band flow in one direction while the holes in the valence band flow in the opposite direction.
Electrical conductivity in intrinsic semiconductors is mainly due to electron-hole pair movement.
In intrinsic semiconductors, the number of electrons is the same as the number of holes created.

EXTRINSIC SEMICONDUCTORS
The electrical conductivity of a pure semiconductor may be increased by adding or introducing a small and controlled amount of other materials (called impurities) into the pure semiconductors.
Doping is the process of introducing very small amounts of impurities into pure semiconductors to improve their conductivity.
Extrinsic semiconductor is the one that has been doped externally.



The impurities used in doping process are elements whose atoms have either three valence electrons or five valence electrons.
Examples of trivalent atoms are boron, aluminium, gallium and indium while pentavalent atoms are phosphorus, arsenic, antimony and bismuth.

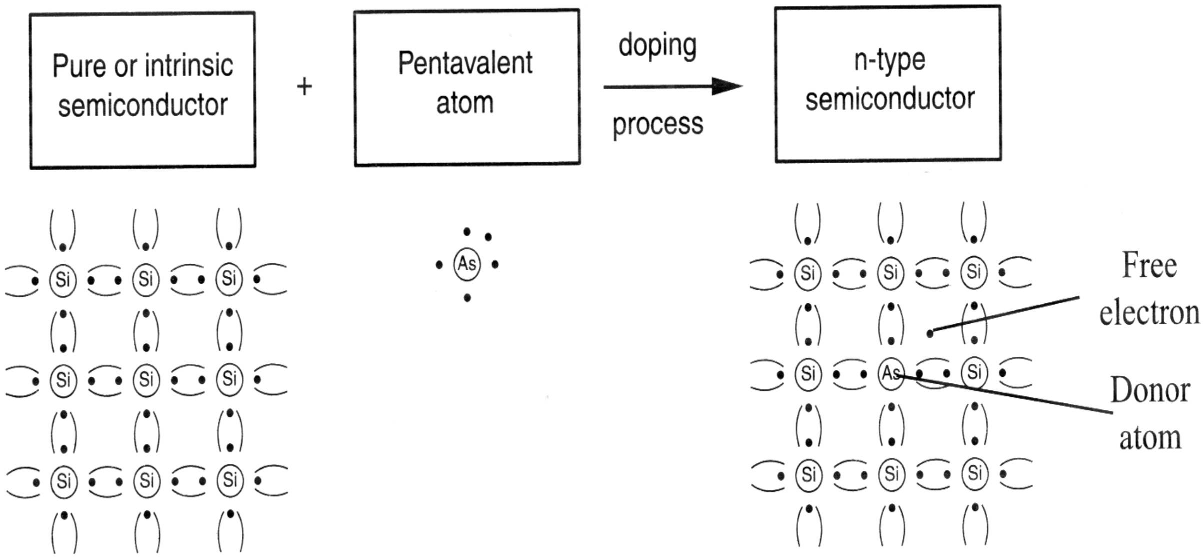
DOPING SEMICONDUCTORS

Nature of the doping element determines whether the semiconductor becomes p-type (positive type) or n-type (negative).

N-TYPE SEMICONDUCTORS

Elements which have five electrons in the outer shell of their atoms e.g. phosphorous give n-type properties to the silicon.

When silicon is doped with arsenic, each silicon atom has four valence electrons and therefore each atom has four neighbouring atoms bonded to it. An atom of arsenic has five valence electrons of which four will participate in bonding with neighbouring atoms. The fifth electron is left free to roam within the lattice. This electron is available for conduction. In this case arsenic is said to be a ***donor impurity.*** The resulting semiconductor has more electrons and is referred to as the n-type semiconductor (n for negative). In this semiconductor the ***majority charge carriers*** are the electrons.



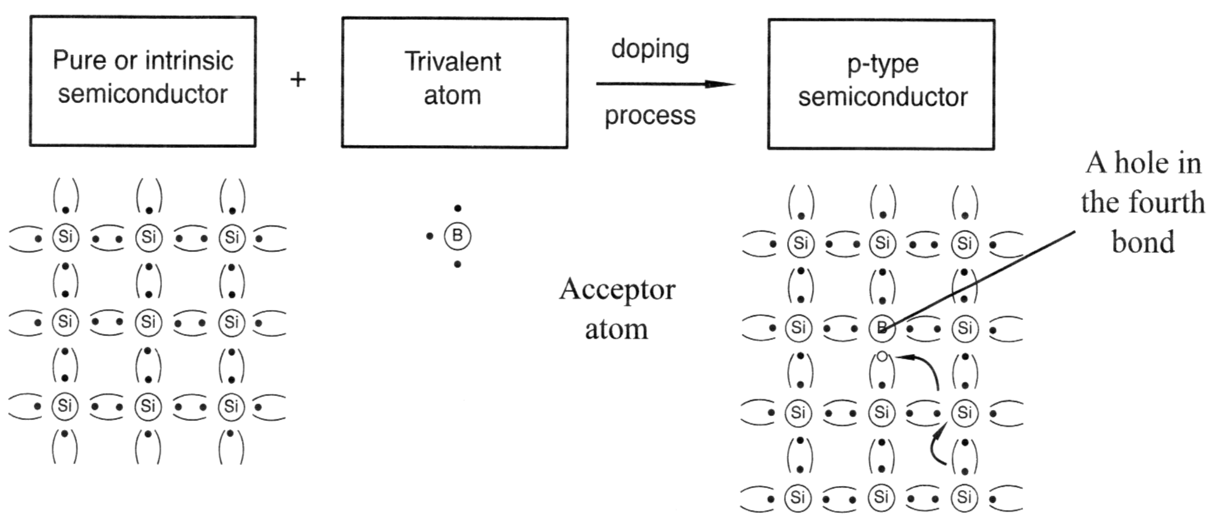
P-TYPE SEMICONDUCTOR

Elements which have three valence electrons in outer shells of their atoms e.g. aluminium, boron, give p-type properties to the semiconductors.

Boron has three electrons which participate in the bonding. This leaves a vacancy in the forth band called a hole. This vacancy forms a hole in the fourth bond. . This positive ‘hole’ readily accepts electrons which may be moving in the silicon. However, the electrons move from atom to atom, and an electron which moves into the ‘hole’ must leave a ‘hole’ in the atom it has come from.

Therefore the positive ‘hole’ appears to move through the material in the opposite direction to the electron movement. This improves the conductivity of the silicon since boron is accepting electrons and it is known as an ***acceptor impurity.***

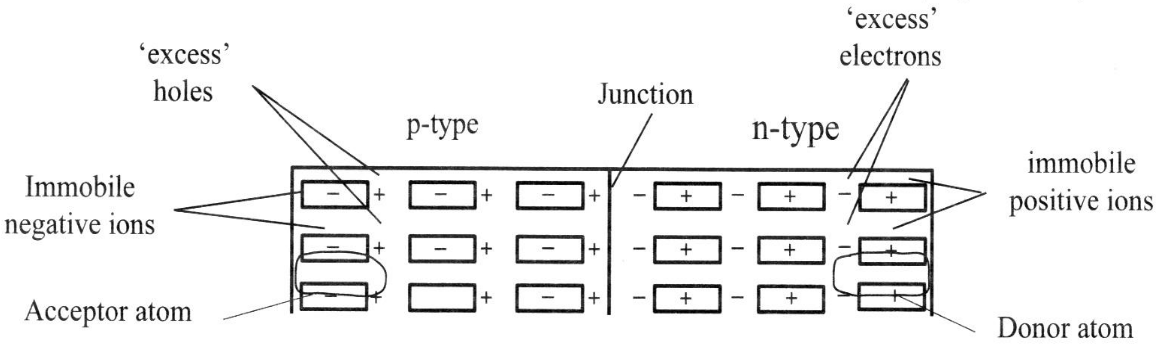
The resulting semiconductor has positive charge carriers and is referred to as the p-type (p for positive) in this type of semiconductors the ***majority charge carriers*** are the holes.There is a mechanism for the conduction of electric current that does not involve the free electrons.



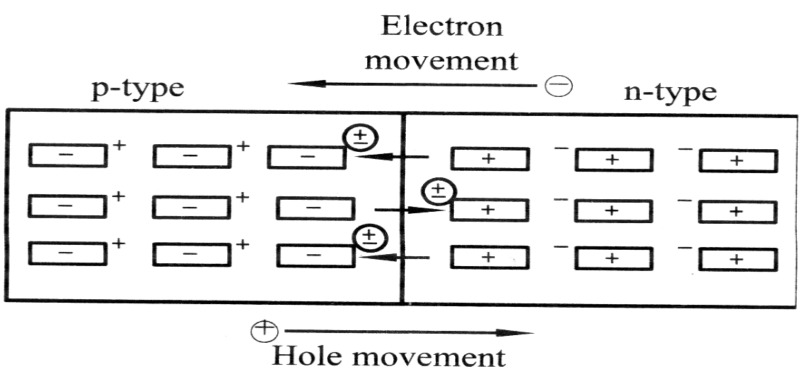
ELECTRICAL COMPONENTS

P-N JUNCTION DIODE

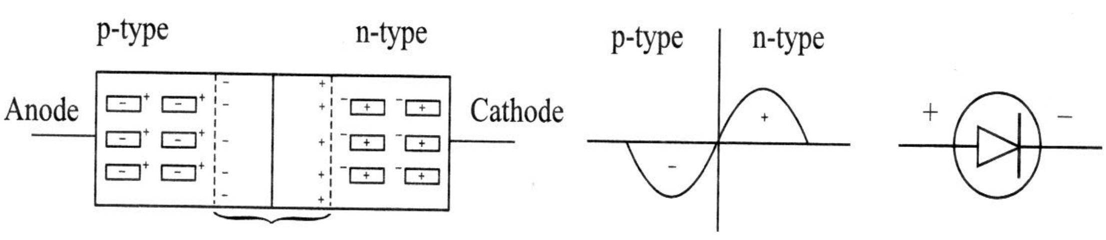
A p-type semiconductor and an n-type semiconductor of the same material e.g. silicon can be "joined" together to form a p-n junction diode.



As soon as this junction is formed, a charge movement begins only in the immediate vicinity of the junction until equilibrium is reached. Charge movement is likened to the diffusion of gases. The p-type and n-type regions are both electrically neutral. The charge movement results to holes combining with electrons thereby producing a net positive charge to the n-type region and leaving a net negative charge in the p-type region. The net positive charge in the n-type prevents any further movement of the holes from the p-type to n-type. Also the net negative charge in the p-type stops any further movement of the electrons from the n-type to the p-type. A region is created which has lost all its free electrons and holes. This region is called ***depletion layer***.



When equilibrium has been achieved, the resulting device is called p-n junction diode.
Due to movement of charges across the junction, a potential difference develops across the junction with its polarity such as to prevent further charge movement. This potential difference is called a ***barrier potential difference***. A lead connected to the n-type becomes a cathode while a lead on the p-type becomes an anode.

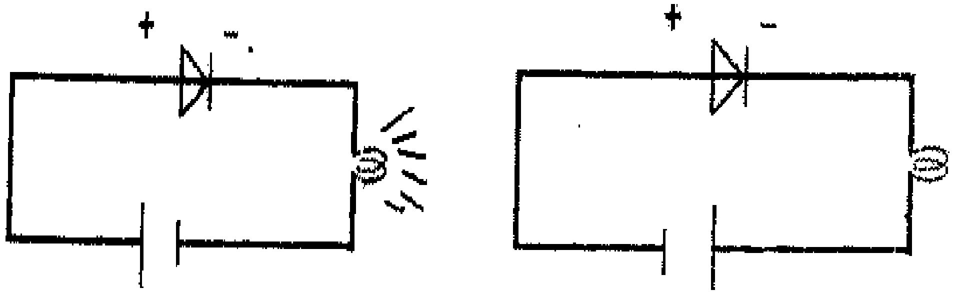


(a) Depletion layer *(b) Barrier potential difference* *(c) Symbol*

WORKING OF A P-N JUNCTION DIODE

HOW TO SHOW THAT A P-N JUNCTION DIODE CONDUCTS ONLY IN ONE DIRECTION

A p-n junction diode is connected with the negative end (n-type) connected to the negative terminal of the cell. Observe what happens to the bulb.

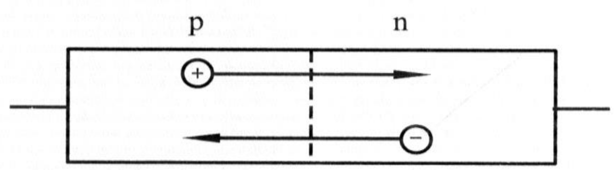


(a) (b)

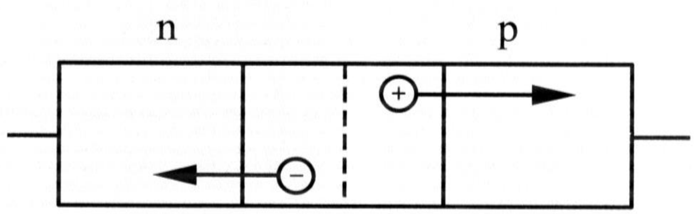
The connection is reversed i.e. the positive end of the junction diode connected to the negative terminal of the cell. Observe what happens to the bulb.

In (a) the bulb lights showing that electric current flows through the circuit while in (b) the bulb does not give light.

The dry cell provides enough energy to overcome the barrier potential difference and to drive the electrons in the circuit. The holes are also able to move towards the junction and complete the circuit. When diode is connected this way it is said to be ***forward biased.***



In (b) the electrons and holes are attracted to the opposite ends of the cell. This increases the width of the depletion layer and hence increases barrier potential difference. No current can flow through the diode. Diode connected in this manner is said to be reverse biased and the diode behaves as an insulator.

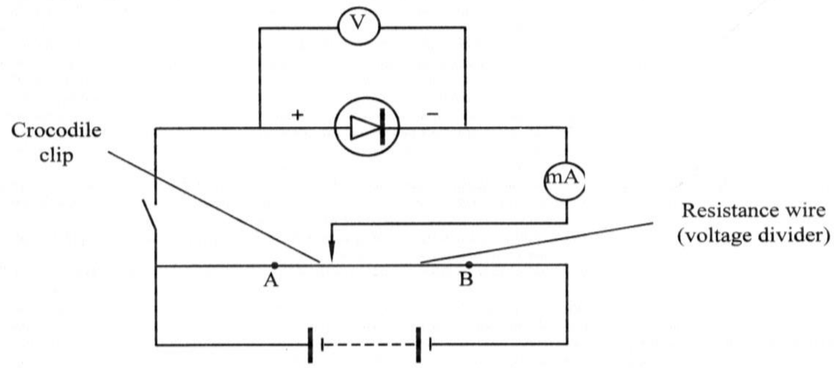


Therefore p-n junction diode is a device that conducts electricity in one direction only.

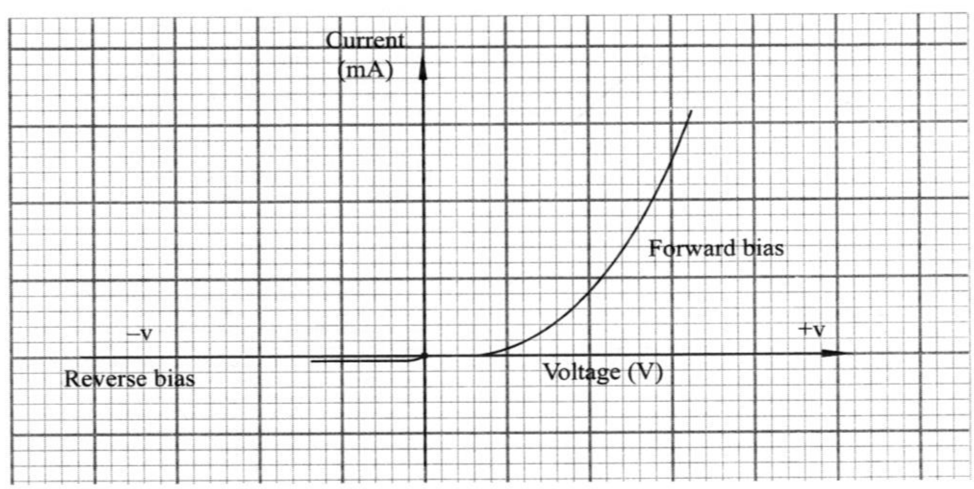
CHARACTERISTICS OF A P-N JUNCTION DIODE

HOW TO INVESTIGATE THE RELATIONSHIP BETWEEN THE CURRENT THROUGH AND THE VOLTAGE ACROSS A P-N JUNCTION DIODE

A p-n junction diode is connected in forward bias mode as shown in the figure below



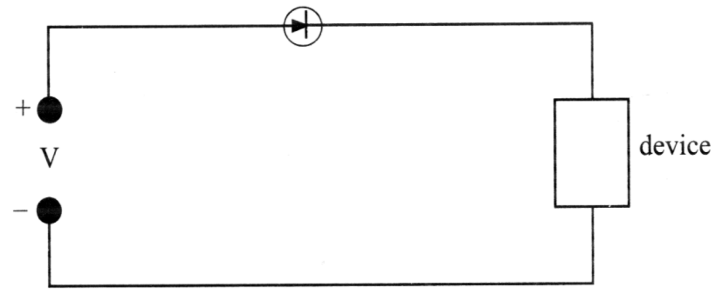
The crocodile clip is connected at A and the switch is closed and voltage across the diode and current through it are recorded.
The experiment is repeated with crocodile clip at other positions along AB and record the voltage and current.
The diode is reversed and the experiment is repeated.
On plotting a graph of current against voltage, the graph isas shown below.



The results show that a p-n junction diode produces non-linear characteristics i.e. ***does not obey Ohm's law*** i.e. it is ***non-ohmic conductor.***
The small current in the reverse bias is due to the intrinsic conduction in the p-n junction diode.

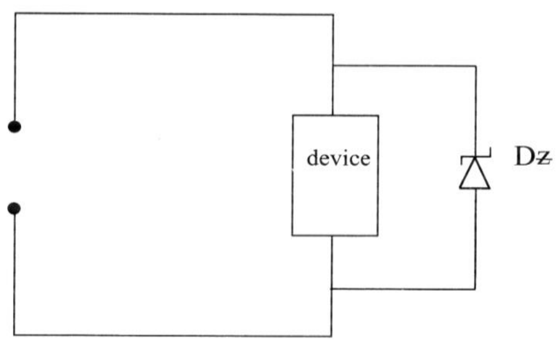
APPLICATIONS OF P-N JUNCTION DIODES

a. PROTECTING ELECTRICAL DEVICES
   Some devices that are operating on direct current (d.c.) break down when large voltages are connected in reverse/opposite order to the supply terminals of the devices reverse.
   To protect such devices a diode is usually connected in series with them and in reverse bias .it ensures that the device is protected by offering very high resistance to the flow of the current in the reverse direction when the terminals are interchanged.



b. ZENER DIODES

Zener diodes are used to protect d.c. devices by regulating the voltages applied across the devices. When the p.d. (voltage) increases or abruptly surges to values that would damage the device, the Zener diode breaks down and conducts. This protects the device by "short circuiting" it. When the voltage falls to normal the diode returns to normal.



Zener diodes do not conduct at normal voltages since it is connected in reverse bias mode. It is made to operate in such a way that, if the reverse voltage connected to it increases beyond a certain value, it breaks down and conducts offering zero resistance.

c. RECTIFICATION

It is the process of converting alternating current to direct current. A p-n junction diode is used to convert a.c. to d.c.

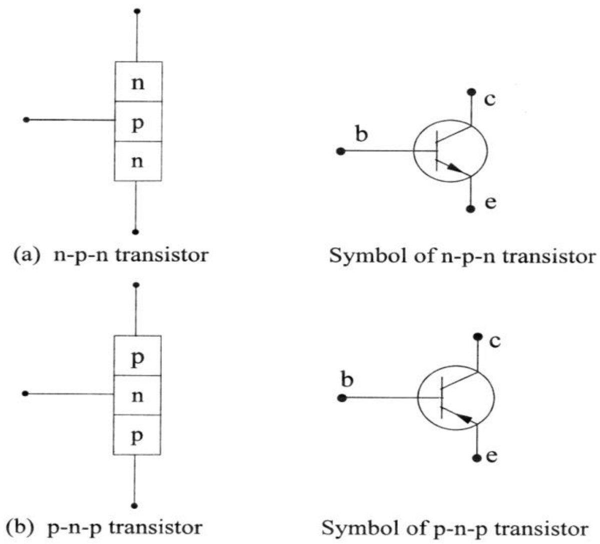
TRANSISTORS

A transistor is a three terminal device formed by merging three pieces of extrinsic (doped) semiconductors. The three terminals of a transistor are known as the

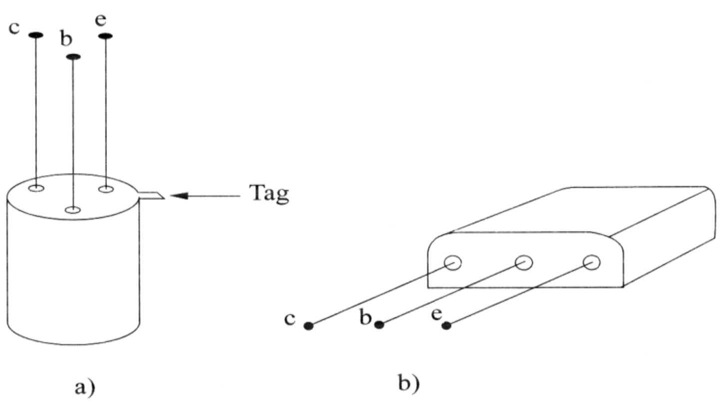
- Base (b)
- Collector (c)
- Emitter (e)

TYPES OF TRANSISTORS AND THEIR SYMBOLS

The transistors are divided into two types: n-p-n transistors and p-n-p transistors.

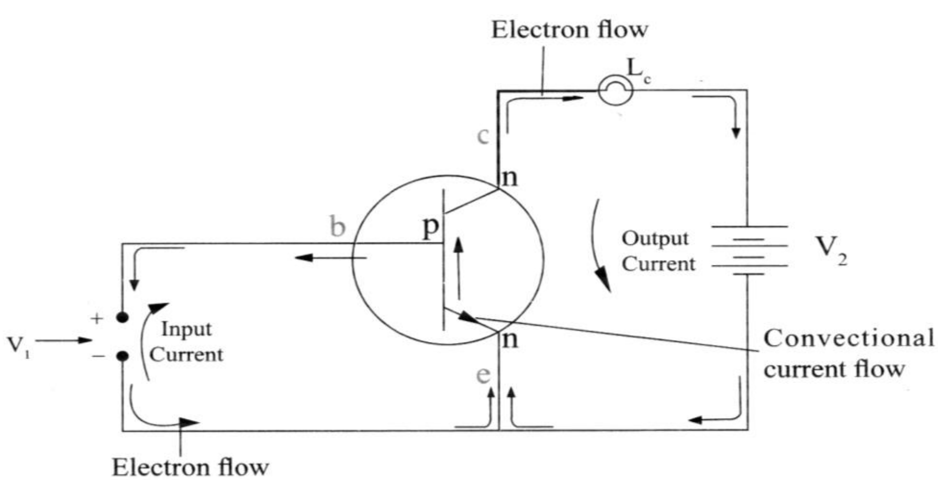


In the symbols, the arrows indicate the direction of the conventional current flow when the transistor is operating normally.
The emitter (e) emits the electrons which pass through the base (b) to the collector (c).
The n-p-n transistors are commonly used than p-n-p because the current moves faster in them.
Transistors are assembled in different sizes and shapes.
Emitter is marked by tags as shown in the figure.



OPERATION OF A TRANSISTOR

The emitter is connected to both the input (base) and the output (collector) side.

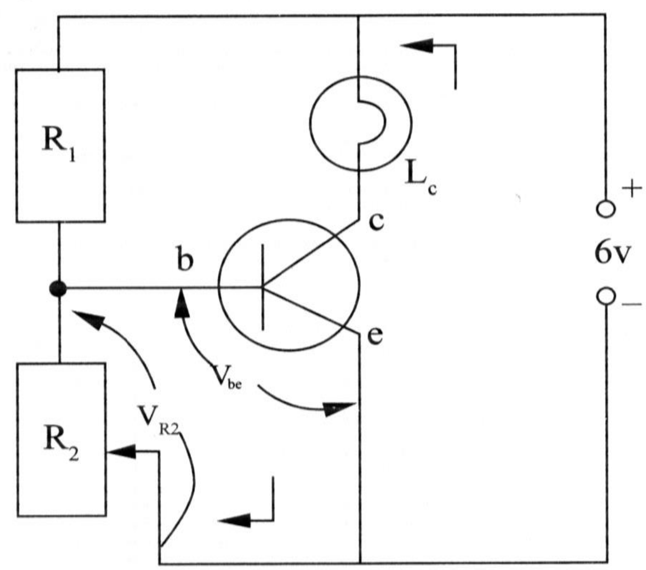


When the output and input circuits are connected as shown, the transmitter is said to be in common-emitter or (CE) mode. The n-type regions are the emitter and collector of the transistor; the p-type region is the base.
The output of this transmitter (collector-base junction) is reverse biased since the positive and the negative terminals of V_2 are connected to the collector (n) and base (p) respectively, hence no current flows.
The input (emitter-base junction) is forward biased since the positive and negative terminals of V_1 are connected to the base and emitter respectively; hence current flows. This current that flows through the input greatly reduces the "current blocking effect" (overcomes barrier voltage) of the output (collector-base junction). Then the output circuit starts conducting and current flows between emitter and collector.
A small current in the input (emitter-base junction) cause a current many times larger to flow in the output (collector-base junction).
The transistor works in such a way that when the input side conducts; i.e. current flows between base and emitter (base-emitter); then the output also conducts i.e. current flows between emitter and collector (collector-emitter) and so lamp L_c lights. When the input is off then the output is also off.

USE OF A TRANSISTOR AS A SWITCH

TO SHOW USE OF A TRANSISTOR AS A SWITCH

The components are connected as shown in the figure below



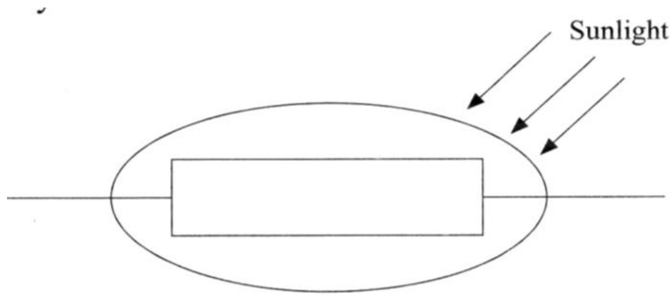
The R_2 is varied to zero and observe what happens to the lamp L_c.
It is observed that when the resistance of R_2 is zero then $l_c$is off and when the resistance of R_2 is high then lamp L_c is on.
The p.d. across resistor R_2 i.e. V_{R2} is equal to the p.d. across the input (base), V_{be}, i.e. base-emitter voltage because they are in parallel arrangement.
Since R_2 is a variable resistor, one can vary its value of resistance from zero to maximum. This in turn causes the voltage (V_{be}) between the base and emitter to change in the range from zero to maximum value.

When V_{be} is zero, no current flows through the output (the collector) thus lamp L_c is off. When $V_{be}$is large enough, it forward biases the b-e junction to conduct and so current flows through the output, lamp L_c lights on.
It can be concluded that a transistor behaves as a switch i.e. the input(base) controls the output (collector).

OTHER ELECTRONIC COMPONENTS

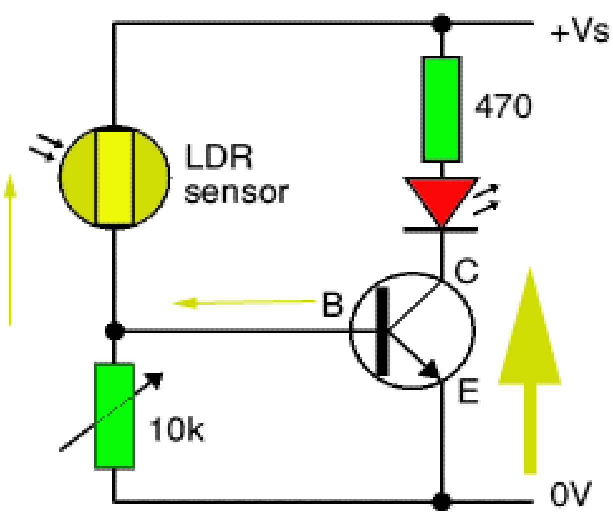
LIGHT DEPENDENT RESISTOR (LDR)

LDR is a type of resistor that naturally has high resistance in the dark. When light energy falls on them electrons become freer to conduct and the resistance decreases considerably.
Symbol for a light dependent resistor is shown below.



Common use of LDR is in the making of a light operated switch. These devices are used where there is a need to sense the presence and absence of light is necessary. These resistors are used as light sensors and the applications of LDR mainly include alarm clocks, street lights, light intensity meters, burglar alarm circuits.

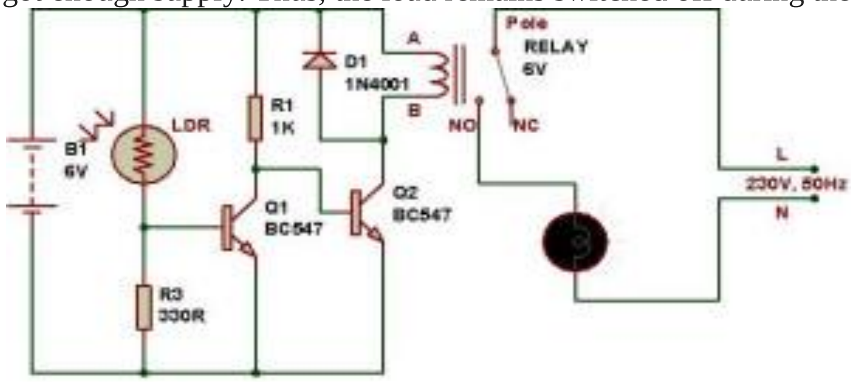
LIGHT ACTIVATED SWITCH



When light strikes the LDR its resistance drops allowing forward bias as current flows out of the base a larger current flows through E-C and energizes the LED

STREET LIGHTING SYSTEM

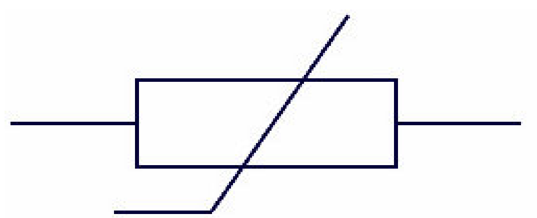
During the day time, the LDR has very-low resistance of around a few 100Ω, and then the entire supply is passed through the LDR and gets grounded through the resistor and variable resistor as shown in the circuit. This is due to the fact that the resistance offered by the LDR is less compared to the remaining path of the circuit. As we know that the principle current always chooses the low resistance path to flow. Hence, the relay coil does not get energized as it has not got enough supply. Thus, the load remains switched off during the daylight.



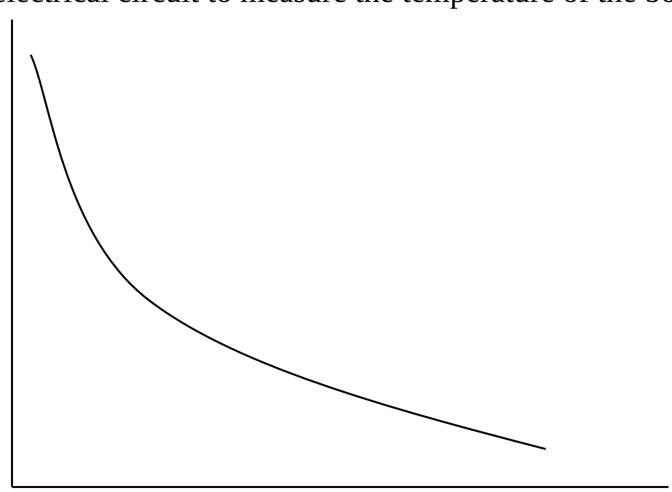
During the night time (when the daylight intensity is very less), the LDR resistance becomes very high: around a few Mega ohms (approximately 20MΩ). Thus LDR offers a very-high resistance (almost an open circuit type), and hence, opposes the flow of current. Again, according to the principle of current, by choosing low-resistance path, no current flows through the LDR, and thus, the current chooses an alternate path to flow such that it causes the voltage to increase more than 1.4v, then the relay coil gets energized, and thus, turns the load to switch on.

THERMISTORS

Thermistor is special type of resistor, whose resistance varies more significantly with temperature than in standard resistors. Thermistor is also called a temperature sensitive resistor.
The symbol of Thermistors can be represented as follows:



The resistance of the thermistors decreases with the increase in temperature. This is the main principle behind Thermistor. As the resistance of thermistors depends on the temperature, they can be connected in the electrical circuit to measure the temperature of the body.



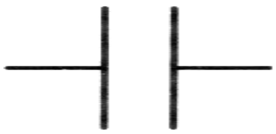
Thermistors are mainly used as temperature sensors, inrush current limiters, self-resetting over-current protectors and self-regulating heating elements. A Thermistor is made from a semiconductor material.

USES OF THERMISTORS

a. Used as current limiting devices for circuit protection.
b. Used in making resistance thermometers used to measure very low temperatures.
c. Used to monitor the temperature of an incubator.

CAPACITORS

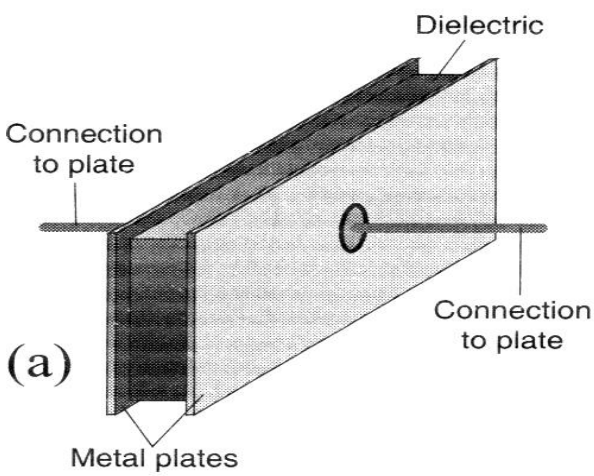
A capacitor is a device that stores charges. It consists of two parallel metal plates held together and separated by an insulating medium called the dielectric.
The symbol for capacitor is shown below:



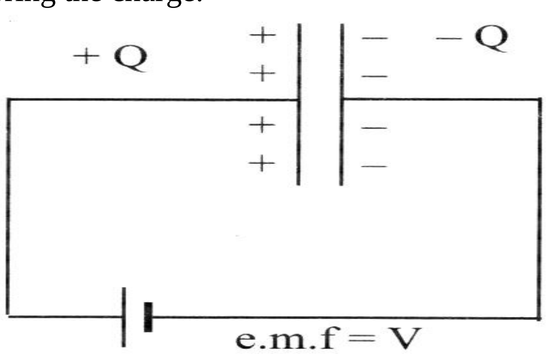
There are different capacitors depending on the dielectric used:

- Electrolytic capacitors
- Metal foil type capacitors
- Variable capacitors

Capacitors consists of two parallel metal plates separated by an insulating material between them



A capacitor stores charge. Electrons get stuck on one plate. That plate develops a negative charge. Positive charges get pushed to the other plate. Two plates are attracted to each other, but the dielectric material keeps them forever apart. This creates an Electric Field, and the capacitor is storing the charge.

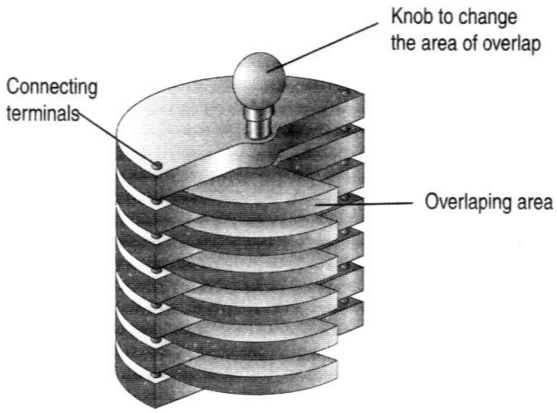


TYES OF CAPACITORS

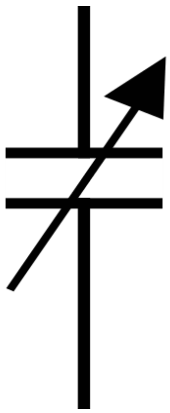
Capacitors come in a variety of forms and sizes but are basically made up of two parallel metal plates.

a. VARIABLE CAPACITORS

A variable capacitor is one in which the area of overlap of the plate can be adjusted and the dielectric between the metal plates is usually air.



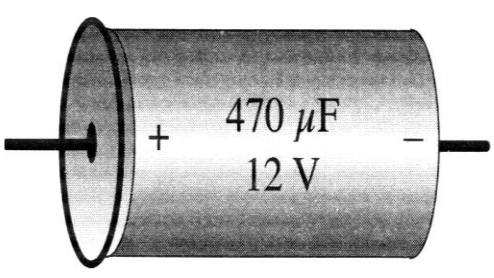
Symbol for a variable resistor



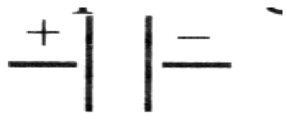
Variable capacitor is useful in radio tuning circuits where radio stations of different frequencies can be selected by changing the value of the capacitance of the variable capacitor.

b. ELECTROLYTIC CAPACITORS

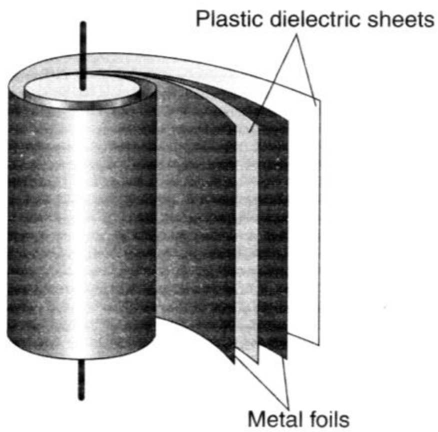
It is a special type of capacitor where one plate is always connected to the positive terminal of the battery and the other plate to the negative terminal. Interchanging polarities damages dielectric layer. These capacitors have large capacitance and are useful in power supply circuits.



Symbol for electrolytic capacitor is shown below:



c. METAL FOIL PLASTIC CAPACITORS
Metal foil capacitors has plastic as its dielectric. It has a small volume compacted to others.
Capacitors of large capacitance are used in the ignition system of car engines and buses.

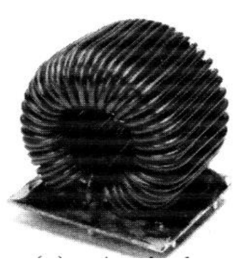


USES OF CAPACITORS

a. Capacitors are used to maintain power to the memory of devices like calculators and mobile phones when batteries are being changed or charged, to avoid loss of data.
b. Capacitors are used in rectifier circuits to smoothen the d.c. voltage signal obtained from rectification of alternating voltages i.e. smoothening.
c. Capacitors are used to absorb electrical signals that cause noise in sound systems.
d. Capacitors are used in U.P.S. (Un-interrupted Power Supply) in computers to store and supply power for a short time to a computer in the event of power blackout taking place unexpectedly.

INDUCTORS

Inductor is an electronic component that stores energy in form of a magnetic field. The inductor measures inductance which is the behavior of a coil of wire in resisting any change of electric current through the coil



Symbol for inductor is shown below

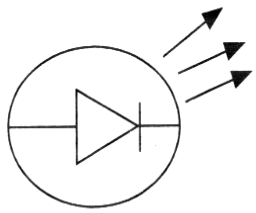
USES OF INDUCTORS

a. Inductors are used in making traffic light sensors that use loop (coil)

b. Inductors are used in the red light cameras that are used to curb traffic violations. This reduces road accidents.

LIGHT EMITTING DIODES (LED)

A light emitting diode (LED) is a two-lead semiconductor light source. This diode emits light when a current passes through it. This effect is called electroluminescence.
The symbol for a light emitting diode is shown below:



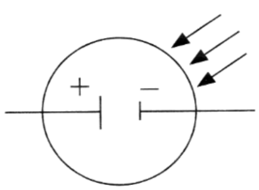
USES OF LIGHT EMITTING DIODE

Light emitting diode are used in

a. Aviation lighting
b. Automotive headlamps
c. Advertising and traffic signals and camera flashes.

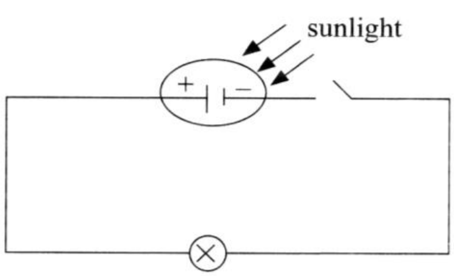
PHOTOVOLTAIC CELL

A photovoltaic cell is an electrical device that converts light energy directly to electric energy by photovoltaic effect. It is called solar cell.
Symbol for photovoltaic cell is shown below:



WORKING OF A PHOTOVOLTAIC CELL

When sunlight falls on the solar cells, a potential is created across the cells. When the circuit is completed a current flow through the components connected in the circuit.



USES OF PHOTOVOLTAIC CELLS

a. Photovoltaic cells are used in the manufacture of solar panels.
b. Can be used to power solar powered cars, boats and aeroplanes.

ELECTRONIC CIRCUITS AND SIGNALS

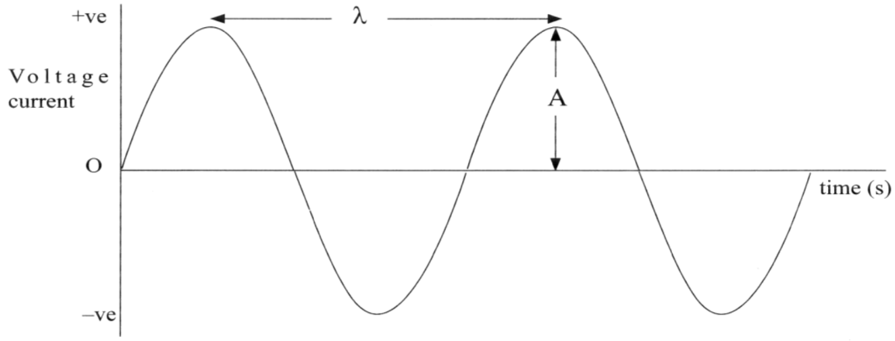
A number of electronic devices have their output in form of data, sound and video signals. Radio uses sound signals, computers, televisions and mobile phones use sound, data and video signals.

TYPES OF SIGNALS

Signals are classified as analogue (in analogue circuits) and digitals (in digital circuits)

Analogue signals

These are electronic circuits that operate with currents and voltages that vary continuously with time and have no abrupt transitions between levels. It is a circuit with a continuous variable signal as shown below.



CHARACTERISTICS OF ANALOGUE SIGNALS

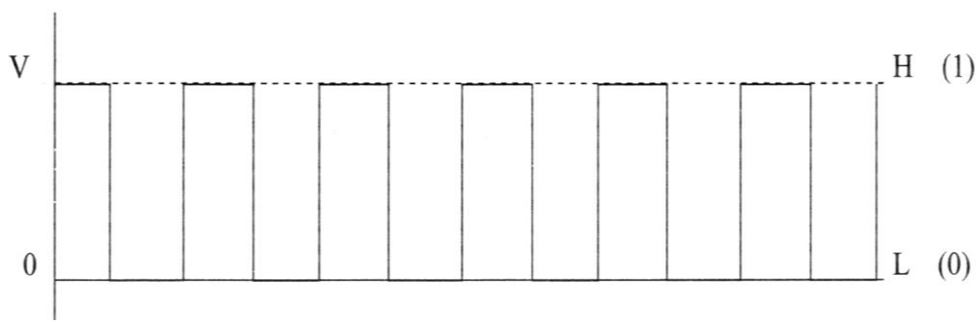
A simple analogue signal is a sine wave characterized by

- Amplitude
- Frequency
- Phase
- Wavelength

a. Amplitude (A) is the maximum displacement of wave particles from the position it shows the highest amount of current or voltage.
b. Frequency (f) is the number of complete oscillations per second. It is measured in Hertz (Hz).
c. Phase are two points on a wave front that appears to be the same.
d. Wavelength (λ) is the distance between two successive points in phase.

DIGITAL CIRCUITS AND SIGNALS

Digital circuit is a circuit where the signal must be one of two discrete levels. The signal must be one or zero (1 and 0). This digital circuit produces digital signals. Digital circuits can either be high (+ve) and lower (-ve) as shown below.



CHARACTERISTICS OF DIGITAL SIGNALS

a. Bit intervals: this is the time required to send one single bit.
b. Digital signals are desecrate,
c. The signal have limited number of defined values such as 1 and 0
d. Bit rate is the number of bit intervals in one second.

ADVANTAGES OF DIGITAL SIGNALS

a. Digital data can be easily compressed and hence transmitted efficiently. This help in transmission of large volume of voice, data and image information.
b. Digital signals are secure. There is minimal loss of data.
c. Digital data transmission is cheaper compared to analogue data.

MODULATION

Modulation is the process by which analogue signal is converted into digital signal.

DEMODULATION

Demodulation is the process by which digital signal is converted into analogue signal.

Logic gates

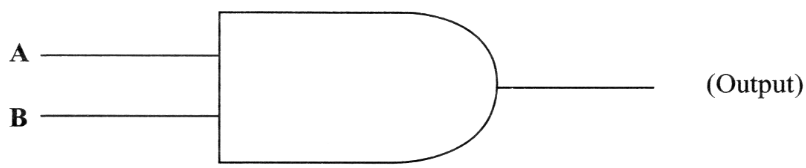
Logic gates normally use tiny transistors as switches. They are of four main forms:

- AND gate
- OR gate
- NOR gate
- NOT gate

a. AND gate

Let A and B represent the input circuits of a transistor while lamp L represents the output circuit.

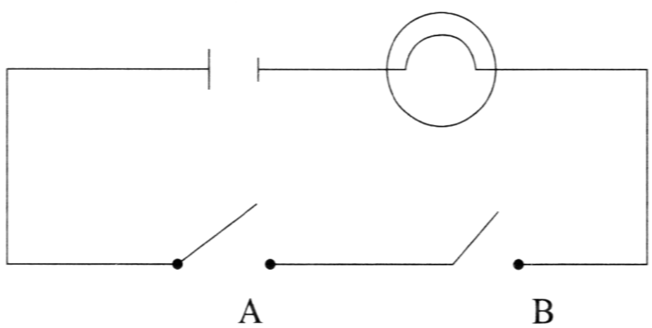
In electric circuit the AND gate is represented by the symbol shown below.



Let **1** represents **ON** and **0** represent **OFF** of any of the three circuits.

The states of the two input circuits, A and B determine the state of the output circuit L.

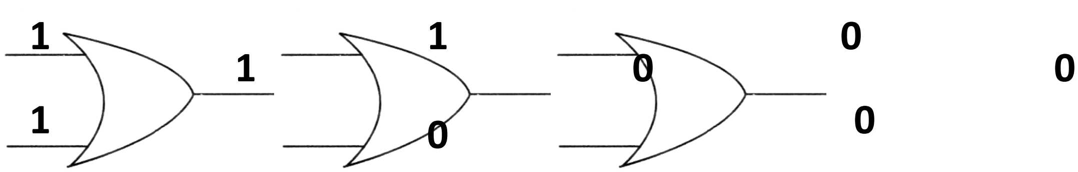
The AND truth table summarizes the possible states of the three circuits at an instant.



Inputs		**Outputs**
A	**B**	**L**
0	0	0
0	1	0
1	0	0
1	1	1

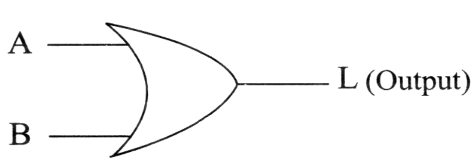
It only turns ON when both inputs are ON. If only one input is ON it spits out OFF. If both inputs are OFF it spits out OFF.

This circuit is called AND gate because circuit A and circuit B must be on for the output circuit (lamp) L to be on.

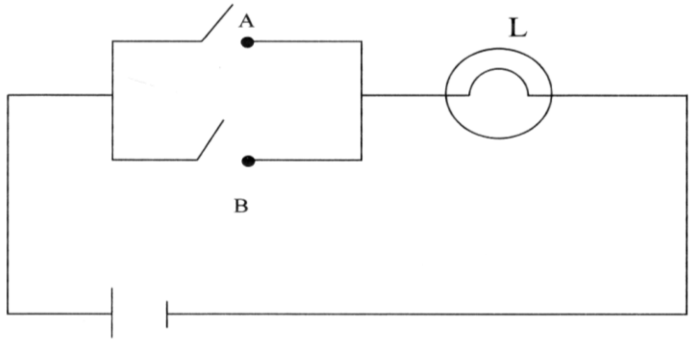


b. OR gate

This has two inputs one output.The symbol for OR gate is shown below.

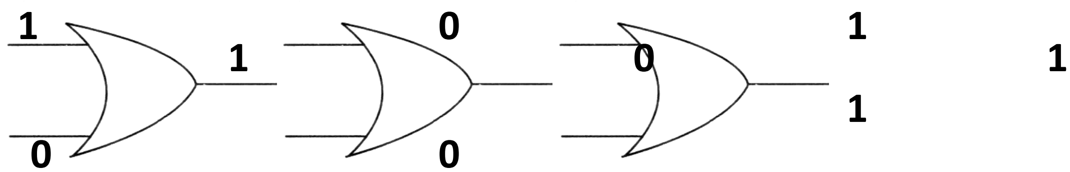


The input A and B are in parallel and their combined circuit in series with the lamp L. The truth table for OR gate is shown below



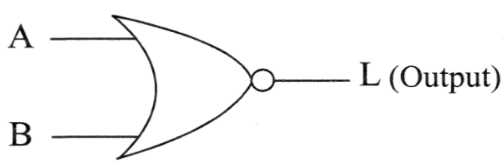
Inputs		Outputs
A	B	L
0	0	0
0	1	1
1	0	1
1	1	1

OR needs one input to be ON for it to spit out ON but also ON when both inputs are ON.



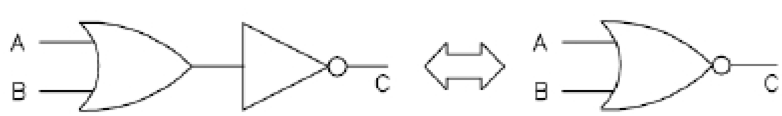
From the OR truth table, it can be observed that the output circuit represented by the lamp L will only be on when either A or B or both are on.

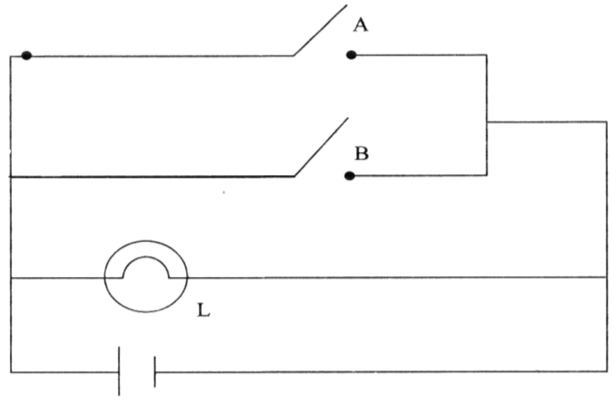
c. NOR gate
   It consists of two input circuits A and B and one output circuit L.
   The symbol for NOR gate is shown below.



Similarly, OR and NOT gates could be combined to form a NOR gate.

The truth table for NOR gate is shown below

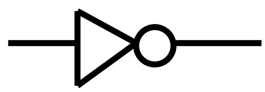




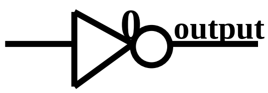
Inputs		Outputs
A	B	L
0	0	1
1	0	0
0	1	0
1	1	0

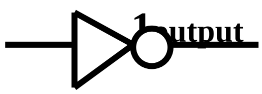
In the NOR gate, neither A nor B should be ON for lamp L to be ON .

d. NOT gate
This is the most simple logic gate. It consists of one input circuit A and output circuit L.

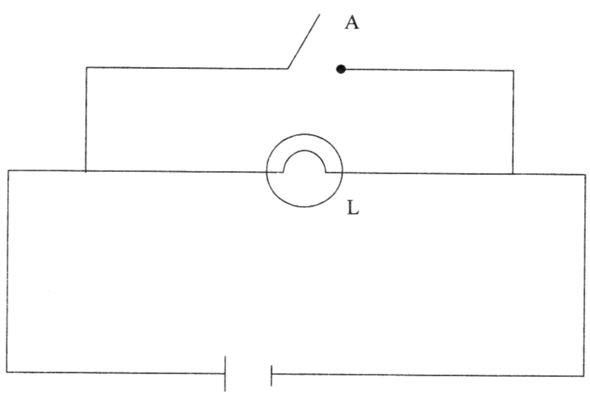
One input  one output

All it does is taking in an input that is either ON or OFF and spits out the opposite i.e. for a 1 it will give a 0 and for a 0, it will give a 1.

input1  **0 output**

input0  **1 output**

Another name for a NOT gate is inverter, because it inverts (makes opposite) the input.
The truth table for a NOT gate is shown below



Inputs	Outputs
A	L
0	1
1	0

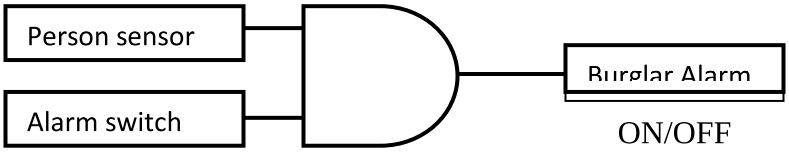
In the NOT gate the output circuit L is ON if A is OFF.
The figure shows a symbol of a NOT gate.

NOTE
The switches in all the above simple circuits represent transistors which are interconnected in such a way that the operations of one (on/off) affect the working of the next and so on. An output of one logic gate can be an input to another logic gate. Thiscreates trees of gates that depend on each other.

APPLICATIONS OF LOGIC GATES

1. BURGLAR ALARM using AND gate

ON/OFF

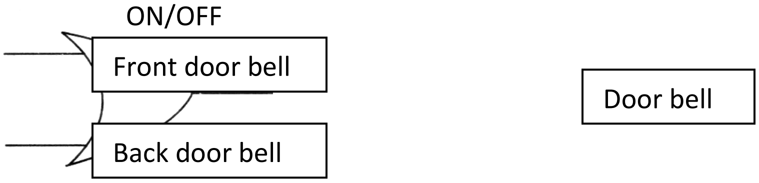


ON/OFF

If both the person sensor and the alarm switch are on then the Burglar Alarm is activated. While going out of the house one sets the **"Alarm Switch"** AND if the burglar enters he will set the "**Person switch**" and the alarm will ring.

2. DOOR BELL using OR gate

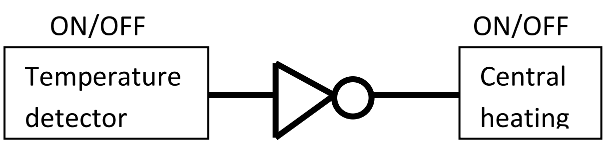
ON/OFF



ON/OFF

If either the front door bell switch OR the Back door bell switch is pressed then the Door bell rings. One would want the front bell to ring when someone presses either the front door switch OR the back door switch

3. TEMPERATURE DC ETECTOR using NOT gate



If the temperature is above 20^{o}C then the central heating is switched off. If the temperature is below 20^{o}Cthen the central heating is switched on.

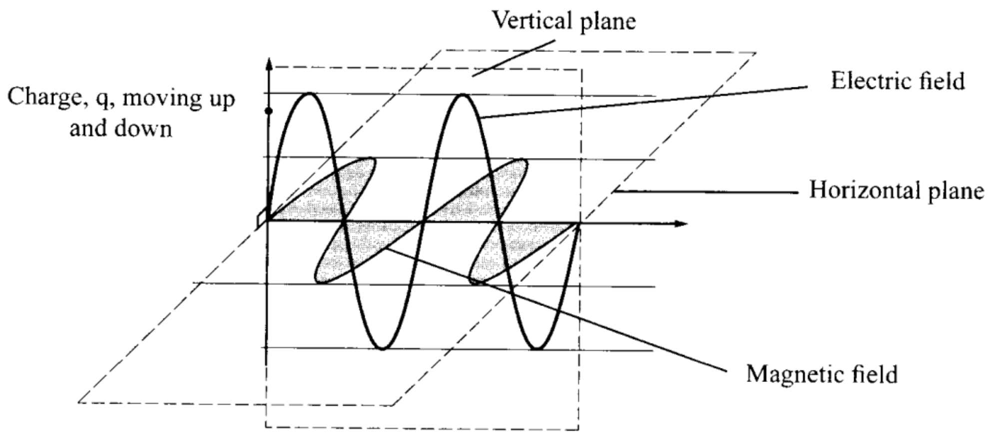
When the temperature falls below 20^{o} C the NOT gate will set on the central heating.

Chapter 11

ELECTROMAGNETIC WAVES

Electromagnetic waves are transverse waves that are propagated in space or matter by oscillations of electric and magnetic fields at right angles to each other and to their line of travel.

Electromagnetic waves are so-
named because it has electric and magnetic fields that simultaneously oscillate
(vibrate) in planes mutually perpendicular to each other and to the direction ofpropagation throug
h space.

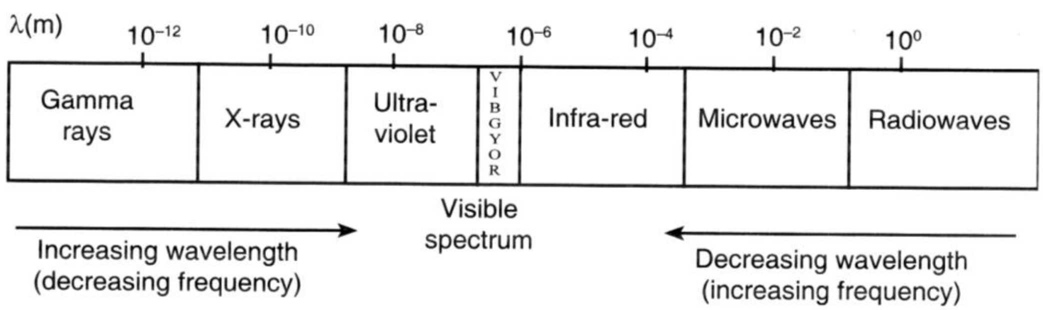


ELECTROMAGNETIC SPECTRUM

It is the entire range of electromagnetic waves in order of increasing frequency and decreasing wavelength.

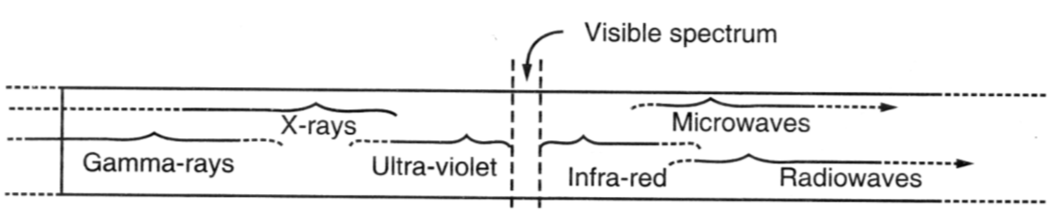
The waves in an electromagnetic spectrum may be arranged in order of their increasing or decreasing wavelengths

Figure shows a complete electromagnetic spectrum arranged in an increasing order of their wavelengths.



Electromagnetic spectrum is a continuous spectrum hence there are no precisely defined boundaries between the bands of the electromagnetic spectrum; rather they fade into each other like the bands in a rainbow (which is the sub-spectrum of visible light).

Some radiations overlap as shown in the figure below



Radiation of each frequency and wavelength (or in each band) has a mix of properties of the two regions of the spectrum that bound it. For example, red light resembles infrared radiation in that it can excite and add energy to some chemical bonds and indeed must do so to power the chemical mechanisms responsible for photosynthesis and the working of the visual system.

Electromagnetic waves form a continuous spectrum of waves. This includes:

i. waves with a very short wavelength, high frequency and high energy
   e.g. x-rays, gamma rays, ultra-violet rays
ii. waves with a very long wavelength, low frequency and low energy
   e.g. radio waves, microwaves and infrared

Electromagnetic waves can be separated and classified into the following seven classes (regions, bands or types): **Radio waves, Microwave radiation, Infrared radiation, Visible radiation, Ultraviolet radiation, X-ray radiation and Gamma radiation.**

Often a phrase is used to help remember the order of the groups of the electromagnetic spectrum such as **R**oman **M**en **I**nvented **V**ery **U**nusual **X**-ray **G**uns.

1. **R** – radio waves
2. **M** – microwave radiation
3. **I** – infrared radiation
4. **V** – visible radiation
5. **U** – ultraviolet radiation
6. **X** – ray radiation
7. **G** – gamma radiation

As one goes from left to right wavelength gets smaller and the frequencies get higher i.e. an inverse relationship between wave size and frequency. This is because the speed of all electromagnetic waves is the speed of light i.e. 300,000km/second. The higher the frequency the more energy the wave has

PHYSICAL PROPERTIES OF ELECTROMAGNETIC WAVES

Electromagnetic waves are typically described by any of the following three physical properties:

a. the frequency f,
b. wavelength λ, or
c. photon energy

Frequencies observed in astronomy range from 2.4×1023 Hz (gamma rays) down to the local plasma frequency of the ionized interstellar medium (~1 kHz).

Wavelength is inversely proportional to the wave frequency,so gamma rays have very short wavelengths that are fractions of the size of atoms, whereas wavelengths on the opposite end of the spectrum can be as long as the universe.

Photon energy is directly proportional to the wave frequency, so gamma ray photons have the highest energy (around a billion electron volts), while radio wave photons have very low energy (around a fem to electron volt). These relations are illustrated by the following equations:

$f = c\lambda$, or $f = E h$, or $E = h c \lambda$,

Whenever electromagnetic waves exist in a medium with matter, their wavelength is decreased. Wavelengths of electromagnetic radiation, no matter what medium they are traveling through, are usually quoted in terms of the vacuum wavelength.

EXAMPLE 1

Calculate the frequency of red light of wavelength 7 x 10^{-7}m given that the speed of electromagnetic wave in free space is 3 x 10^{8}m/s

Solution

$$c = \lambda f \Rightarrow f = \frac{c}{\lambda}$$

$$= \frac{3 \times 10^{8}}{7 \times 10^{-7}}$$

$$= 4.3 \times 10^{14}\ \mathrm{Hz}$$

TYPES OF RADIATION

a. RADIO WAVES

Radio waves are produced from electrons in a conductor having a wide range of wavelengths from 1 x 10^{-3}m and 1 x 10^{6}m.this range covers microwaves, radar and television waves.

Radio waves are emitted and received by antennas, which consist of conductors such as metal rod resonators. In artificial generation of radio waves, an electronic device called a transmitter generates an AC electric current which is applied to an antenna. The oscillating electrons in the antenna generate oscillating electric and magnetic fields that radiate away from the antenna as radio waves. In reception of radio waves, the oscillating electric and magnetic fields of a radio wave couple to the electrons in an antenna, pushing them back and forth, creating oscillating currents which are applied to a radio receiver. Earth's atmosphere is mainly transparent to radio waves, except for layers of charged particles in the ionosphere which can reflect certain frequencies.

Radio waves are extremely widely used to transmit information across distances in radio communication systems such as radio broadcasting, television, two way radios, mobile phones, communication satellites, and wireless networking. In a radio communication system, a radio frequency current is modulated with an information-bearing signal in a transmitter by varying the amplitude, frequency or phase, and applied to an antenna. The radio waves carry the information across space to a receiver, where they are received by an antenna and the information extracted by demodulation in the receiver. Radio waves are also used for navigation in systems like Global Positioning System (GPS) and navigational beacons, and locating distant objects in radiolocation and radar. They are also used for remote control, and for industrial heating.

The use of the radio spectrum is strictly regulated by governments which allocates frequencies to different users for different uses

b. MICROWAVES

Microwaves are radio waves of short wavelength, from about 10 centimeters to one millimeter, in the SHF and EHF frequency bands. Microwave energy is produced with klystron and magnetron tubes, and with solid state devices such as Gunn and IMPATT diodes.

Although they are emitted and absorbed by short antennas, they are also absorbed by polar molecules, coupling to vibrational and rotational modes, resulting in bulk heating.

Unlike higher frequency waves such as infrared and light which are absorbed mainly at surfaces, microwaves can penetrate into materials and deposit their energy below the surface. This effect is used to heat food in microwave ovens, and for industrial heating and medical diathermy.

Microwaves are the main wavelengths used in radar, and are used for satellite communication, and wireless networking technologies such as Wi-Fi, although this is at intensity levels unable to cause thermal heating.

The copper cables (transmission lines) which are used to carry lower frequency radio waves to antennas have excessive power losses at microwave frequencies, and metal pipes called waveguides are used to carry them.

Although at the low end of the band the atmosphere is mainly transparent, at the upper end of the band absorption of microwaves by atmospheric gasses limits practical propagation distances to a few kilometers.

c. INFRARED RADIATION

Infra-red radiation is produced by hot bodies e.g. the sun, electric fires and furnaces. These hot bodies emit red light and infra-red. It is radiant energy. They have a range of wavelengths from 1×10^{-6}m to 1×10^{-3}m.

The infrared part of the electromagnetic spectrum covers the range from roughly 300 GHz to 400 THz (1 mm - 750 nm). It can be divided into three parts:

Far-infrared, from 300 GHz to 30 THz (1 mm – 10 μm). The lower part of this range may also be called microwaves or terahertz waves. This radiation is typically absorbed by so-called rotational modes in gas-phase molecules, by molecular motions in liquids, and by phonons in solids. The water in Earth's atmosphere absorbs so strongly in this range that it renders the atmosphere in effect opaque. However, there are certain wavelength ranges ("windows") within the opaque range that allow partial transmission, and can be used for astronomy. The wavelength range from approximately 200 μm up to a few mm is often referred to as "sub-millimeter" in astronomy, reserving far infrared for wavelengths below 200 μm.

Mid-infrared, from 30 to 120 THz (10–2.5 μm). Hot objects (black-body radiators) can radiate strongly in this range, and human skin at normal body temperature radiates strongly at the lower end of this region. This radiation is absorbed by molecular vibrations, where the different atoms in a molecule vibrate around their equilibrium positions. This range is sometimes called the fingerprint region, since the mid-infrared absorption spectrum of a compound is very specific for that compound.

Near-infrared, from 120 to 400 THz (2,500–750 nm). Physical processes that are relevant for this range are similar to those for visible light. The highest frequencies in this region can be detected directly by some types of photographic film, and by many types of solid state image sensors for infrared photography and videography.

d. VISIBLE RADIATION (LIGHT)

Visible light is the part of the EM spectrum the human eye is the most sensitive to. it is produced by very hot objects or any incandescent object.

It has a range of wavelengths from 4×10^{-7} to 7×10^{-7}m. It consists of seven radiations forming the visible spectrum. The visible spectrum is abbreviated ROY G. BIV which stands for Red, Orange, Yellow, Green, Blue, Indigo and Violet

A rainbow shows the optical (visible) part of the electromagnetic spectrum; infrared (if it could be seen) would be located just beyond the red side of the rainbow with ultraviolet appearing just beyond the violet end..

Visible light (and near-infrared light) is typically absorbed and emitted by electrons in molecules and atoms that move from one energy level to another. This action allows the chemical mechanisms that underlie human vision and plant photosynthesis. The light that excites the human visual system is a very small portion of the electromagnetic spectrum.

The Sun emits its peak power in the visible region, although integrating the entire emission power spectrum through all wavelengths shows that the Sun emits slightly more infrared than visible light.

Electromagnetic radiation with a wavelength between 380 nm and 760 nm (400–790 terahertz) is detected by the human eye and perceived as visible light.. White light is a combination of lights of different wavelengths in the visible spectrum. Passing white light through a prism splits it up into the several colours of light observed in the visible spectrum between 400 nm and 780 nm.

e. ULTRAVIOLET RADIATION

Ultra-violet radiation is produced by arcs (carbon arc lamp, electric spark) gas discharge tube, mercury vapour lamp, hot bodies and the sun. They have wavelengths ranging from 1×10^{-9}m to 1×10^{-7}m.

The wavelength of UV rays is shorter than the violet end of the visible spectrum but longer than the X-ray.

UV is the longest wavelength radiation whose photons are energetic enough to ionize atoms, separating electrons from them, and thus causing chemical reactions.

Short wavelength UV and the shorter wavelength radiation above it (X-rays and gamma rays) are called ionizing radiation, and exposure to them can damage living tissue, making them a health hazard. UV can also cause many substances to glow with visible light; this is called fluorescence.

At the middle range of UV, UV rays cannot ionize but can break chemical bonds, making molecules unusually reactive. Sunburn, for example, is caused by the disruptive effects of middle range UV radiation on skin cells, which is the main cause of skin cancer. UV rays in the middle range can irreparably damage the complex DNA molecules in the cells producing thymine dimers making it a very potent mutagen.

The Sun emits significant UV radiation (about 10% of its total power), including extremely short wavelength UV that could potentially destroy most life on land (ocean water would provide some protection for life there). However, most of the Sun's damaging UV wavelengths are absorbed by the atmosphere before they reach the surface.

Ultra-violet rays with short wavelengths overlap with the x-rays of long wavelengths.

f. X-RAYS

X-rays, which, like the upper ranges of UV are also ionizing. However, due to their higher energies, X-rays can also interact with matter by means of the Compton Effect. Hard X-rays have shorter wavelengths than soft X-rays and as they can pass through many substances with little absorption, they can be used to 'see through' objects with 'thicknesses' less than that equivalent to a few meters of water. One notable use is diagnostic X-ray imaging in medicine (a process known as radiography). X-rays are useful as probes in high-energy physics. In astronomy, the accretion disks around neutron stars and black holes emit X-rays, enabling studies of these phenomena. X-rays are also emitted by the coronas of stars and are strongly emitted by some types of nebulae. However, X-ray telescopes must be placed outside the Earth's atmosphere to see astronomical X-rays, since the great depth of the atmosphere of Earth is opaque to X-rays (with areal density of 1000 g/cm2), equivalent to 10 meters thickness of water.

g. GAMMA RAYS

Gamma are produced from within the nuclei of radioactive atoms. Gamma has the least wavelengths and is located at the end of the electromagnetic spectrum. Their wavelengths range from 1×10^{-15} m to 1×10^{-11}m.

These are the most energetic photons, having no defined lower limit to their wavelength. In astronomy they are valuable for studying high-energy objects or regions, however as with X-rays this can only be done with telescopes outside the Earth's atmosphere.

Gamma rays are used experimentally by physicists for their penetrating ability and are produced by a number of radioisotopes. They are used for irradiation of foods and seeds for sterilization, and in medicine they are occasionally used in radiation cancer therapy.

More commonly, gamma rays are used for diagnostic imaging in nuclear medicine, an example being PET scans. The wavelength of gamma rays can be measured with high accuracy through the effects of Compton scattering.

PROPERTIES OF ELECTROMAGNETIC WAVES

All electromagnetic waves

a. Carry no charge

b. Are transverse in nature
c. Under suitable conditions, they undergo reflection, refraction, diffraction and show interference effect.
d. Do not need any material medium to travel i.e. they can travel through a vacuum.
e. Obey the wave equation $c = f \times \lambda$, where c is the speed of light, f, frequency and λ the wavelength.
f. Travel in free space (vacuum) at a speed of 3.0×10^8m/s.
g. Transfer energy from one place to another.
h. Can be emitted or absorbed by matter.
i. Obey the inverse square law, i.e. intensity (I) is inversely proportional to the square of the distance from the source, r^2. Therefore

$$I \alpha \frac{I}{r^2}$$

j. Possess energy E that is directly proportional to its frequency i.e. E α f. hence E = hf where h is called the Planck's constant

METHODS OF DETECTING ELECTROMAGNETIC WAVES

a. RADIO WAVES

Radio waves can be detected by aerials, diodes and earphones in electrical circuits. This is because they cause small electric current to flow in electrical circuits containing such detectors.

b. MICROWAVE RADIATION

Microwaves of shorter wavelengths, infra-red, visible light, ultra-violet and X-rays of longer wavelengths all cause heating effect. These waves are called thermal radiation and can be detected by instruments that are sensitive to changes in temperature.

c. INFRA-RED RADIATION

Infra-red can be detected by a thermocouple, a blacked bulb of a sensitive thermometer and a heat sensitive paper (thermometric paper) and a phototransistor. These detectors are sensitive to heat produced by infra-red radiation.

d. VISIBLE LIGHT

Visible light is detected by the human eye, photographic film, photocell and a light dependent resistor. Human eye forms an image on the retina. Photographic film forms images of the object through chemical reaction triggered off by light.

e. ULTRA-VIOLET RADIATION

Ultra-violet radiations are detected by photographic films and by the fluorescence they cause in some mineral salts. Other detectors include photocells and light dependent resistor

f. X-RAYS

X-rays are detected by photographic plates/films and flourescencent screens. When X-rays fall on flouresecent screen (Screen coated with Zinc sulphide), the screen glows.

X-rays are also detected by producing photoelectric effects on metals and the ionization of gas.

g. GAMMA RAYS

Gamma rays are detected by photographic plates/films and by Geiger Muller Tube. When gamma rays fall on photographic film, a chemical reaction takes place to confirm its presence.

APPLICATIONS OF ELECTROMAGNETIC WAVES

Each member of the electromagnetic spectrum has its own use.

a. GAMMA RAYS

i. Used as tracers

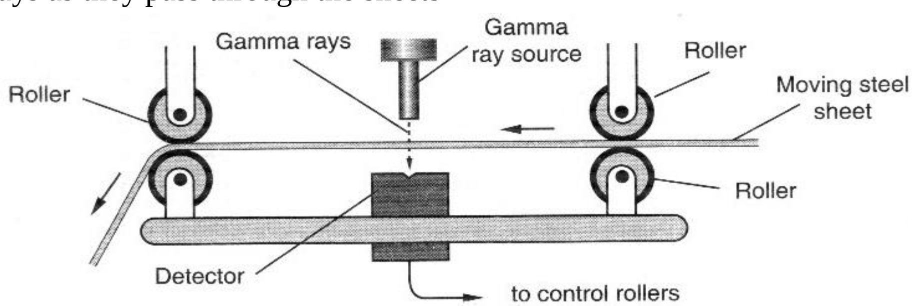
They are used in medicine to locate body organs that are not functioning properly. E.g. a non-functioning of kidneys, a doctor uses small amount of Technetium-99 that produces gamma rays to trace if kidneys have extracted Technetium in the blood.

ii. Used for sterilizing

- Gamma rays kill bacteria, moulds and insects or worms in food hence used to sterilize food preventing it from going bad.
- In hospitals gamma rays are used to sterilize equipment that would otherwise be damaged by heating e.g. plastic syringes.
- Controlled beam of gamma is used to kill cancerous cells. Care is taken because uncontrolled beam of gamma rays cause cancer.

iii. Thickness control

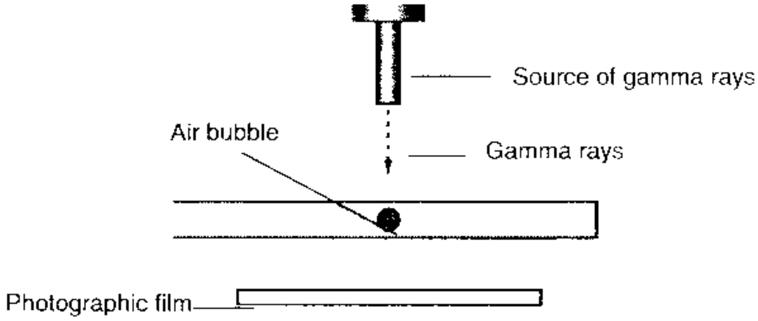
In industry the thickness of sheets of steel can be controlled by monitoring gamma rays as they pass through the sheets



If thickness changes, the current from the detectors automatically adjusts the rollers.

iv. Detecting flaws and cracks

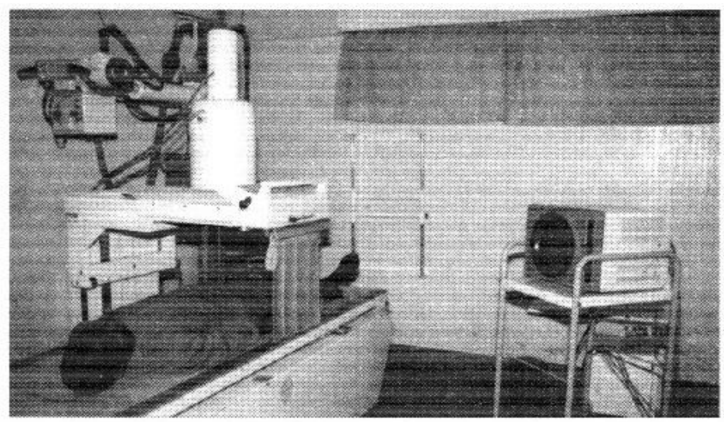
Gamma rays are used to check weak points in welded joints in materials. A gamma source is placed on one side of the welded material and a photographic film on the other side. Any crack or air bubble is shown up on the film.



b. X-RAYS

- High energy waves such as X-rays and gamma rays have high penetrating power and are transmitted through body tissues with very little absorption. They are used take photographs (radiographs) i.e. internal imaging. X-rays are absorbed by dense structures like bones, which is why X-ray photos are used to help identify broken bones.

  Figure shows a patient undergoing X-ray



- They are also used in crime detection e.g. forgery.
- X-ray imaging is also used for scanning the internal structure of objects and in airport security scanners.

c. ULTRA-VIOLET RADIATION

- Small amount of ultra-violet rays produce vitamin D in our skin. Large amount of ultra-violet damage eyes and cause skin cancer. Darker skins absorbs less ultra-violet radiation that pass through the living cells.
- Chemicals which absorbs ultra-violet radiation are put in washing powders so that clothes look brighter in sunlight.
- Ultra-violet lamps are used to detect forged bank notes. Forged bank notes glow differently in ultra-violet light as compared to genuine ones.
- In medicine ultra-violet lamps are used for skin treatment.
- It is used to identify stolen items where security pen is used to mark the items. A security pen uses ink that show up only under ultra-violet light.

d. VISIBLE LIGHT

- Visible radiation helps one to see.
- Plants use visible light to make their own food through photosynthesis.
- Laser and optic fibre are visible light in communication.

e. INFRA-RED

Infra-red is emitted by warm objects i.e. any objects including humans that have a temperature above absolute zero.

- Infra-red is used to take photographs called thermographs on special photographic films which are sensitive to infra-red. These thermographs are sensitive to heat (white images for objects losing a lot of heat while darker images for objects losing less heat). In hospitals thermographs are used to detect/reveal diseased part of the skin which is often hotter.
- Infra-red is also used in burglar alarms. The intruder emits infra-red which are detected by the burglar alarm.

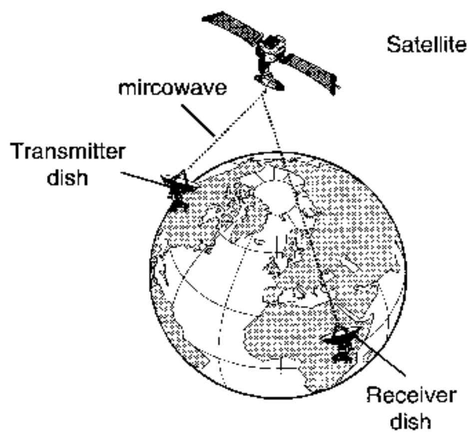
f. RADIO WAVES

They have the longest wavelength in electromagnetic spectrum and includes microwaves, radar, ultra high frequency (UHF), very high frequency (VHF), radio short waves, radio medium waves and long waves.

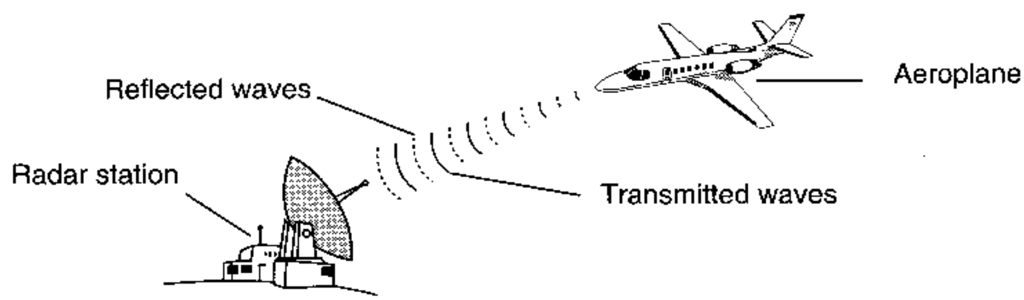
- They are used in radio communication.

g. MICROWAVES

- Microwaves are used for cooking in microwave ovens. The microwaves are absorbed by water molecules in the food and on heating up, the water cooks the food.
- In satellite communication a microwave radio signal is transmitted from a dish aerial up to another dish aerial in another location.



- In navigation, a radar uses the reflected microwaves to detect objects e.g. planes in the



air.

Note

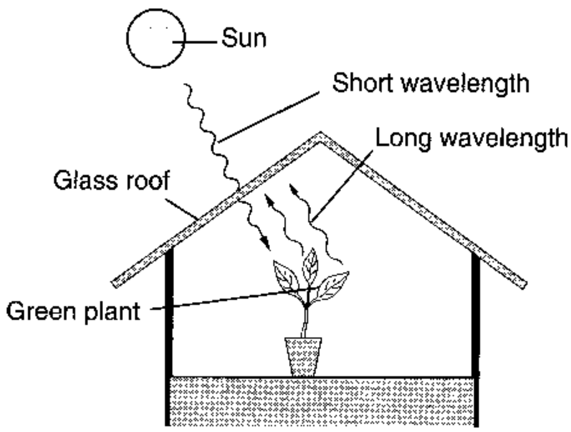
- Ultra High Frequency (UHF) waves are used to transmit television programmes
- Very High Frequency (VHF) are used to transmit local radio programmes and ambulance or police messages.

- Medium waves are used to transmit messages over long distances since they hav long wavelengths and are diffracted around the mountains, hills, and curves of earth

EFFECTS OF ELECTROMAGNETIC WAVES

a. GREEN HOUSE EFFECT

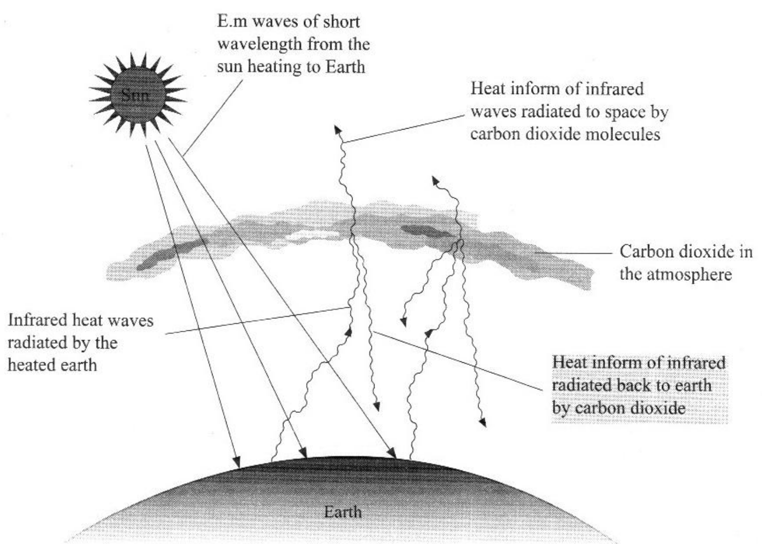
This is the process of allowing in short wavelength radiation and protecting the radiated long wavelength from escaping.



Note that a greenhouse consists of glass enclosure (house) with plants grown inside. Glass allows visible light to and short wavelength radiations emitted by the sun to pass through but glass cannot transmit the long wavelength given out by the plants. This traps the heat from the sun inside the green house making the inside warmer than outside.

b. GLOBAL WARMING

The atmosphere allows short wavelength from the sun to pass easily to the earth surface. This warms up the ground which radiates heat in form of infra-red radiation into the atmosphere. The atmospheric gases (Carbon dioxide, water vapour, etc.) absorb the radiation from the earth and in turn give out heat back to the earth making the earth getting warmer. Without carbon dioxide this energy would be lost and earth would be cooler.



As more and more carbon dioxide is being emitted by factories to the atmosphere, more and more radiation is being directed back to the earth's surface causing global warming.

c. HARMFUL EFFECTS OF ULTRAVIOLET RADIATION

Ultraviolet rays cause sunburn that occurs when skin cells are damaged by the absorption of energy.

d. HARMFUL EFFECTS OF GAMMA RAYS

Gamma rays kill body living cells.

They also cause cell mutation.

e. EFFECTS OF X-RAYS

- X-rays cause cell mutation i.e. DNA changes.
- They can cause skin cancer i.e. abnormal growth of living cells.
- They also affect childbirth i.e. rays can lead to deformity in the infants.

PRECAUTIONS WHEN HANDLING ELECTROMAGNETIC WAVES

When handling radioactive substances one has to wear protective.

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Chapter 12

LIGHT AND LENSES

LENSES

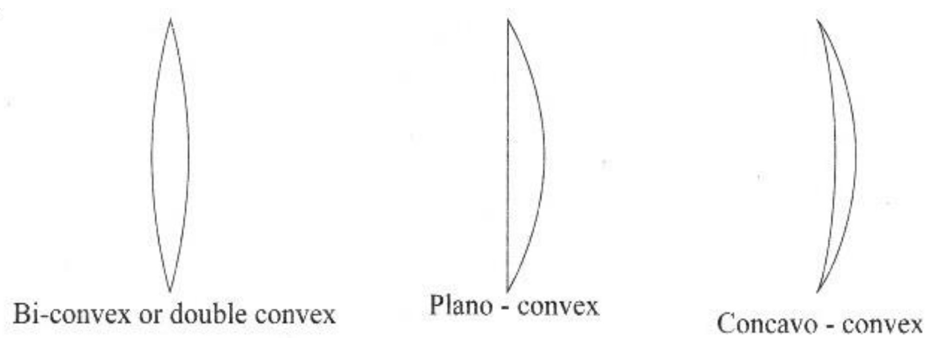
These are pieces of glass or clear plastic with curved surfaces (transparent medium bound between two surfaces of define geometrical shape). Lenses are made in different shapes and from different types of glasses. Lenses are used in many optical instruments.

TYPES OF LENSES

These lenses can either be curved outwards or inwards and there are two types; convex and concave.

CONVEX (CONVERGING) LENS

A convex lens is the one which is thicker in the middle (centre) than at its edges. The three diagrams below show three shapes which act as converging lenses.



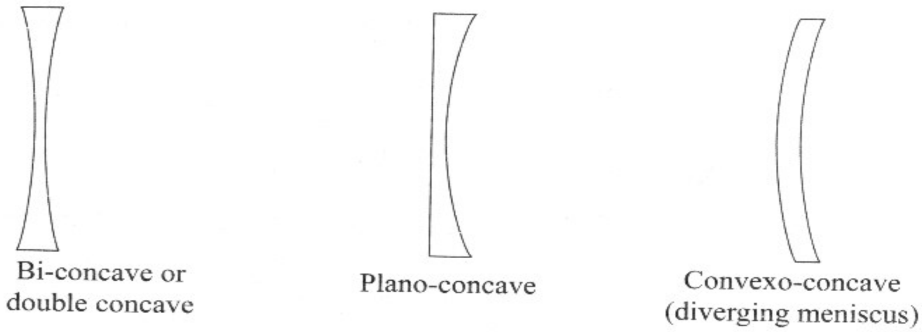
A bi-convex or double convex lens has both its surfaces curving out. Other convex lenses are plano-convex and concavo convex or converging meniscus.
A convex lens converges (brings together) parallel rays of light passing through.

The distance from the optical centre O of the lens to the focal point F is known as the focal length f of the lens. If the parallel rays which are not parallel to the principal axis are incident on the lens these rays will also focus at one point F1 which lies directly below F. A plane passing through F and F2 is called the focal plane of the lens. Any parallel beam of light rays incident on the lens will be refracted so as to form a point which lies on the focal plane. This can be easily understood in the figure that follows:

CONCAVE (DIVERGING) LENS

A diverging lens is the one which is thinner in the middle than it is at its edge ie thicker at the edges than its centre and diverges light rays incident on it.. The figures below show diverging lenses.
A biconcave lens or double concave lens has both of its surfaces curving inwards.
Other concave lenses are plano-concave and convexo-concave or diverging meniscus.

Concave lenses diverge (spread out) parallel rays of light that pass through the lens. In other words, light rays passing through a concave or diverging lens are bent away from the principal axis.



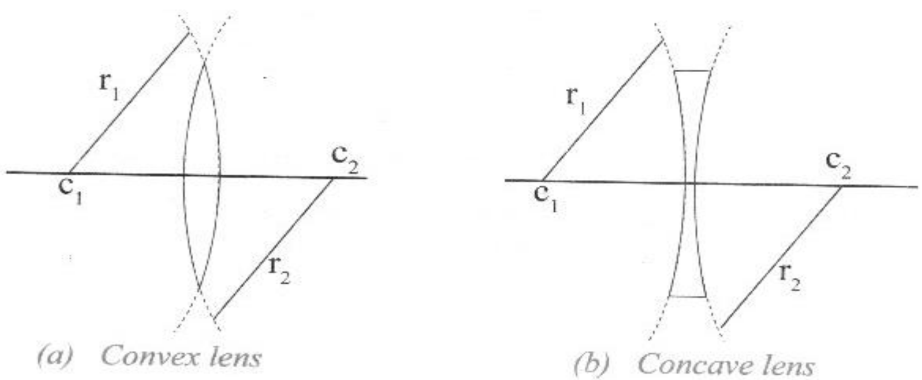
TERMS COMMONLY USED IN THIN LENSES

CENTRE OF CURVATURE

This is the centre of the sphere of which the surface forms a part. For each spherical lens there are two centres of curvature c_1, c due to the two curved surfaces.

THE RADIUS OF CURVATURE (R)

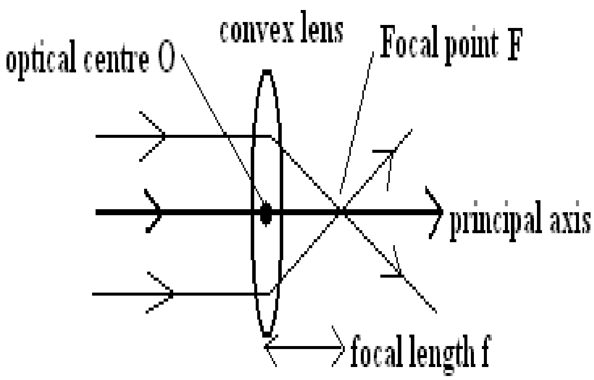
The radius of curvature of the surface of a lens is the radius of the sphere of which the surface forms a part. Each surface has its own radius of curvature r_1, r



PRINCIPAL AXIS

This is a line passing through the two centres of curvature (c_1, c).

This is a line which passes symmetrically through the optical centre O of the lens.

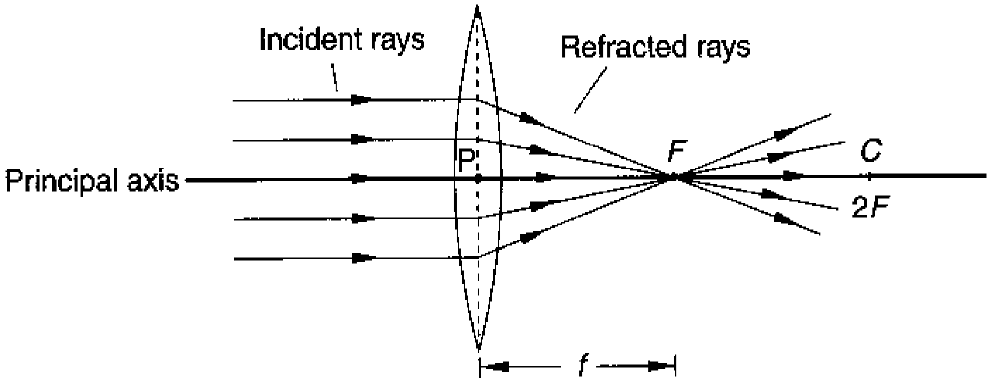


PRINCIPAL FOCUS

This is a point where all rays parallel to the principal converge after passing through the lens.

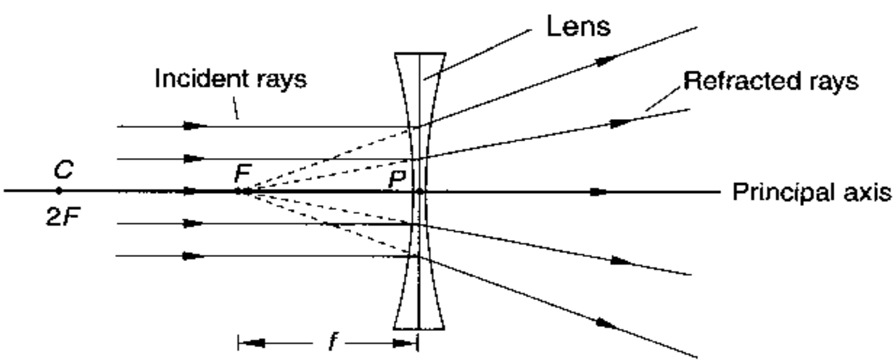
PRINCIPAL FOCUS OF A CONVERGING LENS

A set of incident rays parallel and close to the principal axis of a convex lens after refraction through the lens, pass through point F. Since this point can be projected on the screen, it is called real principal focus.



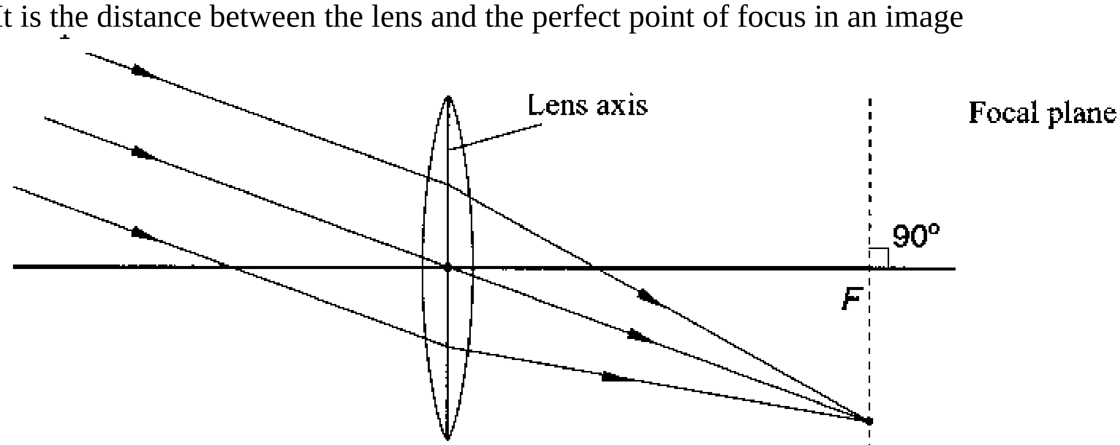
PRINCIPAL FOCUS OF A CONCAVE LENS

A set of incident rays parallel to the principal axis of a concave lens, after refraction appears to diverge from the fixed point on the principal axis. This point is a virtual principal focus because it cannot be projected on the screen.



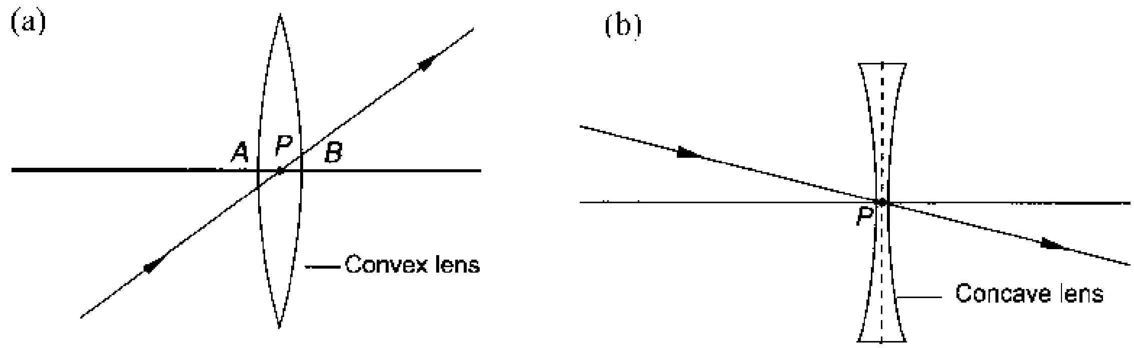
THE FOCAL PLANE

It is the distance between the lens and the perfect point of focus in an image



OPTICAL CENTRE

This is the point which lies exactly in the middle of the lens i.e. PA = PB. Light rays going through this point go straight through without any deviation or displacement.



FOCAL LENGTH

This is the distance from the optical centre to the principal focus of the lens. Biconvex and biconcave lenses have a focal length on each side of the lens.

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USES OF LENSES

Lenses are used in many different kinds of optical instruments – cameras, telescopes, microscopes, binoculars e.t.c. and the focal length (f) of the lens is an important property of a lens. The focal length helps when deciding which lens to use in which instrument.

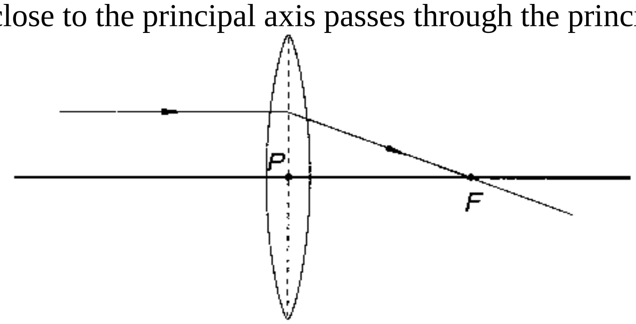
It should also be noted that the more curved the lens faces are, the smaller the focal length (f) and the more powerful is the lens.

IMAGE FORMATION (RAY DIAGRAMS)

An image of any object may be located by use of ray diagrams. Ray diagrams are always drawn to scale using lines to represent rays. The position of the object decides what kind of light ray diagram will be drawn and the image position. Information about the images formed by a lens can be obtained by drawing any two of the following rays:

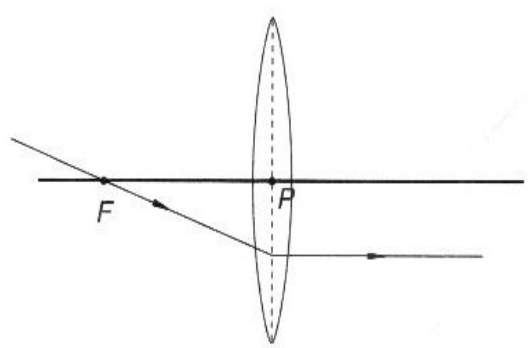
RAY 1

A ray of light parallel and close to the principal axis passes through the principal focus F.

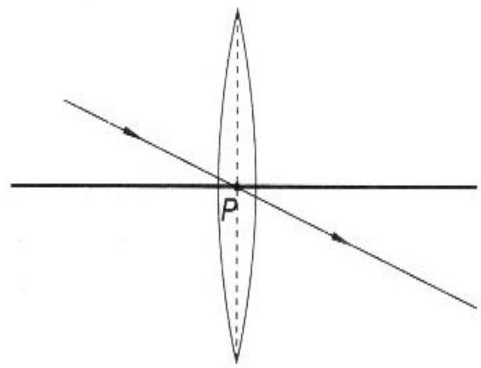


RAY 2

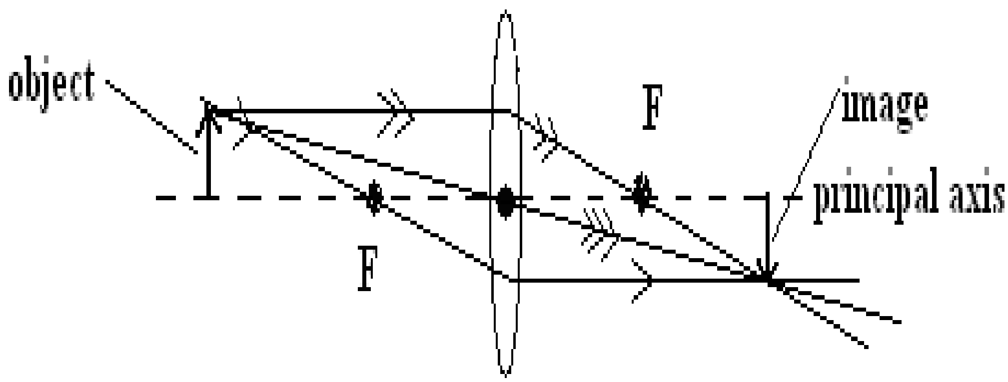
A ray of light through the principal focus F emerges parallel to the principal axis after refraction.



RAY 3
A ray through the optical centre, P is undeviated after passing through the lens.



All rays always start from the same point and a combination of any two of three will give us the position of the image.



The images formed from objects which are placed at different object distances have different characteristics. The following three characteristics show the nature of the image produced depending on the object distance.
Upright or upside down
Real or virtual
Magnified (enlarged) or diminished.

LOCATING IMAGES BY RAY DIAGRAMS
To locate the image of an object, one needs a minimum of two incident rays from the object.
If refracted rays converge***, a real image*** is obtained but if the refracted rays diverge, then a ***virtual image*** is obtained.

CONVEX LENS

1. OBJECT FAR AWAY FROM THE LENS(AT INFINITY)
   Object at infinity has the incident rays almost parallel. The refracted rays converge at a point on the focal plane.

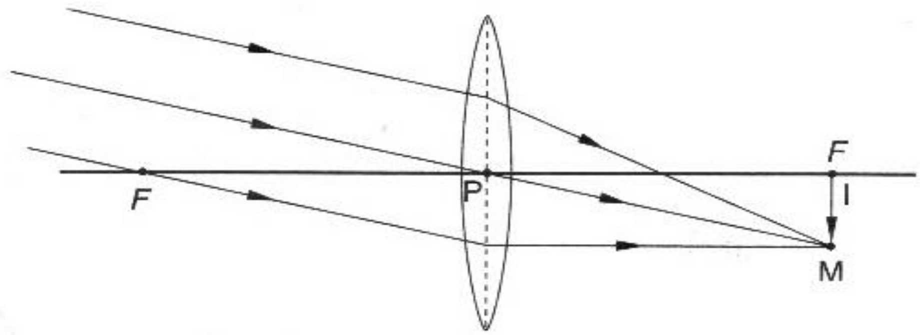


Image characteristics
- Diminished
- Real
- Inverted
- Image formed at F

2. OBJECT BEYOND 2F

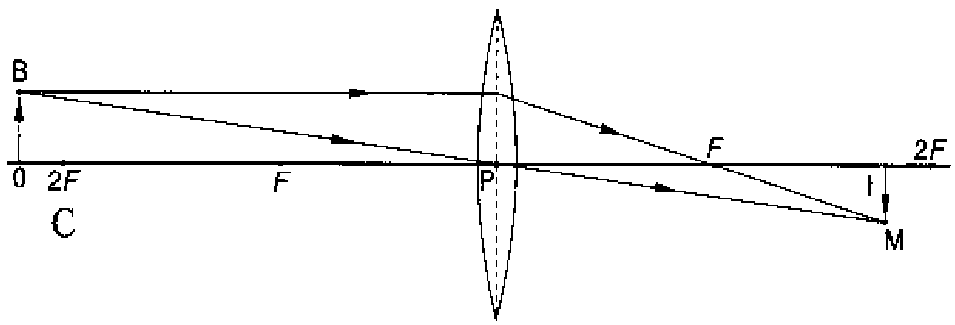


Image characteristics
- Diminished
- Real
- Inverted
- Image formed between F and 2F

Object distance (u)	Image distance (v)	Nature of image
1. Infinity	At F	Real, upside down, diminished
2. After 2F	Between F and 2F	Real, upside down, diminished
3. At 2F	At 2F	Real, upside down, same size as the object
4. Between F and 2F	After 2F	Real, upside down, magnified
5. At F	Infinity	Image not formed
6. Between F and lens	On the same side of the object	Virtual, upright, magnified

DETERMINING FOCAL LENGTH OF A CONVEX LENS

a. DETERMINATION OF FOCAL LENGTH BY EXTIMATION METHOD

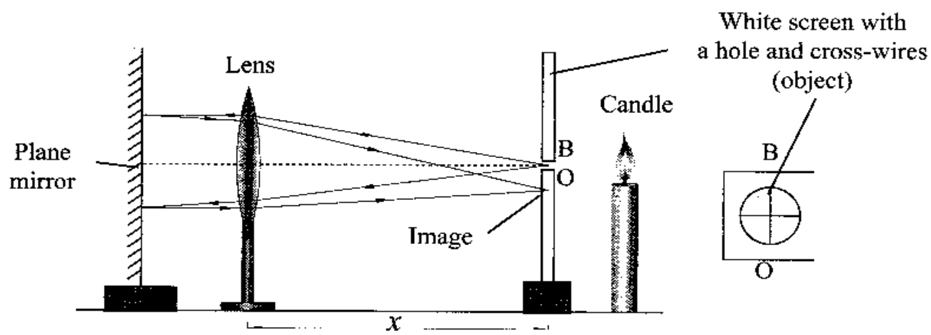
A convex lens is positioned vertically in front of the classroom furthest from the lens. A white screen is placed on the other side of the lens and adjusted until a sharp image of the classroom is seen. Distance from the lens to the screen is measured.

An inverted, real and diminished image of the classroom is formed at the focal plane of the lens.

Since the object is ar awayfrom the lens, i.e. at infinity, the image distance, v = focal length of the convex lens, f.

b. DETERMINATION OF FOCAL LENGTH USING ILLUMINATE OBJECT AND A MIRROR

A cnvex lens is positioned vertically with a plane mirror behind it so that light passing through the lens is reflected back. The object used is a hole and cross-wires on a white screen illuminated by a candle or electric lamp.



The position of the lens is adjusted until a sharp IM of the cross-wire is formed alongside the object OB.

Distance ***x*** (i.e. between the optical centre P of the lens and the screen) is measured. This is repeated two or more times to get average value of x.

$$X_{av} = \frac{x_{1+} x_{2+} x_3}{3}$$

Average value of x = focal length.

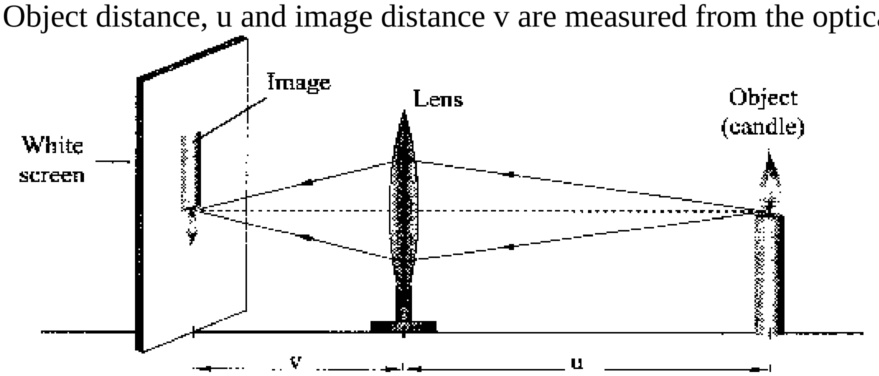
Since the reflected rays from the plane mirror are almost parallel, the reflected rays from the lens converge at the principal focus of the lens. Hence the distance ***x*** is the focal length ***f*** of the lens.

c. DETERMINATION OF FOCAL LENGTH USING ILLUMINATED OBJECT AND THE LENS FORMULA

Convex lens is placed in front of illuminated object so that the real image is formed on a white screen placed on the opposite side.

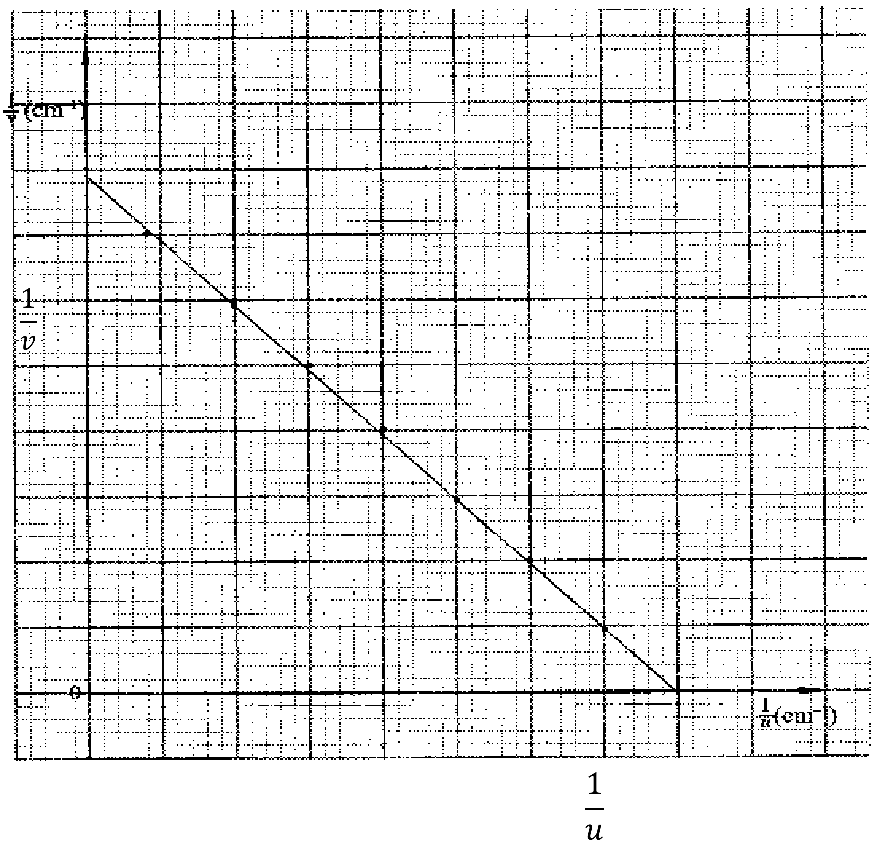
Position of the lens is adjusted so that a sharp image is seen on the screen.

Object distance, u and image distance v are measured from the optical centre of the lens.



The experiment is repeated for different values of u and measure v each time.

When a graph of $\frac{1}{v}$ against $\frac{1}{u}$ a straight line graph is obtained.



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

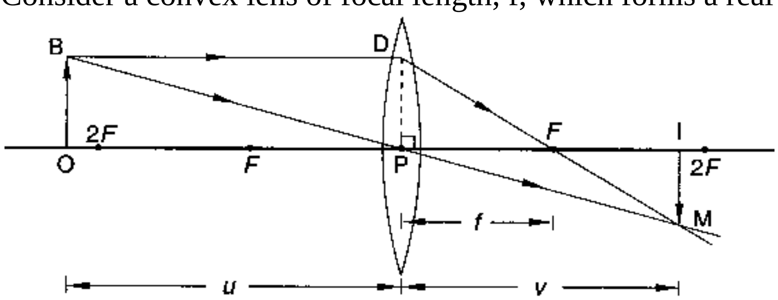
If $\frac{1}{u} = 0$, then $0 + \frac{1}{v} = \frac{1}{f}$

Hence $\frac{1}{v} = \frac{1}{f}$ which is the intercept on the y-axis.

THE LENS FORMULA

The lens formula is a formula relating focal length, image and object distance.

Consider a convex lens of focal length, f, which forms a real image IM of an object OB.



Lens formula states

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

U stands for distance of the object from the optical centre (object distance)

V stands for the distance of the image from the optical centre (image distance)

F stands for the focal length of the lens.

SIGN CONVENTION

There are several sign conventions used when the distances of the object and the image are measured from the lens.

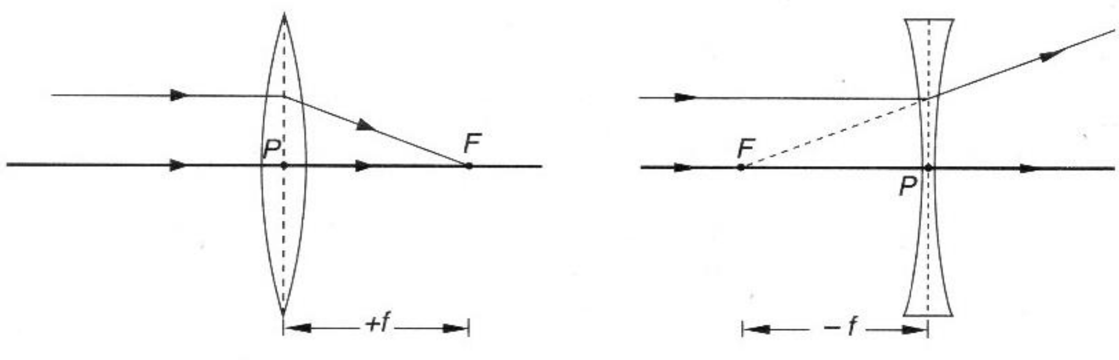
REAL IS POSITIVE

The distances of the real objects and the real images from optical centre are taken as positive.

VIRTUAL IS NEGATIVE

Distances of the virtual objects and virtual images from the optical centre are taken as negative

Figure shows positive focal length (a) and negative focal length (b)



(a) (b)

The focal length of a convex lens is positive and that of a concave lens is negative

Example 1

An object is placed 24cm from the centre of a convex lens of focal length 20cm. calculate the distance of the image from the lens

Solution

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

Therefore

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

u = 24cm; f = 20cm

$$= \frac{1}{20} - \frac{1}{24}$$

$$\frac{6-5}{120}$$

$$\frac{1}{v} = \frac{1}{120}$$

v = 120cm

Example 2

An object is placed 12cm from the centre of a concave lens of focal length 20cm. calculate the distance of the image from the lens.

Solution

Solution

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

Therefore

$$\frac{1}{v} = \frac{1}{f} - \frac{1}{u}$$

U = 12cm; f = -20m

$$\frac{1}{-20} - \frac{1}{12}$$

$$\frac{-3-5}{60}$$

$-8v = 60$

$v = -7.5cm$

v is negative because the image is virtual

MAGNIFICATION

Magnification refers to how many times an image is bigger than the object. Linear magnification (m) is defined as the ratio of the height of the image to the height of the object.

Linear magnification(m) = $\frac{\text{height of the image}}{\text{height of the object}} = \frac{h_1}{h_o}$

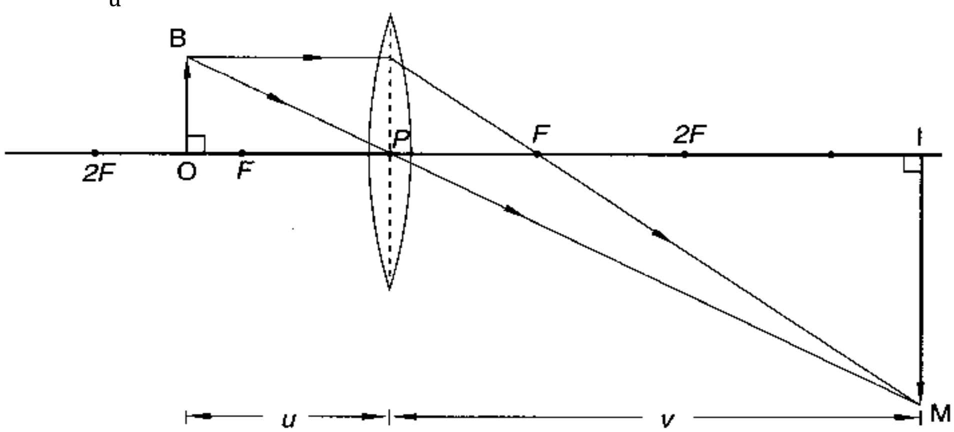
Where it might be difficult to measure the height of the image or object accurately; magnification can be calculated in terms of object distances, u and image distances, v.

$$= \frac{\text{image distance}}{\text{object distance}} = \frac{v}{u}$$

Therefore

$$M = \frac{h_i}{h_o} = \frac{v}{u}$$

That is the ratio of image to object sizes ($\frac{h_i}{h_o}$) is also equal to the ratio of image to object distances($\frac{v}{u}$) measured from the optical centre.



Magnification, m = $\frac{IM}{OB} = \frac{v}{u}$

$$m = \frac{\text{image distance (v)}}{\text{object distance (u)}}$$

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

Example 1

An object of height 2cm is placed 20cm in front of a convex lens. A real image is formed 80cm from the lens. Calculate the height of the image.

Solution

$$m = \frac{h_i}{h_o} = \frac{v}{u}$$

h_o = 2cm; u = 20cm; v = 80cm

$\frac{h_i}{2} = \frac{80}{20}$

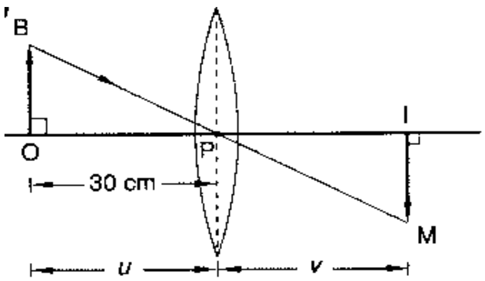
$h_i = \frac{80 \times 2}{20}$

= 8cm

Example 2

An object placed 30cm from a convex lens produces an image of magnification 1. What is the focal length of the lens?

Solution



Magnification, m = $\frac{OB}{IM} = \frac{OP}{IP} = 1$

u = 30cm

since m = 1; then v = u

this occurs when object is at 2f

hence 2f = 30cm

f = $\frac{30cm}{2}$

= 15cm

Example 3

An object of height 1.2cm is placed 12cm from a convex lens and a real image is formed at 36cm from the lens. Calculate

a. Focal length of the lens
b. Magnification produced by the lens
c. The size of the image

Solution

a. From lens formula, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$\frac{1}{12} + \frac{1}{36} = \frac{1}{f}$

3 + 1

36

$\frac{4}{36} = \frac{1}{f}$

4f = 36cm

f = 9cm

b. Magnification

$m = \frac{v}{u} = \frac{36}{12} = \underline{\mathbf{3}}$

c. Size of the image

$m = \frac{h_i}{h_o}$

$\therefore$ h_i = 3 x 1.2

= 3.6cm

Example 4

An object of height 2cm is placed 8cm from a convex lens and a virtual image is formed on the same side as the object at 24cm from the lens. Calculate

a. The focal length of the lens
b. The height of the image

Solution

a. From lens formula, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

u = 8cm; v = -24cm 9

$\frac{1}{8} + \frac{1}{-24} = \frac{1}{f}$

$\frac{3 + 1}{24}$

$\frac{1}{12} = \frac{1}{f}$

Focal length, ***f = 12cm***

b. Magnification, $m = \frac{v}{u} = \frac{h_i}{h_o}$

$\therefore h_i = \frac{-24 \times 2}{8}$

= -6cm (negative because it is a virtual image)

Example 5

A convex lens produces a real image of an object and the image is 3 times the size of the object. The distance between the object and the image is 80cm. Calculate the focal length of the lens.

Solution

Magnification, $m = \frac{v}{u} = 3$

$\therefore$ v = 3u

But u + v = 80cm

u + 3u = 80

4u = 80cm

$\therefore$ u = 20cm

Hence v = 3u – 3 x 20 = 60cm

From lens formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$= \frac{1}{20} + \frac{1}{60}$

$\frac{3 + 1}{60}$

$\frac{1}{f} = \frac{4}{60} = \frac{1}{15}$

f = 15cm

APPLICATIONS OF LENSES IN OPTICAL DEVICES

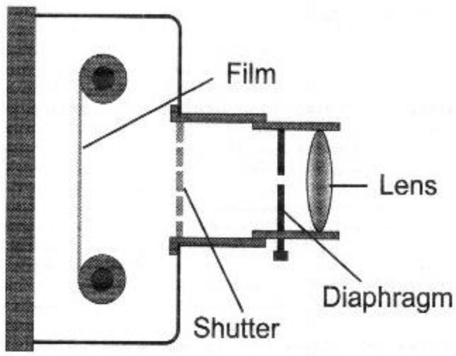
Optical instruments which use single or a system of lenses or a combination of convex lenses and concave lenses include photographic camera, microscopes, binoculars, spectrometers and overhead projector.

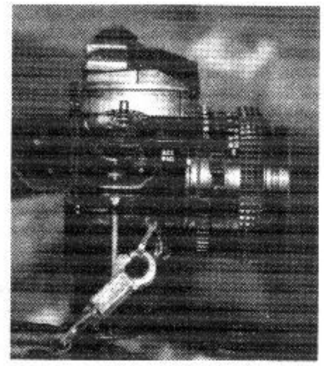
The human eye also makes use of lenses that help in the formation of the image on the retina.

The following are uses of lenses

THE CAMERA

A camera is a device used to take photographs. A human eye is similar to a camera but far too superior to the finest camera ever made by man.





A camera consists of a converging lens and a light sensitive film or plate enclosed in a light-tight box, blackened from inside. The lens focuses light from the object to form a real image, diminished and inverted image on the film. Focusing of objects is done by adjusting the distance between the lens and the film. The amount of light entering the camera through the lens is regulated with the help of a diaphragm with an adjustable opening in the middle.
Light is admitted by the shutter, which opens for different required intervals of time and then closes automatically. During this interval of time, the film is exposed to light from the object. The film contains light sensitive chemicals that change on the exposure to light. The film is then developed to get what is called a negative. From the negative, a photograph (positive) may be printed.

Example

A lens camera is used to take a photograph of a distant building. A well focused image is formed on the film. The lens of the camera is 6cm from the film.

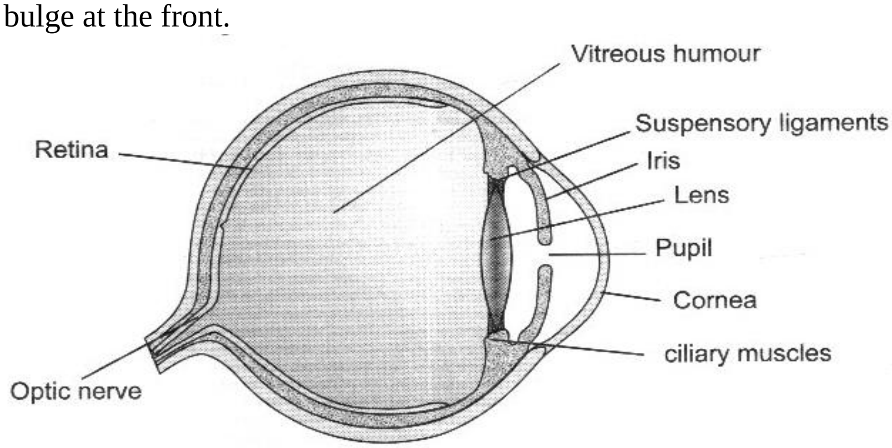
a. What is the focal length of the lens? Give reasons for your answer,
b. If the camera is then used to take a photograph of a person 2.0 m away from the lens, without moving the camera, in which direction should the lens be moved in order to produce the best possible image?

Solution

a. Focal length of the lens = 6cm. since the object is a distant building, the light rays incident on the lens are almost parallel and are brought to focus at the principal focus.
b. As the object distance is only 2.0 m i.e. object distance, u, has decreased as compared to the distance in (a). Hence the image distance, v, must be increased. To achieve this, has to be moved forward towards the person.

THE HUMAN EYE

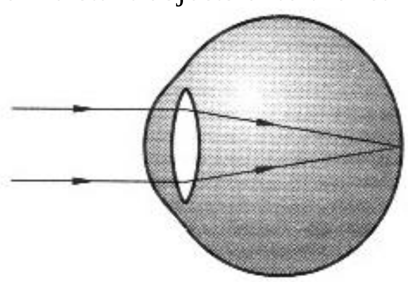
The human eye consists of a nearly spherical ball of about 2.5 cm in diameter except for a slight bulge at the front.



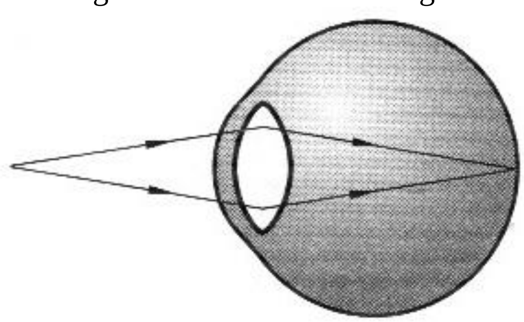
The front part of the eye is known as the cornea and is slightly bulged outwards and transparent in nature. Behind the cornea, there is the diaphragm called the iris with a hole in the middle known as pupil.
Behind the iris is a crystalline lens. This is a biconvex converging lens made of a large number of jelly-like layers which are flexible and transparent in nature. The lens is suspended inside the eye with the help of suspensory ligaments which fasten it to the ciliary muscles. These muscles control the shape o the lens.
The lens forms a real, diminished and inverted image on the retina. Light falling on the retina produces a sensation in the cells which send the electrical signals to the brain by the nerve known as optic nerve.
The amount of light reaching the retina is regulated by the size of the pupil. When a bright object is viewed, the iris reduces the size of the pupil so as to admit less light , whereas in dark light, the iris dilates so as to admit as much light as possible.
An image formed by the eye lens leaves an impression on the retina for about 0.1 second. This persistence of the vision enables one to see cinema or television pictures which appear to change smoothly from one image to the next without any interruption.

IMAGE FORMATION IN THE EYE

When one looks at far objects, the eye lens becomes thinner and focal length of the lens increases. The ciliary muscle contract and the lens has the longest focal length. This enables it to focus rays from distant objects onto the retina.



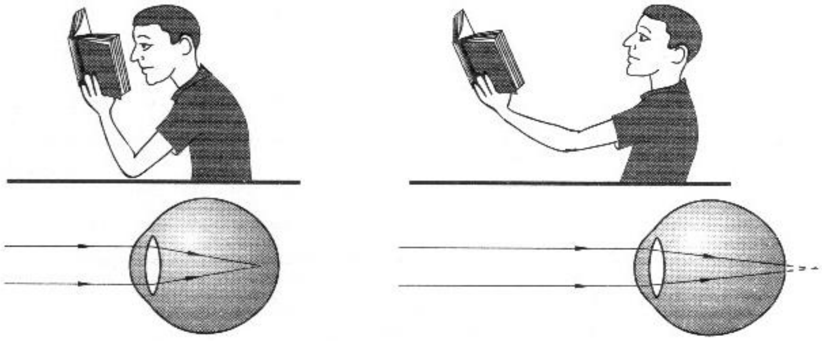
To view closer objects, the lens becomes thicker and the focal length of the lens decreases. The ciliary muscles relax to reduce tension in the lens and the lens becomes more curved with short focal length. The lens focuses images of near objects onto the retina.



The process by which the lens of the eye changes its focal length and produces focused images of both distant and near objects on the retina is called accommodation.

DEFECTS OF VISION

A normal human eye can accommodate the range of distances from far objects to objects close to the eye.
The most common defects of vision are short-sightedness (myopia) and long-sightedness (hypermetropia)
These defects may arise due to the eyeball being slightly too long or too short compared to the normal spherical ball or due to the curvature of the cornea being defective.



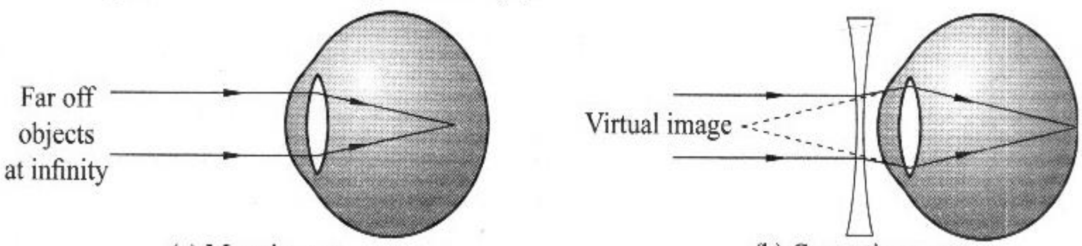
(a) Short-sightedness (b) Long-sightedness

a. SHORT-SIGHTEDNESS OR MYOPIA

A person suffering from short-sightedness can only see nearby objects. The image of a distant object is formed in front of the retina. This defect arises due to the eyeball being too long or more refraction tales place at the cornea and therefore focal length of the eye lens becomes short.

CORRECTION OF SHORT-SIGHTEDNESS

A concave lens of appropriate focal length is used. This lens diverges the rays from a distant object so that it appears to come from a virtual image formed at a point closer to the lens. The eye can focus on this virtual image.



(a) Myopic eye (b) Corrective measure

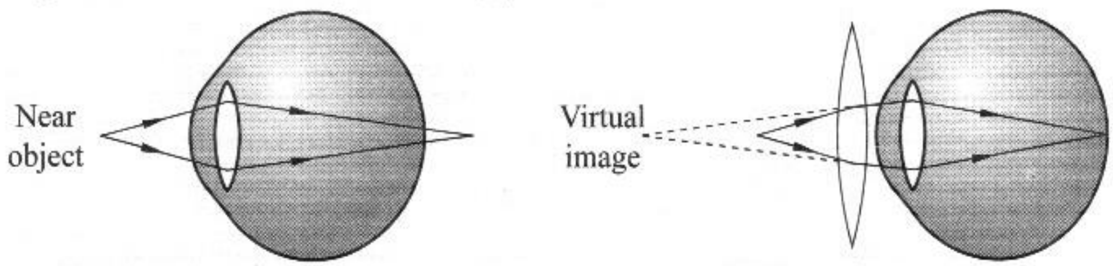
b. LONG-SIGHTEDNESS OR HYPERMETROPIA

A person suffering from long-sightedness sees distant objects clearly, but cannot see distinctly objects lying closer than a certain distance. The image of a nearly object is formed behind the retina.

This defect is due to the eyeball being too short or due to the curvature of the cornea being defective and the focal length of the eye lens becoming larger.

CORRECTION OF LONG-SIGHTEDNESS

A convex lens of appropriate focal length is used. This lens converges the ray from a near object so that they appear to come from a virtual image formed at a point far off from the lens. The eye focuses on this virtual image.



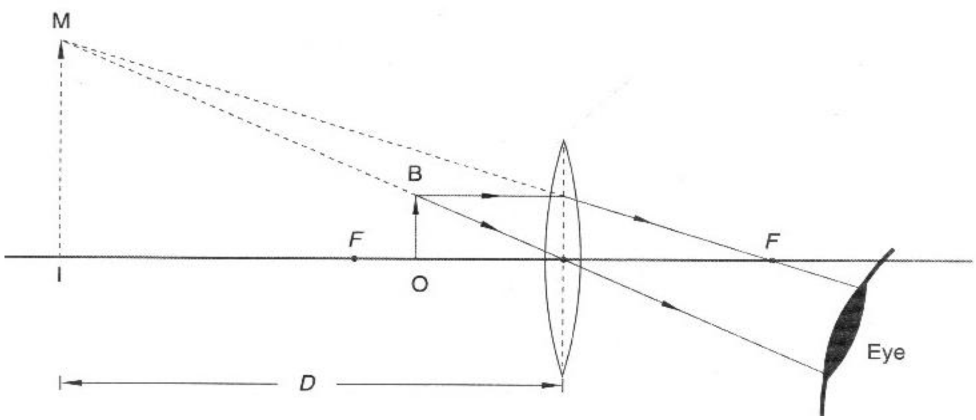
(a) Hypermetropic eye (b) Corrective measure

COMPARISON OF A CAMERA WITH THE HUMAN EYE

SIMILARITIES	DIFFERENCES
Both use converging lens	Focal length of the eye lens changes with the thickness of the lens.
Both produce a real, inverted, diminished images.	Distance between the eye lens and the retina is constant
Both can control the amount of light entering the eye	Focuses objects between 25cm from the eye lens to infinity
Both are black inside.	Form temporary images at the retina

SIMPLE MICROSCOPE

Also called a simple microscope is an instrument used to view the details of very small objects. It consists of a simple converging lens f short focal length. When an object is placed within the focal length of such lens, a magnified image which is virtual and upright is formed on the same side of the object. The distance of the object from the lens is adjusted till an enlarged image is formed.



Simple microscope enables one to bring an object very close to the eye making it appear magnified and yet clearly visible.

MAGNIFYING POWER OF A SIMPLE MICROSCOPE

Linear magnification m = $\frac{IM}{OB} = \frac{v}{u}$

In a simple microscope, the image distance, v, is negative, as the image is virtual.

Hence from the lens formula $\frac{1}{u} - \frac{1}{v} = \frac{1}{f}$

$$m - 1 = \frac{v}{f}$$

$$m = 1 + \frac{v}{f}$$

From the above expression, the shorter the focal length of the lens, the greater is the magnifying power of the instrument.

Example

Calculate the magnification produced by a lens of focal length 5.0cm used in a simple microscope, the least distance of distinct vision being 25cm.

Solution

Image distance, v = 25cm

Magnification, m = 1 + $\frac{v}{f}$

= 1 + ($\frac{25}{5}$)

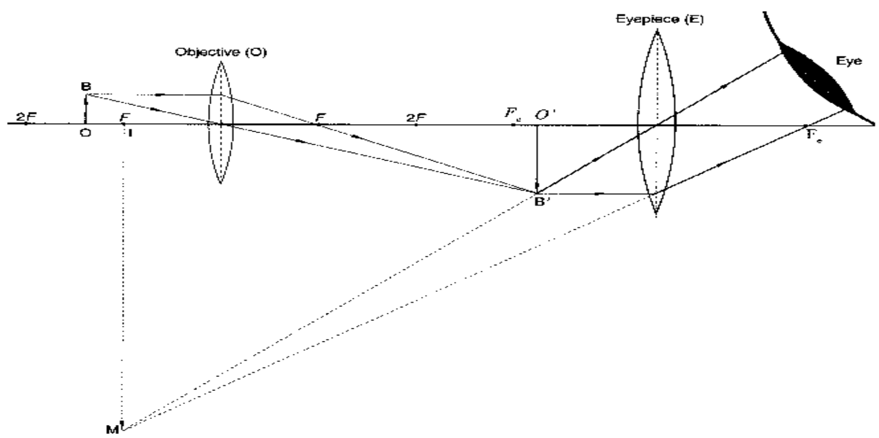
= 1 + 5

= 6

COMPOUND MICROSCOPE

A compound microscope uses two separate converging lenses, placed coaxially within two sliding tubes, to obtain a higher magnifying power.

The lens nearer to the object is called objective lens and the lens close to the eye is called eyepiece lens. Both lenses are of shorter focal lengths but eyepiece lens has a larger focal length than the objective lens. Final image is magnified, virtual and inverted.



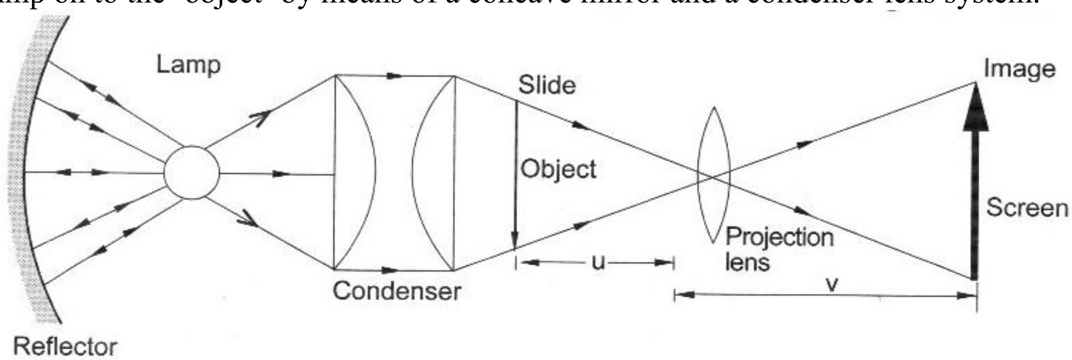
If m_1 magnification produced by the objective lens and m_2 is the magnification produced by the eyepiece lens, then magnification produced by the compound microscope is given by

$$M = m_1 \times m_2$$

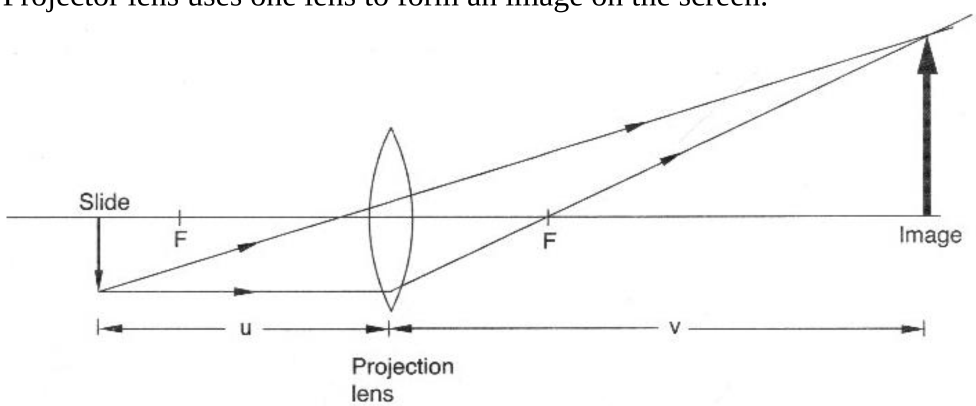
A good compound microscope produces a very high magnification.

PROJECTOR

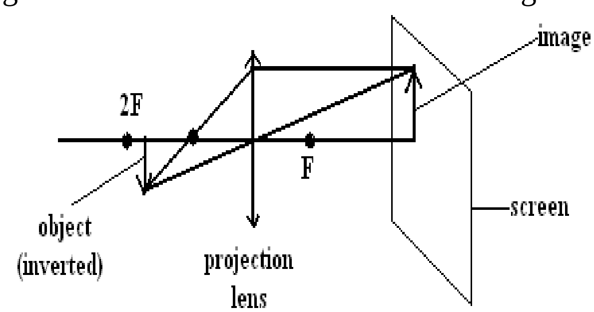
A projector forms a real image on a screen of a slide in a slide projector, or of a film in a cine-projector. The image is larger than the slide or frame of film and is further away from the lens. It is usually so highly magnified that very strong but even illumination of the slide or film is needed if the image is also to be bright. This is achieved by directing light from a small but powerful lamp on to the 'object' by means of a concave mirror and a condenser lens system.



The projector has the following parts:
A Quartz-Halide lamp (a very bright source of light) is placed at the centre of the curvature of a concave reflector.
Reflector which reduces loss of light produced. The light rays that are directed away from the object are therefore reflected back towards the object by the **concave mirror**.
Condensing lens consists of a pair of converging lens called condenser. It controls the beam of light so as to evenly illuminate the slide i.e. it concentrates (condenses) as much as possible the light energy onto slide. The condenser and the lamp are arranged such that the image of the lamp is formed on at the projection lens position. This ensures that all light passes through the projection lens and the image of the lamp is not formed on the screen.
Slide contains the pictures to be viewed on the screen. The slide is introduced into the projector upside down so that images seen on the screen are right way up. The slide is positioned such that 2f >u>f to form magnified real images.
Projector lens uses one lens to form an image on the screen.



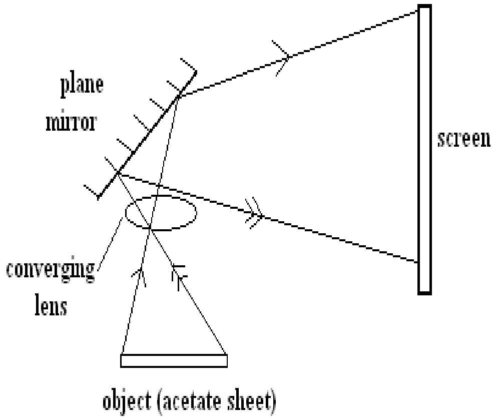
The **projection lens** is a lens of long focal length and its function is to produce a focussed, magnified, real and upright image (when object is inverted) on the screen.
A ray diagram can be drawn to show how the image is formed.



Since the distance v is very large compared to the distance u, the image is highly magnified i.e. m = $\frac{v}{u}$
In order to increase the magnification of the image on the screen, there must be:
a decrease in object height
an increase in image height
To do this it is necessary to move the projection lens nearer to the object (slide or film) or the object nearer to the projection lens. Another way is by moving the screen away from the projection lens. Each of these actions will increase **v** and decrease **u**, and so increase **m**.

Another type of projector in fairly common use in education is the overhead projector (OHP). This consists of a quartz-halogen line-filament lamp sited at the centre of curvature of a converging mirror such that light goes directly from the lamp and by reflection from the mirror to

a special type of lens called a Fresnel lens. The figure below shows the main components of an OHP in use and a ray diagram of the formation of the image on the screen.
In using an OHP the teacher or lecturer can write or draw on the acetate sheet without turning away from the audience and the image is projected onto a white screen which is also facing the audience.



Chapter 13

NUCLEAR PHYSICS

STRUCTURE OF AN ATOM

An atom is the smallest electrically neutral particle of an element that carries all properties of that element and can take part in a chemical reaction.

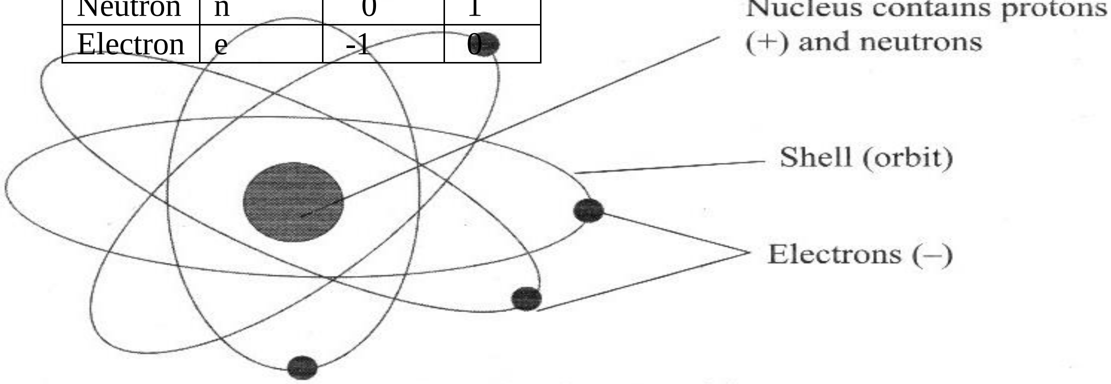
Atoms are made up of three subatomic particles called protons, neutrons and electrons which are held together by nuclear forces.
Protons which are positively charged and neutrons which carry no charge are located at the centre of the atom called nucleus, hence they are collectively known as nucleons.
Electrons which are negatively charged are found in the space moving around the nucleus called shells or energy levels where they orbit like planets in the solar system.

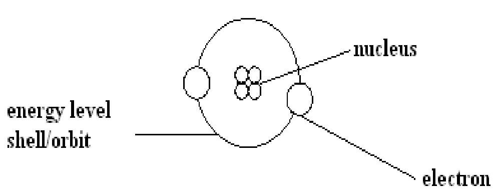
Normally, an atom has the same number of electrons as protons, so its overall charge is zero. As an example, consider a sodium atom (Na): it has atomic number of 11 (number of protons) and around the nucleus there are 11 electrons.

Total charge of protons = +11
Total charge of electrons = - 11

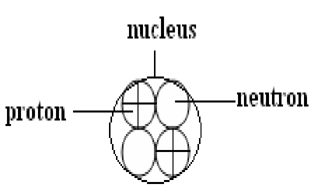
Particle	symbol	Charge	Mass
Proton	p	+1	1
Neutron	n	0	1
Electron	e	-1	0

Overall charge = + 11 – 11 = 0





Electrons are held in orbits by the force of attraction between opposite charges while protons and neutrons are bonded tightly together in the nucleus by a different kind of force called **strong nuclear force**.



Structure of nucleus

ATOMIC NUMBER (Z)

The atomic number is the number of protons in the nucleus of an atom. In the neutral atom, the number of protons (positive charges) equals the number of electrons (negative charges). The atomic number identifies a particular element since no two elements can have the same atomic number.

In nuclear notation, the atomic number is indicated on the left lower side of the symbol of an element, ie subscript number e.g. the atomic number of sodium is 11 i.e. $_{11}Na$

Atomic symbol is Z.

MASS NUMBER (A)

The mass number of an atom is the sum of the protons and neutrons in the nucleus of the atom or the total number of nucleons (protons and neutrons) in the nucleus of the atom i.e. atomic mass. It is the sum of the atomic number and the number of neutrons.

Mass number is indicated on the upper left side of the symbol of an element i.e. superscript number. The symbol for the mass number is A.

Therefore A = Z+ N where N is number of neutrons.

An atom of element X with mass number A and atomic number Z is written as $^{A}_{Z}X$ e.g. carbon atom of mass number 12 and atomic number 6 is represented as $^{12}_{6}C$.

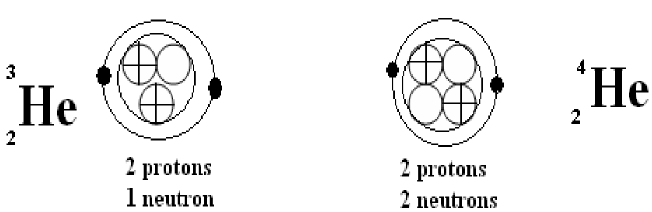
ISOTOPES

Isotopes are atoms of the same element with the same atomic number but different mass numbers or are atoms of the same element with the same number of protons but different numbers of neutrons.

E.g. hydrogen has three isotopes- hydrogen (1 proton 0 neutron), deuterium (1 proton and 1 neutron)and tritium (1 proton and 2 neutrons)

$^{1}_{1}H$	$^{2}_{1}H$	$^{3}_{1}H$
Hydrogen	Deuterium	Tritium

The difference in the number of neutrons in the two helium atoms below results to two different atoms, one with a mass number of 3 amu while the other with a mass number of 4 amu and are called **helium-3** and **helium-4** respectively.



To differentiate between different isotopes of an element, the mass number of the isotope is attached to the name of the element e.g.

Isotopes of hydrogen are named as hydrogen-1, hydrogen-2 and hydrogen-3 while isotopes of carbon are named as carbon-12, carbon-13 and carbon-14

RADIOACTIVITY

Radioactivity is the process by which unstable nuclei spontaneously disintegrate to release energy by emitting radiations or particles. The disintegration is random and haphazard and it is not possible to predict which atoms are going to decay and when.

Some substances contain atoms with unstable nuclei. In time, each unstable nucleus disintegrates (breaks up). As it does so, it shoots out tiny particles and, in some cases, a burst of wave energy as well. The particles and waves ‘radiate’ from the nucleus, so these are called **Nuclear Radiations**.

The materials whose unstable nuclei disintegrate and emit nuclear radiation are known as **Radioactive Materials**. The process whereby the nuclei disintegrate and emit nuclear radiation is called **Radioactive Decay**.

BACKGROUND RADIATION

It is the stray radiation present in the atmosphere and it is not due to any particular radioactive material. The possible causes of background radiation include

- Cosmic radiation which originates outside the earth i.e. from the sun
- Presence of natural radioactive materials in the rocks e.g. granite rocks
- Fossil fuels e.g. very old tree trunks, etc

NATURAL AND ARTIFICIAL RADIOACTIVITY

a. Natural radioactivity is the type of radioactivity by which atoms disintegrate on their own in order to be stable. Naturally occurring radioactive substances have high nucleon numbers. These elements have extremely long half lives e.g.

Natural nuclide	**Half life**
Uranium – 283 $^{238}_{92}U$	4.5×10^9 years
Carbon – 14 $^{238}_{92}$	C 5.7×10^3 years
Radium – 226	$^{238}_{92}Ra$ 1.6×10^3 years

b. Artificial radioactivity is the type of radioactivity which has been induced by bombardment with a neutron.

$$^{1}_{0}n + ^{31}_{15}P \longrightarrow ^{32}_{15}P$$

(stable) (Unstable)

Radioactive ${}^{32}_{15}P$ has been obtained by bombardment of a stable isotope ${}^{31}_{15}P$ with a neutron ${}^{1}_{0}n$.

TYPES OF NUCLEAR RADIATION

There are three main types of nuclear radiation and these are:

a) ALPHA PARTICLES (α)

A nucleus of an atom of a particular substance is said to have undergone alpha decay when it loses two (2) protons and two (2) neutrons leaving the nucleus with 2 protons and 2 neutrons less than before. For example, Radium-226 (with atomic number 88), when the nucleus undergoes alpha decay, it loses 2 protons and 2 neutrons making the atomic number to drop by 2 and the mass number by 4 i.e.

Atomic number = 88 – 2 = 86

Mass number = 226 – 4 = 222

$$ {}^{226}_{88}Ra - {}^{4}_{2}\alpha \rightarrow {}^{222}_{86}Rn $$

The equation above is showing that the Radium-226 nucleus, on the left hand side, is losing 2 neutrons and 2 protons forming a new nucleus on the right hand side with the atomic number 2 less than before. The equation can be rewritten as shown:

$$ {}^{226}_{88}Ra \longrightarrow {}^{222}_{86}Rn + {}^{4}_{2}\alpha $$

The equations above are referred to as **Nuclear Equations**. From the equation above, there are two products which have been formed on the right hand side and these products are called **Daughter nucleus** and **Alpha particle** respectively, and the original nucleus is called **Parent nucleus**.

During the alpha decay:

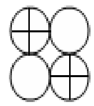
- The top numbers balance on both sides of the equation i.e. (226 = 222 + 4), so that the nucleon number is unchanged.
- The bottom numbers also balance on both sides of the equation i.e. (88 = 86 + 2), so that the charge is conserved.
- A new element is formed with atomic number 2 less than before and the mass number 4 less than before.
- Checking on the periodic table the element with atomic number 86 is called Radon (Rn). So the Radium (Ra) nucleus has undergone alpha decay to form a Radon (Rn) nucleus and alpha particle i.e.

alpha decay

Radium nucleus → **Radon nucleus** + **alpha particle**

(Parent nucleus) **(Daughter nucleus)** **(Helium nucleus)**

The alpha particle is the **helium-4 nucleus** and can be shown as follows:

 OR $^{4}_{2}He^{+2}$ OR $^{4}_{2}\alpha$

PROPERTIES OF ALPHA PARTICLES

- Each alpha particle is 2 protons and 2 neutrons and it is identical to Helium-4 nucleus.
- Alpha particles have a relative charge of +2.
- Alpha particles have a relative bigger mass as compared to the other particles.
- Alpha particle have strong ionising effect, that is to say, alpha particles have a better ability to remove electrons from their shells in atoms. Remember alpha particles are positively charged and electrons are negatively charged so there is attraction.
- Alpha particles are not very penetrating; they are easily stopped by a thick sheet of paper, or by skin, or by a few centimetres of air.
- Alpha particles are deflected by magnetic and electric fields.
- Alpha particles have a speed of up to 0.1 x speed of light (one-tenth of the speed of light).

b) BETA PARTICLES (β)

During beta decay a neutron in the nucleus decays (breaks) into a proton and an electron. The electron leaves the nucleus at a high speed. The radioactive particle is the **electron**. The number of nucleons does not change, but we have got one proton more than before decay.

For example, Iodine – 131 (atomic number 53), decays by beta emission. There is addition of proton in the nucleus making the atomic number to be 54 i.e.

$$\underset{\text{53 protons, 78 neutrons}}{^{131}_{53}I} \longrightarrow \underset{\text{54 protons, 77 neutrons}}{^{131}_{54}Xe} + \underset{\text{beta particle}}{^{0}_{-1}\beta}$$

This is a nuclear equation for beta minus decay. During this type of decay:

i. The top numbers balance on both sides of the equation (131 = 131 + 0), so the nucleon number is conserved.
ii. The bottom numbers balance on both sides of the equation [53 = 54 + (-1)], so that the charge is conserved.
iii. A new element is formed, with an atomic number 1 more than before.
iv. Checking at the periodic table the element with an atomic number 54, it is found to be Xenon-131 nucleus as indicated in the equation before:
beta decay

Iodine-131 nucleus ⟶ Xenon-131 + beta particle (an electron)

(these are decay products)

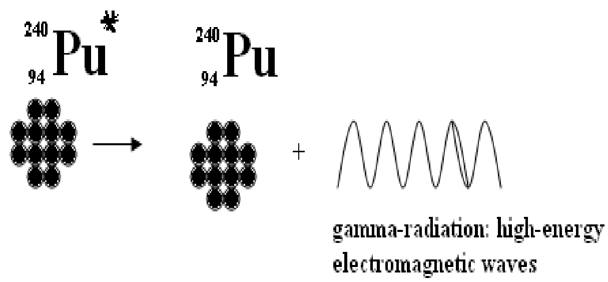
PROPERTIES OF BETA PARTICLES

- The beta particle is an electron.
- Beta particles have a relative charge of -1.
- Beta particles have low mass.
- Beta particles have weak ionising effect.
- Beta particles are penetrating, but stopped by a few millimetres of aluminium or any other metal.
- Beta particles are deflected by magnetic and electric fields.
- Beta particles have a speed of up to 0.9 x speed of light (nine-tenth of the speed of light).

c) GAMMA RADIATION (γ)

- When a gamma radiation occurs, high energy electromagnetic waves are emitted from the atomic nucleus. These waves are photons (small amount of energy released at a time), which have got higher frequency. A gamma radiation can happen after an alpha decay or beta decay.
- With some isotopes, the emissions of these alpha and beta decays leave the protons and neutrons in an excited arrangement. As the protons and neutrons rearrange to become more stable, they lose energy. This energy is emitted as a burst of gamma radiation/ray.
- Gamma emission by itself causes no change in mass number or atomic number of the nucleus.

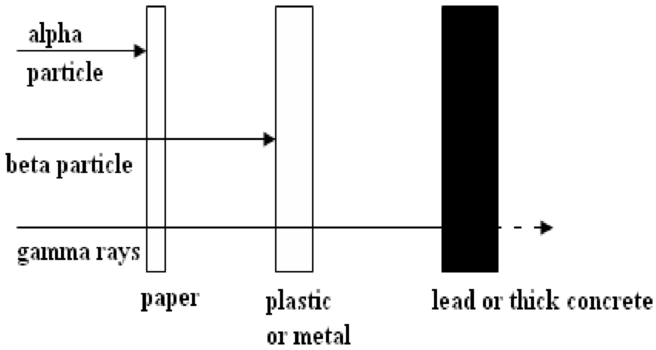
The diagram below shows gamma decay process of Plutonium-240 forming Plutonium-240 with its both mass and atomic numbers unchanged:



PROPERTIES OF GAMMA RAYS

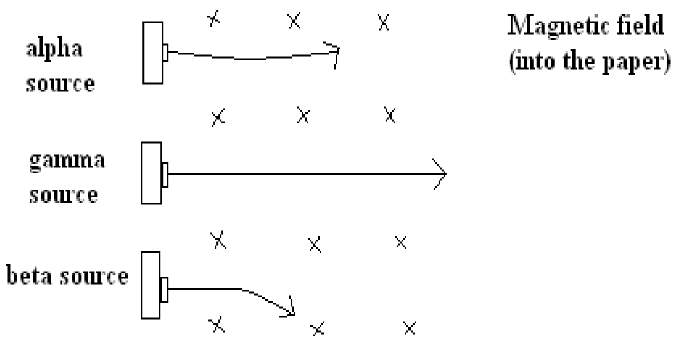
- They are electromagnetic waves similar to X-rays.
- Gamma rays have a speed of light.
- Gamma rays have a very weak/ no ionizing effect, that is, gamma rays have a very little ability to remove electrons from their paths in the atoms.
- Gamma rays are very penetrating; never completely blocked or stopped, though lead and thick concrete can reduce the intensity of penetration.
- Gamma rays are not deflected by magnetic or electric fields.
- Gamma rays have no mass and no charge.

DIAGRAM SHOWING PENETRATING DISTANCES OF THE THREE DECAYS:



THE EFFECT OF ELECTRIC AND MAGNETIC FIELDS

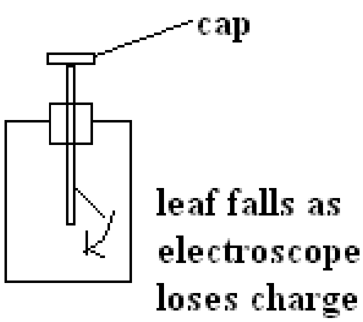
Like any stream of moving charged particles, alpha and beta rays are deflected by electric and magnetic fields. Beta particles show much greater deflections than alpha particles because of their lower mass. As stated already, gamma rays are not deflected by a magnetic field.



DETECTING NUCLEAR RADIATION

Most methods of detecting alpha, beta and gamma rays are based on the fact that these radiations have an ionising effect.

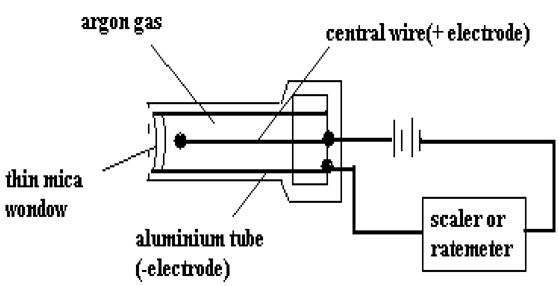
a. **LEAF ELECTROSCOPE**:
   Alpha particles can be detected using a charged electroscope. The source is brought near the cap of a charged leaf electroscope, and the air around the cap becomes ionised. Ions with a charge opposite to that on the electroscope are attracted to the cap where they neutralise some charge on it. The leaf falls as a result. In effect, the ionised air conducts charge away from the electroscope. The more intense the radiation, the faster the leaf falls. The method is not suitable for detecting beta and gamma radiation as these cause insufficient ionisation of the air.



b. GEIGER-MULLER TUBE:

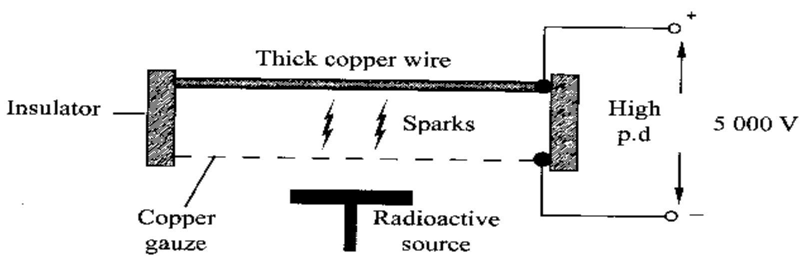
The tube contains argon gas at low pressure. A p.d. of about 400V is applied between the central wire electrode and the aluminium wall of the tube. The end of the tube is sealed by a mica 'window' thin enough to allow alpha particles to pass into the tube as well as beta and gamma radiation.

When a charged particle or gamma radiation enters the tube, the argon gas becomes ionised. This triggers a whole avalanche of ions between the electrodes. For a brief moment, the gas conducts and a pulse of current flows in the circuits. The circuit includes either a **scaler** or a **ratemeter**. A scaler counts the pulses and shows the total on a display. A ratemeter indicates the number of pulses or counts per second. The complete apparatus is often called a **Geiger counter**.



c. SPARK COUNTER

The high voltage applied makes air to conduct electricity. When the air between the gauze and the neutral wire is ionized by the radiations from the source a spark occurs. It is useful means of detecting alpha rays but not suitable for beta and gamma due to their weak ionizing effect.



d. IONIZATION CLOUD CHAMBERS

The radiation emitted by a radioactive source ionizes the medium through which they travel. The path along which ionization takes place is visible since the ionizing particle passing through the medium leaves a trail or line of a cloud.

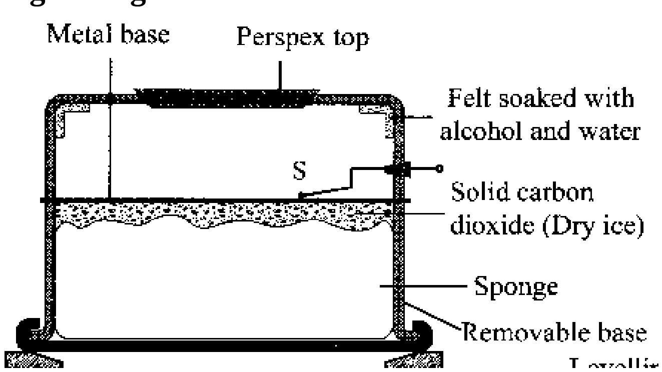
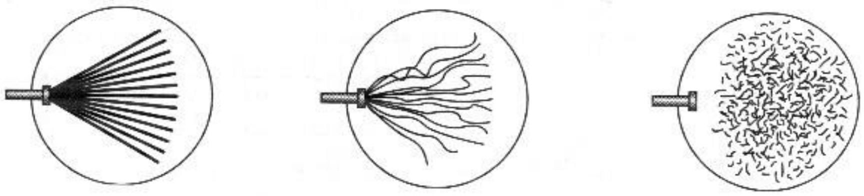


Figure shows tracks produced by different radiations in a cloud chamber

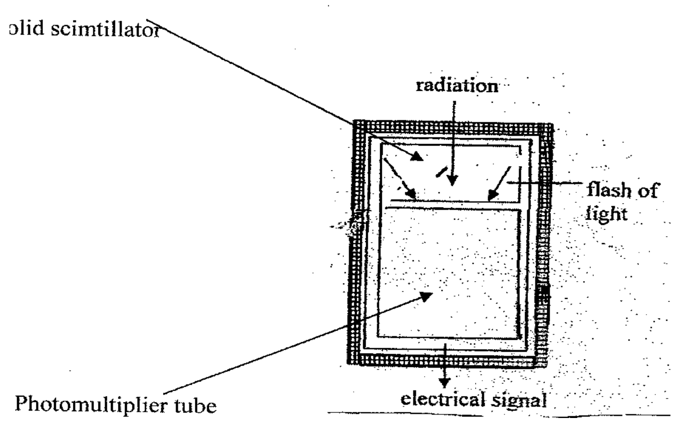


(a) α - tracks (b) β - tracks (c) γ - tracks

Alpha particles having maximum ionizing power produce straight thick tracks of short length.
Beta particles give rise to thin broken erratic tortuous tracks. Length of tracks is greater than in alpha
Gamma rays do not produce any tracks

e. SCINTILLATION COUNTER

It uses material such as sodium iodide which produces flashes of light when it is hit by radiation.



f. SOLID-STATE DETECTOR:

The incoming radiation ionises atoms in a reverse-biased ***p-n*** junction diode. This makes the diode conduct and a pulse of current flows in the circuit as a result. As with GM tube, current pulses are detected using a scaler or a ratemeter.

g. PHOTOGRAPHIC PLATES

HALF LIFE AND ACTIVITY

In radioactive sample, the average number of disintegrations per second is called the **Activity**. The SI unit of activity is the **Becquerel** (Bq). An activity of, say, 100Bq means that 100 nuclei are disintegrating per second.

Half life is the time required for the activity of a radioactive material to be reduced to half its original value.

It is the time taken for half of the number of radioactive nuclei present to decay.

If the original activity is A_0, it reduces to $A_0/2$ in 1^{st}half life; $A_0/2$ reduces to $A_0/4$ in second half life etc.

$$A_0 \xrightarrow[T_{\frac{1}{2}}]{} \frac{A_0}{2} \xrightarrow[T_{\frac{1}{2}}]{} \frac{A_0}{4} \xrightarrow[T_{\frac{1}{2}}]{} \frac{A_0}{8} \xrightarrow[T_{\frac{1}{2}}]{} \frac{A_0}{16} \xrightarrow[T_{\frac{1}{2}}]{} \frac{A_0}{32}$$

Hence the activity reduces to $\frac{1}{32}$ of the original value after 5 half-lives.

If original number of nuclei present in a sample is N_0, it reduces to $N_0/2$ in 1st half-life; $N_0/2$ reduces to $N_0/4$ in 2nd half-lifeetc.

$$N_0 \xrightarrow[t_{\frac{1}{2}}]{} \frac{N_0}{2} \xrightarrow[t_{\frac{1}{2}}]{} \frac{N_0}{4} \xrightarrow[t_{\frac{1}{2}}]{} \frac{N_0}{8} \xrightarrow[t_{\frac{1}{2}}]{} \frac{N_0}{16}$$

Hence number of nuclei reduces to $N_0/16$ in 4 half-lives

If N_0 is the quantity of the radioactive material present at the beginning, the quantity N remaining after a given time T is given by

$$N = N_0\left(\frac{1}{2}\right)^{\frac{T}{t}}$$

EXAMPLE 1

The half-life of iodine-131 is 8 days. If at time t =0, the mass of iodine is 1g, how much of iodine-131will be left after 48 days?

Solution.

48 days correspond to 6 half-lives 48 ÷ 8. A mass of 1 g will reduce to half a gram in one half-life; to quarter gram in another half-life, etc. as shown below.

$$1 \longrightarrow \frac{1}{2} \longrightarrow \frac{1}{4} \longrightarrow \frac{1}{8} \longrightarrow \frac{1}{16} \longrightarrow \frac{1}{32} \longrightarrow \frac{1}{64}$$

Alternatively by using the formula

$N_0 = 1g$, $t = 8$ days, $T = 48$ days, $N = ?$

$$N = N_0\left(\frac{1}{2}\right)^{\frac{T}{t}} = 1 \times \left(\frac{1}{2}\right)^{\frac{48}{8}} = 1 \times \left(\frac{1}{2}\right)^6 = \frac{1}{64}g$$

Hence the mass of iodine left behind after 48 days = $\frac{1}{64}$ g.

EXAMPLE 2

A radioactive substance has decayed to $\frac{\mathbf{1}}{\mathbf{128}}$th of its original activity after 49 days. What is its half life?
Solution

$$1 \xrightarrow[1]{} \frac{1}{2} \xrightarrow[2]{} \frac{1}{4} \xrightarrow[3]{} \frac{1}{8} \xrightarrow[4]{} \frac{1}{16} \xrightarrow[5]{} \frac{1}{32} \xrightarrow[6]{} \frac{1}{64} \xrightarrow[7]{} \frac{1}{128}$$

There are 7 half lives

Let $N_0 = x$, $N = \frac{1}{128}x$, T = 49 days, t = ?

$$N = N_0(\tfrac{1}{2})^{\frac{T}{t}} \Rightarrow \frac{x}{128} = x(\tfrac{1}{2})^{\frac{49}{t}}$$

$$\text{Cancelling x} \Rightarrow \frac{1}{128} = (\tfrac{1}{2})^{\frac{49}{t}} = (\tfrac{1}{2})^7 = (\tfrac{1}{2})^{\frac{49}{t}}$$

$$7 = \frac{49}{t} \Rightarrow t = \frac{49}{7} = 7 \text{ days}$$

The time taken is 7 half-lives = 49 days

$\therefore$ Half-life of the substance = $\frac{49}{7}$ = 7 days

EXAMPLE 3

A radioactive element is giving count rate of 15 counts per second. What was its count rate hours ago if its half-life is 2 hours.

Solution

N = 15, t = 2 h, T = 8 h, N = ?

$$N = N_0(\tfrac{1}{2})^{\frac{T}{t}} \Rightarrow 15 = N_0(\tfrac{1}{2})^{\frac{8}{2}}$$

$$15 = N_0(\tfrac{1}{16}) = No = 15 \times 16 = 240$$

Its count rate 8 hours ago is 240 counts per second

EXAMPLE 4

When a source is placed in front of a GM tube and scaler, the initial count rate after the background count has been deducted is 4000. After twenty minutes the count rate after deduction of the background count is 125. What is thehalf-life of the source?

First method:

It is necessary to find out how many half-lives there are in 20 minutes. Thus

1st half life count rate falls from 4000 to 2000

2nd " " " " 2000 to 1000

3rd " " " " 1000 to 500

4th “ “ “ “ 500 to 250

5th “ “ “ “ 250 to 125

Thus the activity has halved five times during the 20 minute interval and thehalf-life is

$\frac{20}{5}$= 4 minutes.

Second method:

Original count rate A_0 = 4000

Number of half-lives = n

Final count rate A_n = 125

$$\frac{A_0}{A_n} = 2^n$$

$$\frac{4000}{125} = 2^n$$

$32 = 2^n$

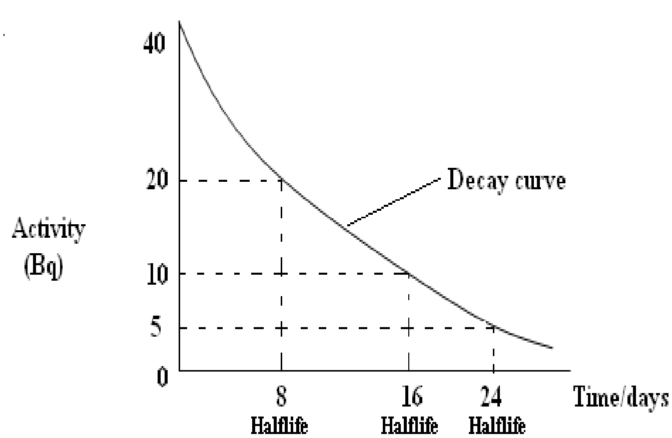
$2^5 = 2^n$

$5 = n$

Half-life = 20/5 = 4 minutes.

All radionuclide have a particular half-life, some of which very long, while others are extremely short. For example, Uranium-238 has a long half-life, 4.5 x 10^9 years. In contrast, Carbon-11 has a half-life of only 20 minutes.

The graphs showing this decay are called **Decay curves**.



The decay of Iodine-131: its half life is 8 days

NUCLEAR ENERGY

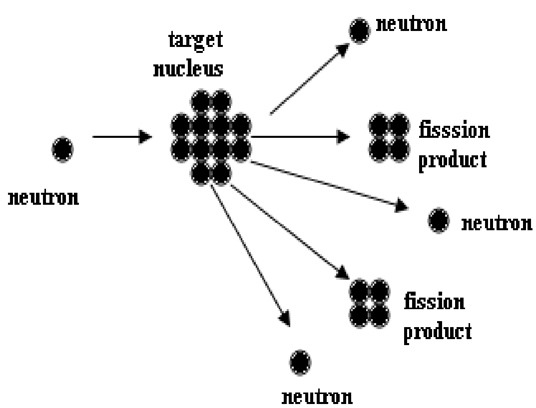
The protons and neutrons in a nucleus possess nuclear potential energy – or **nuclear energy** for short. When alpha or beta particles are emitted by a radioactive isotope, they collide with surrounding atoms and make them move faster. In other words, the temperature rises as nuclear energy is transformed into thermal energy (heat).

During radioactive decay, the energy released per atom is around a million times greater than that given off during a chemical change such as burning. However, rates of decay are usually very slow. Much faster decay can be produced in some cases by bombarding nuclei with other particles. Neutrons make the most effective missiles; being uncharged, they are not repelled by nuclei, can penetrate and disrupt them relatively easily.

Any process in which a particle penetrates a nucleus and changes it in some way is called a **nuclear reaction**.

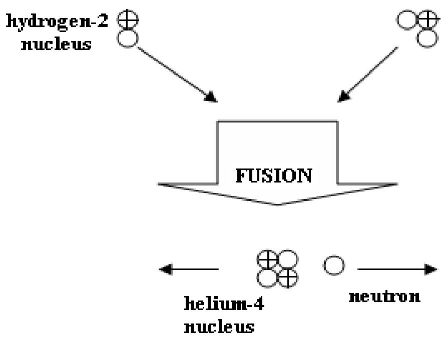
i. NUCLEAR FISSION

When a neutron is made to strike and penetrates a nucleus, the nucleus becomes highly unstable and splits into two nuclei; shooting out two or three neutrons as it does so. This splitting process is what we call **nuclear fission**. Nuclear fission is an example of chain reaction and the fragments are thrown apart as **energy** is released.
The number of nuclei undergoing fission multiples rapidly, and an enormous quantity of energy is released in a short space of time.



ii. NUCLEAR FUSION

Nuclear fusion is the process by which multiple nuclei join together to form a heavier nucleus. Nuclei have to collide at very high speeds for fusion to occur, otherwise the repulsion between their charges prevents them from coming close enough to combine. It is accompanied by a release or absorption of energy. This reaction produces far more energy for a given mass of material than any fission reaction. The diagram below shows a fusion reaction between two nuclei to form one heavier nucleus.



APPLICATIONS OF RADIOACTIVE SUBSTANCES

a. USED IN MEDICINE

- Radiotherapy: Cobalt-60 emits high energy **γ –** radiation. This is used in cancer therapy instead of the more elaborate high energy X-radiation. These gamma rays can penetrate deep into the body and kill living cells. So a highly concentrated beam from Cobalt-60 source can be used to kill cancer cells. Treatment like this is called **radiotherapy**.
- Used as tracers in medicine. Radioactive iodine-131 is used as a tracer to monitor the function of thyroid gland which controls the metabolism in the body
- Sodium is used to trace blood clots in the body. Sodium is injected in the body and using detectors to find where blood flows stop.
- Plastic disposal syringes are irradiated with gamma rays from cobalt-60 to kill bacteria and keep them sterile.

b. USED IN BIOLOGY AND AGRICULTURE

- Used to monitor how plants take up fertilizers.
- Radiation used to sterilize insects to eliminate pests which destroy crops. Wheat or maize may be irradiated with mild gamma rays so that it can be stored for a long time without damage.

c. USED IN ARCHAEOLOGY (CARBON-DATING)

Carbon dating is the process of finding age of fossils by use of radioactive decay.

Living plants contain carbon-14 obtained through photosynthesis. When living things die the radioactive atoms start to decay by emitting beta particles and nitrogen atoms. Thus one can estimate the age of organic materials by working out the count rate of the dead remains by considering that half-life of carbon is 5600 years.

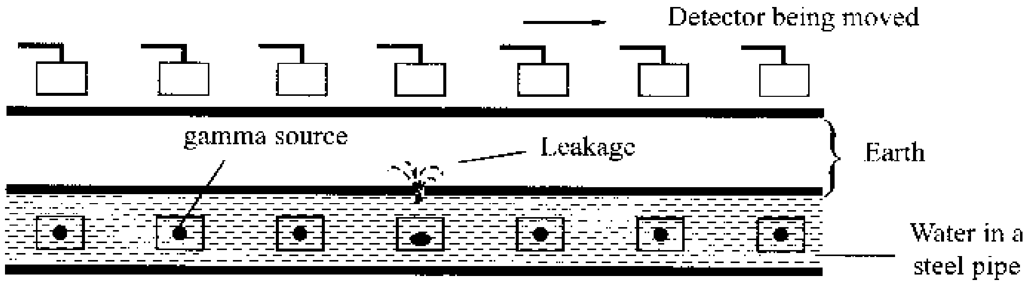
E.g. if a freshly cut piece of wood gives out 64 counts/minute and a sample of wood dug by an archaeologist gives 8 counts/minute, the age of the sample wood is 3 half-lives, i.e. about (5600 x 3)16, 800 years.

d. USED IN AUTOMOBILES

Radioisotopes can be used to estimate the amount of wear in bearings. If the radioisotope is impregnated into bearings, the fine bearing filings are radioactive and are carried away by the oil. If a sample of the oil containing the filings is tested for radioactivity, the amount of wear can be estimated from the results.

e. USED IN INDUSTRY

- Leaks in pipes may be traced by introducing a small quantity of a radioisotope into the fluid in a pipe. A radiation detector can be used to determine where the radioisotope is escaping.



- Radioisotopes are widely used in industry, e.g. to check that the thickness of a material being produced is constant. As the material passes between the radioactive source and a counter, any variation in thickness causes a change in the count rate (if the thickness decreases, the count rate increases) and irregularities can be pinpointed.
- Radioactive substances can be used in sterilization as well as food preservation.

f. SOURCE OF ELECTRICAL ENERGY

The energy released in the fission or fusion process is used to drive turbines of a generator to generate electrical energy.

DANGERS OF RADIOACTIVE SUBSTANCES

Some of the effects on humans of exposure to large doses, or prolonged small doses, of radiations are

a. Burns
b. Leukaemia (cancer of the blood)
c. Sterility (inability to produce children)
d. Some children born with serious abnormalities
e. Damage to the blood may lower resistance to normal diseases.

PRECAUTIONS WHEN HANDLING RADIOACTIVE MATERIALS

The growth and use of radioactive products has increased considerably since about 1930. Radioactive sources have become part of normal school equipment and although the sources are very weak, it is essential to take stringent safety precautions:

a. The sources should only be handled by forceps provided and never touched by hand.
b. They should never be pointed towards a person.
c. Food should not be taken where the sources are being used, because it may become contaminated.
d. Never smoke near a radioactive source.
e. The user should wear rubber gloves, and hands should be washed after the sources have been put away safely.
f. Do not stay much long within the area where there is radioactive substances because the longer the exposure time, the greater the risk.