

PHYSICS NOTES

FORM 4 SIMPLIFIED VERSION

QUICK REVISION NOTES

*An Updated Well-Organized Detailed Revision Notes for the
Current Form 4 Syllabus.*

SERIES 1

THIS IS A FREE SAMPLE OF THE
ORIGINAL NOTES

CONTACT US FOR FULL VERSION OF THE NOTES

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THIN LENSES

Objectives

By the end of this lesson the learner should be able to:

- Describe converging lenses and diverging lenses.
- Describe using ray diagrams the principal focus, the optical centre and the focal length of a thin lens.
- Determine experimentally the focal length of a converging lens.
- Locate images formed by thin lenses using ray construction method.
- Explain the image formation in the human eye.
- Describe the defects of vision in the human eye and how they are corrected.
- Describe the uses of lenses in various optical devices.
- Solve numerical problems involving the lens formula and the magnification.

Introduction

Lens- Is a carefully molded piece of a transparent material that refracts light in such away as to form an image. They normally operate on **refractive property** of light.

- They are made of glass, clear plastic, or Perspex.
- They are found in cameras human eye, spectacles, telescopes, microscope and projectors e.t.c

Types of lenses

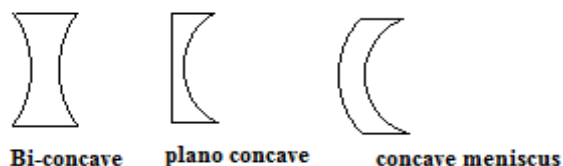
There are two major types of lenses, namely:

- Convex (converging) - they are thickest at the middle and thinnest at the ends.
- Concave (diverging) - they are thinnest at the middle and thickest at the ends.

Convex lenses



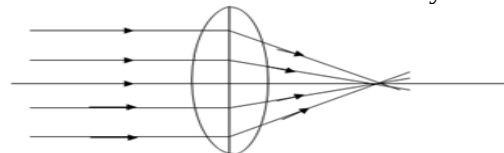
Concave lenses



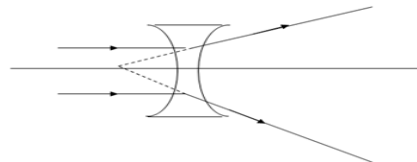
Effect of lenses on parallel rays of light.

A lens relies on the principal of refraction of light. Therefore when parallel rays are directed towards the lens the rays will be refracted either by being converged or by being diverged.

- When the convex lens is used the rays are converged.

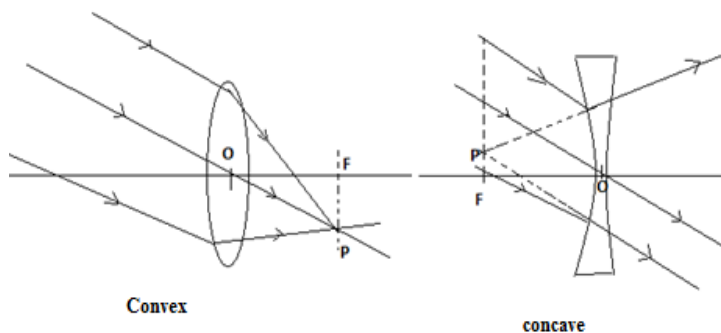


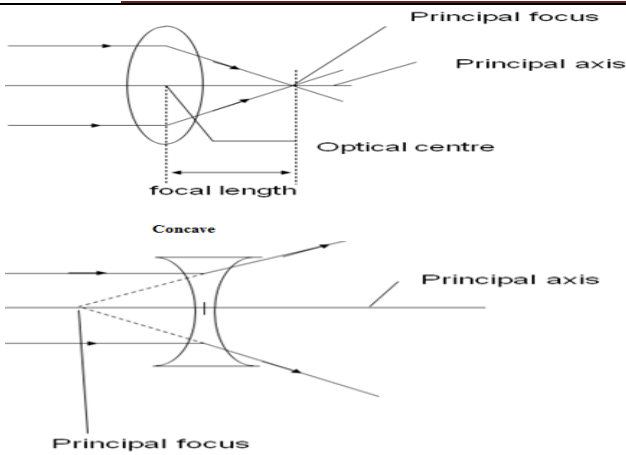
- If a concave lens is used then the rays are diverged.



Definition of terms

- Centre of curvature** - the centre of the sphere which the lens is part.
- Radius of curvature (r)** - the radius of the sphere of which the surface of the lens is part.
- Principal axis** - it is an the line joining the centres of curvature of its surfaces.
- Optical Centre (O)** - it is a point on the principal axis midway between the lens surfaces.
- Principal focus (F)** - For a convex lens, is a point on the principal axis where all rays converge after passing through the lens. While for a concave lens, is a point on the principal axis behind the lens from which rays seem to diverge from after passing through the lens.
- Focal length (f)** - it is the distance between the optical centre and the principal focus.
- Focal plane** - it is a plane perpendicular to the principal that all the rays seem to converge to or seem to appear to diverge from. The incident rays in this case are not parallel to the principal axis.
- Paraxial rays**- these are rays that are parallel and close to the principal axis.
- Marginal rays**- these are rays that are parallel and far away from the principal axis.





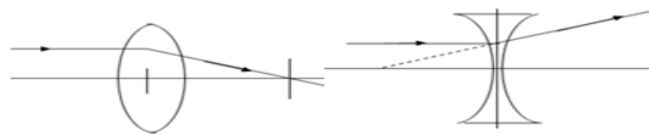
1.2 Ray Diagrams

For one to locate the image when using a lens, ray diagrams are of great importance. There are three major rays that are used in ray diagrams for the location of images formed by the lens.

These rays are;

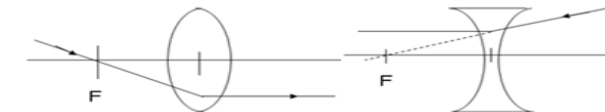
(i) A ray of light parallel to the principal axis.

This ray passes through the principal focus (for convex lens) or seem to appear to emerge from the principal focus (for concave lens) after refraction by the lens



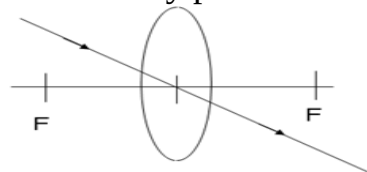
(ii) A ray of light passing (or appearing to pass through) the principal focus

-the ray emerges parallel to the principal axis after refraction by the lens



(iii) A ray of light through the optical centre

This ray passes on un-deviated

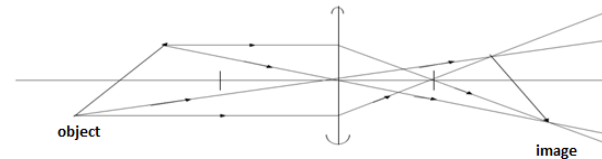


1.3 Image Formation

It is important to note:

- Real rays and real images are drawn in full lines.
- Virtual rays and virtual images are drawn in broken/dotted lines.
- To locate the image, two or three rays from the tip of the object are drawn.
- Should the foot of the object cross the principal axis, the method on 3 above is used to get the foot of the image. The top is joined to the foot to get the image.

Example



- Converging and diverging lenses are represented by the symbols shown below.



convex(converging)

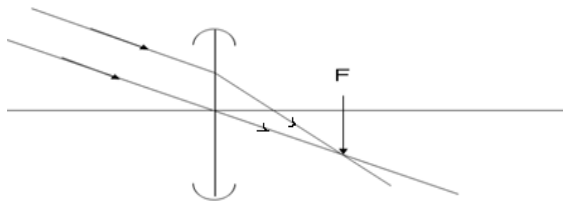


concave(diverging lens)

Characteristics of images formed by lenses

Converging lenses.

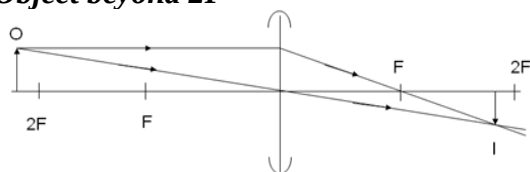
Object at infinity.



The image is

- Real
- Inverted
- Diminished
- Formed at F

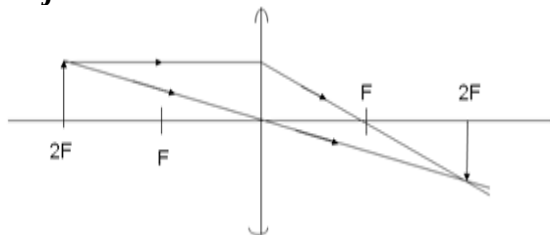
Object beyond 2F



The image is

- (i) Real
- (ii) Inverted
- (iii) Diminished
- (iv) formed between F and 2F on the other side of the lens

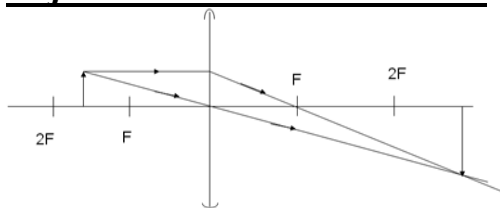
Object at 2F



The image is

- (i) real
- (ii) Inverted
- (iii) Same size as the object
- (iv) Formed at 2F, on the other side of the lens

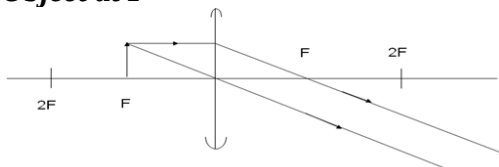
Object between F and 2F



The image is

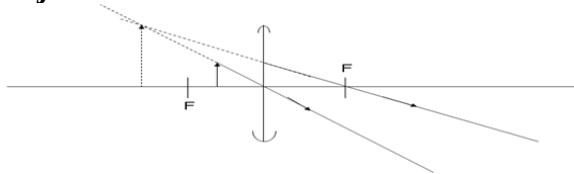
- (i) Real
- (ii) Inverted
- (iii) Magnified
- (iv) formed beyond 2F on the other side of the lens

Object at F



The image is at infinity

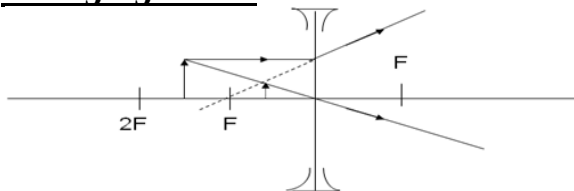
Object between F and lens



The image is

- (i) Virtual
- (ii) Erect
- (iii)
- (iv) Magnified
- (v) Formed on the same side as object

Diverging lenses



The image is

- (i) Virtual
- (ii) Erect
- (iii) diminished

Linear Magnification

- Magnification is a measure of the extent to which an optical system enlarges or reduces an image.
- Linear magnification is a ratio of height of image to the height of the object **OR** the ratio of the image distance to the object distance.

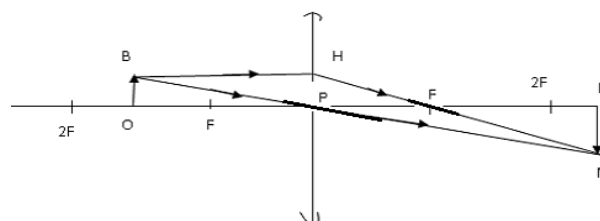
$$\text{magnification} = \frac{\text{height of image}}{\text{height of object}}$$

$$\text{Or } \text{magnification} = \frac{\text{image distance}}{\text{object distance}}$$

$$\text{Therefore, } m = \frac{v}{u} = \frac{h_i}{h_o}$$

The lens formula

Consider an image formed by converging lens as shown below.



PO is the object distance, u, PI is the image distance, v, and PF the focal length, f.

OB=PH

Triangles POB and PIM are similar. Therefore;

$$\frac{OB}{IM} = \frac{PO}{PI}$$

$$= \frac{u}{v} \dots \dots \dots (1)$$

Similarly, triangles PFH and IMF are similar. So;

$$\frac{PH}{IM} = \frac{PF}{IF}$$

$$\dots \dots \dots (2)$$

But, PF=f

$$IF = PI - PF; \quad IF = v - f$$

Substitute these values in equation (2);

$$\frac{OB}{IM} = \frac{f}{v - f} \dots \dots \dots (3)$$

Combining equations (1) and (3);

$$\frac{u}{v} = \frac{f}{v - f}$$

$$uv - uf = vf$$

$$uv = vf + uf$$

$$uv = f(v + u)$$

$$\frac{uv}{f} = v + u$$

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

$$\text{Hence } \frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

This is called the lens formula and holds for both converging and diverging lens.

Examples

(i) An object 0.05m high is placed 0.15m in front of a convex lens of focal length 0.1m. find the position and size of the image. what is the magnification?

Solution

$$h_o = 0.05m, u = 0.15m, f = 0.1m, v = ? , h_i = ?$$

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

$$\frac{1}{0.1} = \frac{1}{0.15} + \frac{1}{v}, \quad v = 0.3m$$

$$\frac{h_i}{h_o} = \frac{v}{u} = m \Rightarrow h_i = \frac{v}{u} \times h_o,$$

$$h_i = \frac{0.3}{0.1} \times 0.05 = 0.15m, \quad m = \frac{0.3}{0.1} = 3$$

(ii) An object placed 6m from a converging lens forms an erect image that is five times larger. State the type of the image formed. Find the focal length of the lens.

Solution

The image is virtual since it is upright and magnified.

$$\text{From } \frac{v}{u} = m, \quad \frac{v}{u} = 5 \Rightarrow v = 5u, u = 6m, v = 5 \times 6 = 30m$$

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}, \quad \frac{1}{f} = \frac{1}{6} + \frac{1}{30}, f = 5m$$

Relationship between magnification and focal length

We have;

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

Multiply both sides by v;

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

But, $\frac{v}{u} = m$ and $\frac{v}{v} = 1$, therefore,

$$\frac{v}{f} = m + 1$$

Re-arranging;

$$m = \frac{v}{f} - 1$$

To determine u and v, real-is -positive sign convention is adopted. According to this convention:

- I. All distances are measured from the optical centre.
- II. Distances of real objects and real images are positive whereas distances of virtual objects and images are negative.
- III. The focal length of a converging lens is positive while that of diverging lens is negative.

Exercise

1. An object is placed 12cm from a converging lens of focal length 18cm. Find the position of the image.
2. An object is placed 10cm from a diverging lens of focal length 15cm. Find the nature and the position of the image.
3. The focal length of a converging lens is found to be 10cm. how far should the lens be placed from an illuminated object to obtain an image which is magnified five times on a screen?
- 4.

Graphical interpretation of the lens formula

CASE 1:

A graph of $\frac{1}{v}$ against $\frac{1}{u}$;

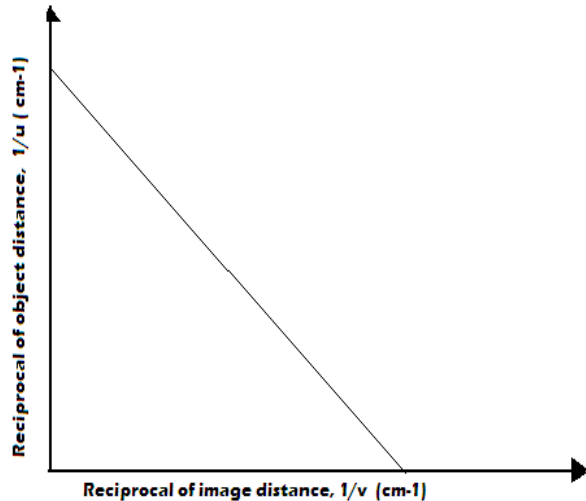
From the lens formula, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Re – write the equation in the form y

$$= mx + c$$

$$\frac{1}{v} = -\frac{1}{u} + \frac{1}{f} \text{ Hence, slope}$$

$$= -1 \text{ and } \frac{1}{f} - \text{intercept} = \frac{1}{f}$$



CASE 2

A graph of uv against $u + v$

From the lens formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$, $\frac{1}{f} = \frac{v+u}{uv}$

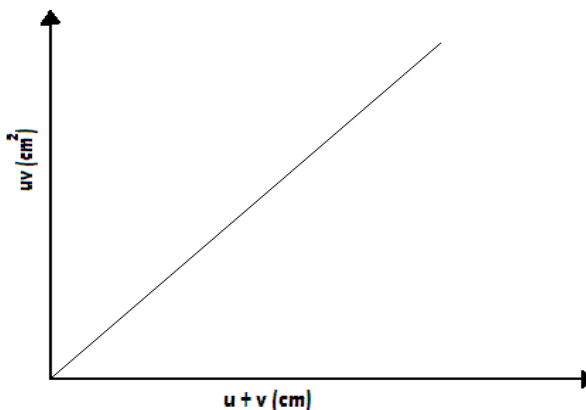
$$uv = (u + v)f$$

In the form $y = mx + c$

$$uv = f(u + v) + 0$$

Thus gradient = f and uv intercept = 0

It is a graph of a straight line passing through the origin.



Exercise

Interpret a graph of:

- (i) $\frac{1}{u}$ against $\frac{1}{v}$
- (ii) $u + v$ against uv

CASE 3:

Graph of u against $\frac{1}{m}$

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

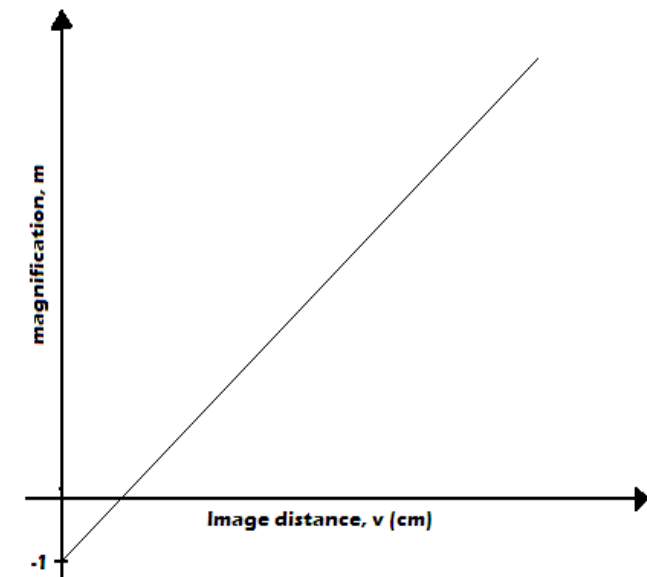
$$\frac{u}{f} = \frac{u}{u} + \frac{u}{v}$$

$$\frac{u}{f} = 1 + \frac{u}{m}$$

$$u = f \frac{1}{m} + f$$

Implying that $f = \text{slope}$ and $u - \text{intercept} = f$

It is a straight line that cuts the vertical axis at f .



Exercise

Interpret a graph of:

- (i) m against v
- (ii) V against m

Experimental Determination Of The Focal Length Of A Converging (Convex) Lens

Method (1):

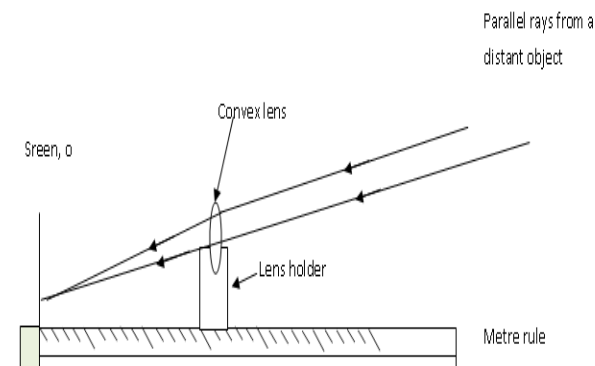
Focusing A Distant Object

Apparatus

Metre rule, lens, a lens holder, screen

Procedure

1. Mount a convex lens on a lens holder and fix a metre rule on a bench using plasticine as shown below.



2. Place a white screen at one end of the metre rule.
3. Move the lens to and fro along the metre rule to focus clearly the image of a distant object, like a tree or window frame.
4. Measure the distance between the lens and the screen.

Focal length-----cm

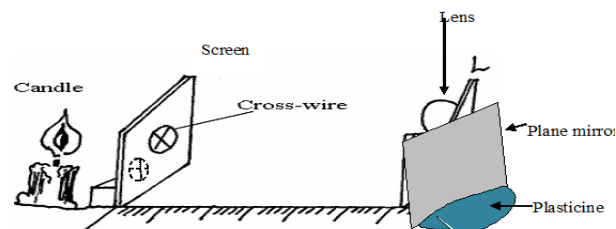
Note: The distance between the lens and the screen gives a rough estimate of the focal length of the lens. This is because parallel rays from infinity are converged at the focal point on the screen.

Method (2):

Using an Illuminated Object And Plane Mirror/Reflection Method

Procedure

1. Set the lens in its holder with a plane mirror behind it so that light passing through it can be reflected back as shown below.



2. Adjust the position of the lens holder until a sharp image of the object is formed on the screen alongside the object itself.
3. Record the distance between the lens and the screen.

Focal length-----cm

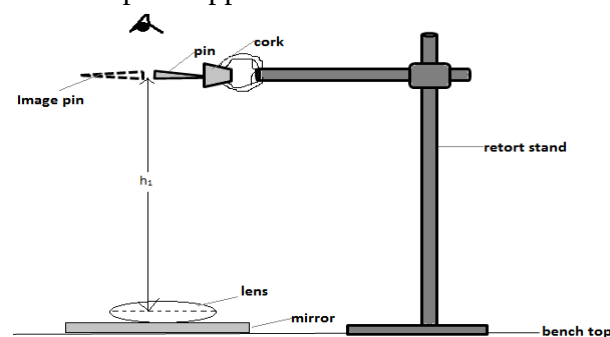
NOTE:

Under these conditions, rays from any point on the object will emerge from the lens as parallel rays. They are therefore reflected back through the lens and brought to a focus in the same plane as the object. The distance between the lens and the screen now give the focal length of the lens.

Method (3):

Using A Pin And Plane Mirror/No Parallax Method

1. Set up the apparatus as shown below.



2. Adjust the position of the pin up and down till its tip is at the same horizontal level as the centre of the lens. A position is found for which there is no parallax between it and the real image formed. For best results, attention should be given to the tilt of the plane mirror so that the tip of the image of the object pin appears to touch at the same level as the centre of the lens.
3. The distance between the pin and the lens will then be equal to the focal length of the lens.

Focal length-----cm

The power of a lens

Is a measure of refractive property of a lens. It is given by

$$\text{power} = \frac{1}{\text{focal length in metres}}$$

The unit of power of a lens is dioptres (D)

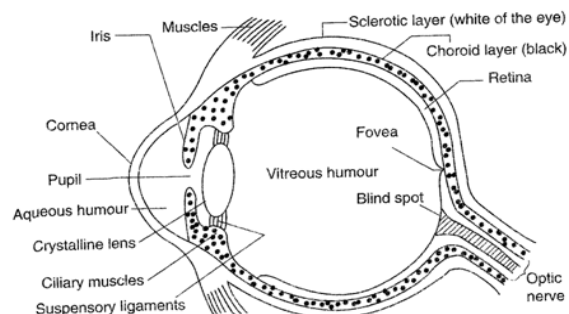
USES OF LENSES IN OPTICAL DEVICES

Due to their ability to converge or diverge light rays, lenses are widely used in optical devices. The devices include;

- Human eye
- Simple microscope
- Compound microscope
- The camera

The human eye

It is a natural optical instrument



1. **Sclerotic layer** – hard shell that encloses the eye and is white.

The front part is transparent and spherical known as the cornea.

Most bending of light entering the eye occurs at the cornea.

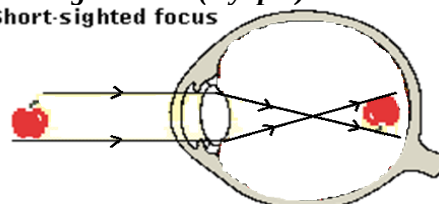
2. **Aqueous Humour** – clear liquid between the cornea and the lens. It helps the eye maintain shape.
3. **Iris** – it is the colouring of the eye. It has pupil which regulates the amount of light entering the eye.
4. **Crystalline lens**– it is a converging lens. It can change its focal length by the action of Ciliary muscles
5. **Vitreous humour** – transparent jelly like substance filling another chamber between the lens and the retina
6. **Retina** – it is where the image is formed and Made of cells that are light sensitive
7. **Fovea** – central part of the retina that exhibits best details and colour vision at this place.
8. **Blind spot** – this contains cells that are not light sensitive.
9. **Ciliary muscles** – these are muscles that support the lens. They control the shape of lens by contracting or relaxing. In relaxing the muscles it enables the lens to increase hence focus distance objects. In contraction the muscles reduce tensions in the lens to increase its focal length thus focus near objects. This process is known as **accommodation**.

Near point – closest point which the normal eye can focus. **Far point** - furthest point that a normal eye can focus.

Defects of vision

Short sightedness (myopia)

Short-sighted focus

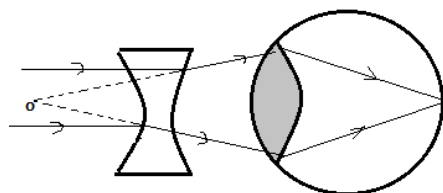


- Can only clearly see near objects
- Rays of near objects are focused on the retina but those for distance objects are focused in front of the retina

Causes

- Short focal length of the eye lens
- Long eyeball

Corrected by diverging lenses as shown



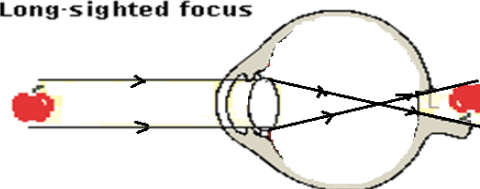
Long sightedness (hypermetropia)

- Can see distant objects but not near ones
- The images of near objects are formed behind the retina

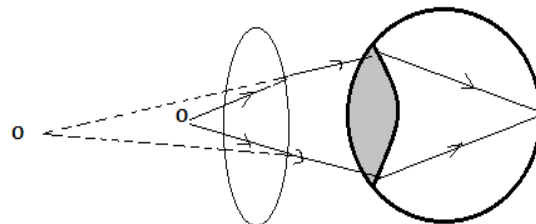
Causes are:

- Too long focal length of the eye
- Too short eyeball

Long-sighted focus



- It is corrected by using converging lenses



Camera

- The camera has **lenses** that focus light from the object to form an image of the object on the film.
- Focusing is done by adjusting the distance between the lens and the film .the diaphragm controls the amount of light entering the eye.
- The shutter** allows light to reach the film only for a precise period when the camera is operated.
- The inside is blackened to absorb any stray light.

Similarities between the eye and the camera

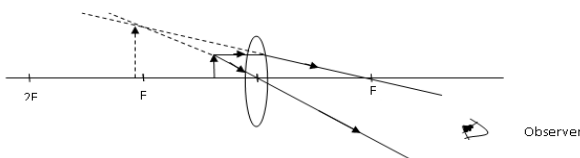
Eye	Camera
Has crystalline convex lens	Has a convex lens
Choroid layer is black	Box painted black inside
The retina where images are formed	Light-sensitive film where images are formed.
Iris which controls the amount of light entering the eye	Diaphragm which controls the amount of light entering the camera.

Differences between the eye and the camera

Eye	Camera
Variable focal length	Fixed focal length
Constant image distance	Variable image distance
Constantly changing pictures	Only one photograph can be taken at a time

Simple microscope

It is sometimes referred to as a magnifying glass. When the object is placed between a convex lens and its principal focus, the image formed is virtual, erect and magnified.



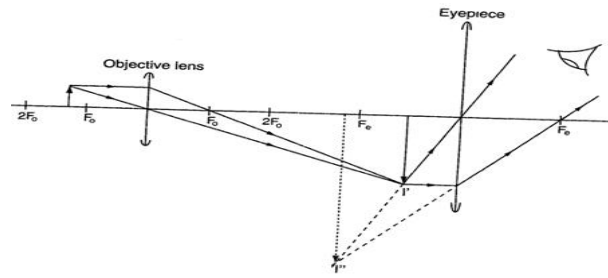
Compound microscope

There are two cases under which a converging lens can produce magnified images;

When the object is between F and 2F.

When the object is between the lens and F.

A compound microscope combines the above two cases. It consists of converging lenses of short focal length .The focal length next to the object is called **objective lens** and the one next to the eye is called **the eyepiece or ocular**. The objective lens is of short focal length.



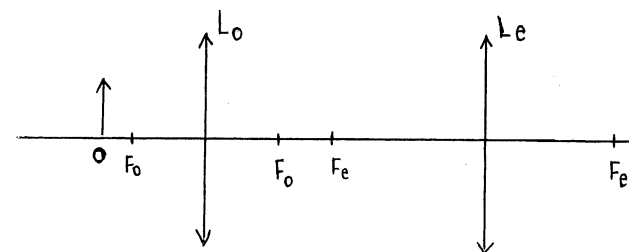
The eye piece is also of short focal length but longer than that of the objective lens. A compound microscope overcomes the limitations of a simple microscope by use of objective lenses with many lenses and an eyepiece with more than one lens.

Total magnification produced by a compound microscope is given by;

$(\frac{v_e}{f_e} - 1)(\frac{v_o}{f_o} - 1)$ Where v_o is the image distance from I and v_e the image distance from I'.

REVISION QUESTIONS

- The diagram below shows an arrangement of lenses, L_o and L_e used in a compound microscope F_o and F_e are principal foci of L_o and L_e respectively.



Draw
the rays to show how the final image is formed in the microscope

UNIFORM CIRCULAR MOTION

Specific Objectives

By the end of this topic, the learner should be able to:

- Define angular displacement and angular velocity
- Describe simple experiments to illustrate centripetal force
- Explain the application of uniform circular motion
- Solve numerical problems involving uniform circular motion

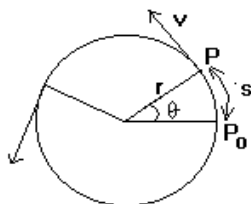
Content

- The radian, angular displacement, angular velocity
- Centripetal force; $F = \frac{mv^2}{r}$, $F = mr\omega^2$ (derivation of formulae not required) (experimental treatment is necessary)
- Applications of uniform circular motion
- Centrifuge, vertical, horizontal circles banked tracks (calculations on banked tracks and conical pendulum not required)
- Problem solving (Apply $F = \frac{mv^2}{r}$, $F = mr\omega^2$)

Definition of Terms

(A) Angular Displacement, θ

It is the angle swept through a line joining to the centre of circular path. It is measured in radians.



It is calculated as angular displacement

$$= \frac{\text{arc length}}{\text{radius}}$$

$$\theta = \frac{s}{r}$$

Radian

Is defined as an angle of sector of the circumference whose length is equal to its radius or is the ratio of arc length to the radius of a circular.

$$\begin{aligned} \text{radian} &= \frac{\text{arc length}}{\text{radius}} \\ \text{radian} &= \frac{s}{r} \\ \text{radian} &= \frac{2\pi r}{r} \\ &= 2\pi \\ 2\pi r &= 360^\circ \end{aligned}$$

Convert the following into radians:

- 80°C
- 120°C

(b) Angular Velocity

It is the rate of change of angular displacement. It is denoted by Greek letter omega (ω).

$$\omega = \frac{\theta}{t}$$

Is measured in radian per second

Example

1. A particle moving in a circular path covers one revolution in ten seconds. Calculate its angular velocity.

Period/Periodic Time

Is the time taken to complete one revolution.

periodic time

$$= \text{angle covered in one} \frac{\text{revolution}}{\text{angular velocity}}$$

$$T = \frac{2\pi}{\omega}$$

Frequency (f)

$$\text{Frequency, } f = \frac{1}{T}$$

$$\frac{1}{f} = \frac{2\pi}{\omega} \rightarrow \omega = 2\pi f$$

Relationship between angular displacement, θ and angular velocity.

$$V = \frac{\Delta S}{\Delta t} \text{ -----}$$

----- (i)

$$\Delta \theta = \frac{\Delta S}{\Delta r} \text{ -----}$$

----- (ii)

For small change in equation (ii)

$$\Delta \theta = \frac{\Delta S}{r} \text{ -----}$$

--- (iii)

Dividing equation (iii) by Δt

$$\frac{\Delta \theta}{\Delta t} = \frac{\Delta S}{r \Delta t}$$

$$\omega = \frac{v}{r} \rightarrow v = \omega r$$

Anybody in circular motion has both linear velocity in m/s and angular velocity in rads/s.

Examples

1. A turn table rotates at the rate of 60 revolutions per minute. What is its angular velocity in rads/s
2. A model car moves around a circular path of radius 0.6m at 25 Rev/s. Determine its;
 - (a) period
 - (b) Angular velocity (ω)
 - (c) Speed (v)
3. The car moves with uniform velocity of 3m/s in a circle of radius 0.2m. Find its angular velocity and frequency.
4. Distinguish between angular and linear velocity.

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Centripetal Acceleration

- An object going through a circular path is said to accelerate.
- If the velocity of such object is constant the object still accelerates because there is continuous change in velocity as the object continuously changes direction. From Newton's second law of motion, the body experiences a resultant force as it moves rounds path .This resultant force is directed towards the circular path.
- Acceleration of this body is in the direction of force applied to it i.e. it accelerates towards the centre of the circular of the circular path. This acceleration is called centripetal acceleration.

The centripetal acceleration is given by the following equation.

$$\text{Centripetal acceleration } a = \frac{v^2}{r}$$

But $v = \omega r$

$$a = \omega^2 r$$

Centripetal Force

Is a force that is required to keep a body moving in a circular path and is directed towards the centre of the circular path.

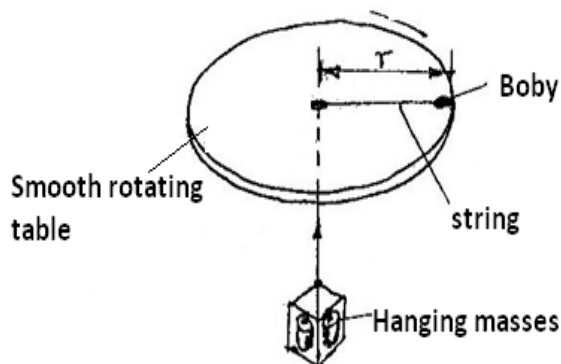
If an object moving through a circular path is released suddenly it flies off tangentially.

Factors Affecting Centripetal Force.

1. **Mass of the object, m-** the heavier the object the more the centripetal force needed to maintain it in circular path.
2. **Angular velocity of the object, ω -** an increase in centripetal force needed to maintain the object in circular path.
3. **Radius of the path r-**the shorter the radius of the path the larger the centripetal force required to maintain the object in circular path.

Example

The figure below shows the diagram of set up to investigate the variation of centripetal with the radius r , of the circle in which a body rotated



Describe how the set up can be used to carry out the investigation

- Keep angular velocity ω constant;
- Centripetal force provided by mg ;
- Fix the mass m and measure of m ;
- Repeat for different values of m ;

The above factors are proofed using a turntable.

The turntable has the following features

- Increase in speed of the turn table increases length of the spring (increase in centripetal force)
- When using a shorter spring there is more extension of the spring than using along spring.
- When using a heavier metal bar will produce more extension than using a lighter ball.

This is a proof to the above factors.

The graph of force against the square of angular velocity is a straight line through the origin.

$$F \propto \frac{MV^2}{r}$$

$$F = \frac{KMV^2}{r}$$

When $k=1$, $F = \frac{MV^2}{r}$, but $v = \omega r$

Hence, $F = \frac{m\omega^2 r^2}{r}$, thus, $F = mr\omega^2$

Examples of Uniform Circular Motion**A car rounding a level circular bend**

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

Therefore- $F_r = \frac{mv^2}{r}$

If the road is slippery then frictional force may not be sufficient so to provide centripetal force

To prevent skidding the car should not exceed certain speed limits referred to as the **critical speed**

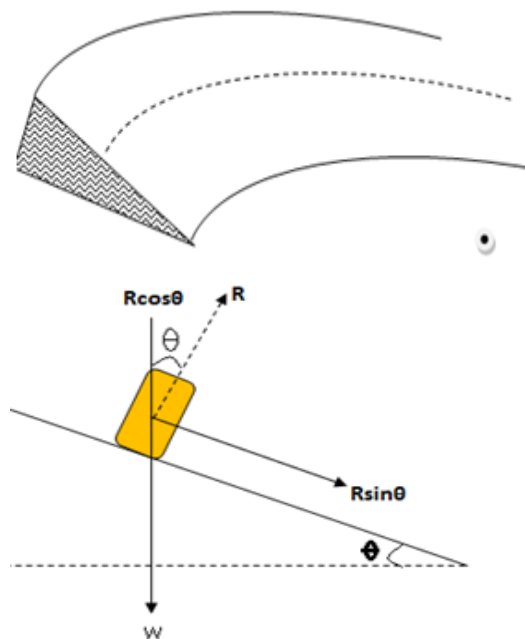
This critical speed depends-

Radius of the bend i.e. one may negotiate the a bend at higher critical speed the radius of the bend is big

Condition of the tyre and the nature of the road surface this will produce the frictional force need to negotiate the bend

Banked tracks

Condition in which a road is raised gradually from the inner side of the bend.



$R\sin\theta$ -Is the horizontal component which is responsible for providing centripetal force.

$R\cos\theta$ -Is the vertical component that is responsible for balancing the weight of the vehicle.

If a vehicle of mass m is travelling along a circular path of radius r at uniform speed v , then

$$R\sin\theta = \frac{mv^2}{r} \dots\dots\dots (i)$$

$$R\cos\theta = mg \dots\dots\dots (ii)$$

Divide (i) by (ii)

$$\frac{R\sin\theta}{R\cos\theta} = \frac{mv^2}{r} \times \frac{1}{mg}$$

$$\frac{\sin\theta}{\cos\theta} = \tan\theta$$

$$\text{Hence } \tan\theta = \frac{v^2}{rg}$$

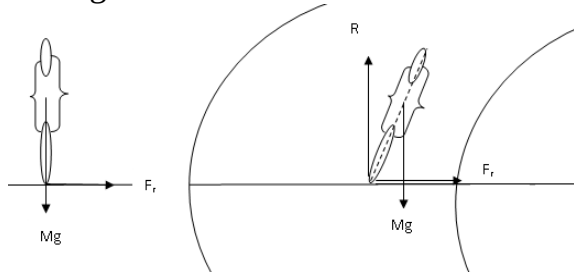
The maximum speed required for a body moving in a circular path whose angle of banking is θ is given by;

$$v^2 = rg\tan\theta \text{ Hence, } v = \sqrt{rg\tan\theta}$$

A cyclist moving round a circular track

Frictional force (F_r) is provided by centripetal force which is directed towards the car however if frictional force is not sufficient to provide centripetal force skidding takes place. To avoid skidding the cyclist leans inwards so that normal reaction of frictional force produces the turning effect to the clockwise and anticlockwise directions.

Taking moments about G



BY principle of moments

$$R \cdot x = F_r \cdot y$$

$$\frac{x}{y} = \frac{mv^2}{rg}$$

$$\frac{x}{y} = \frac{v^2}{rg}$$

$$\tan\theta = \frac{v^2}{rg}$$

Making v the subject of the formula

$$v = \sqrt{rg\tan\theta}$$

$$\tan\theta = \frac{F_r}{mg}$$

$$Mg \tan\theta = F_r$$

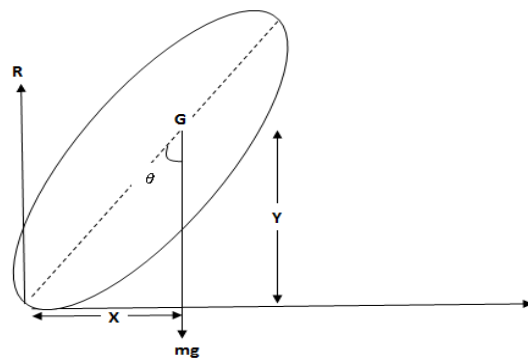
$$F_r = \mu R$$

$$Mg \tan\theta = \mu mg$$

$$\tan\theta = \mu$$

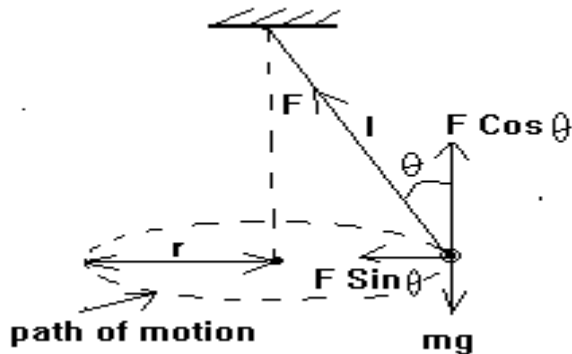
Where μ is coefficient of friction

Skidding occurs when $\tan\theta$ is greater than μ



Conical pendulum

If a pendulum bob moves in such a way that the string sweeps out a cone, then the bob will describe a horizontal circle.



As it can be clearly seen, there are two forces acting on the pendulum bob;

- (i) its weight (mg)
- (ii) The tension in the string.

Centripetal force is provided by the horizontal component of the tension ($F \sin \theta$). Hence from Newton's second law;

$F \sin \theta = \frac{mv^2}{r}$ (1) (Where symbols have their usual meaning). Since there is no vertical acceleration

$$F \cos \theta = mg \text{ (2)}$$

Again, from the two equations; $\tan \theta = \frac{v^2}{rg}$

Note that this equation is similar to the one we got earlier for banked tracks.

When the angular velocity ω the cork rises hence Q increases. This concept is applied in merry go round and speed governors.

Motion in a Horizontal Circle

The tension in the string provides the centripetal force.

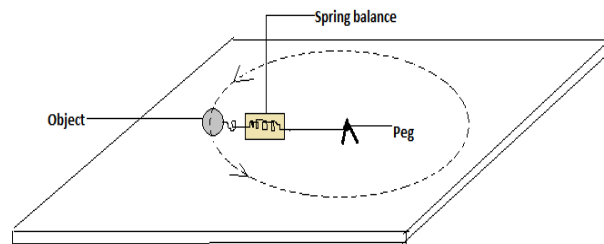
$$T = F_c$$

$$T = \frac{MV^2}{r}$$

Where the length of the string
= radius of rotation

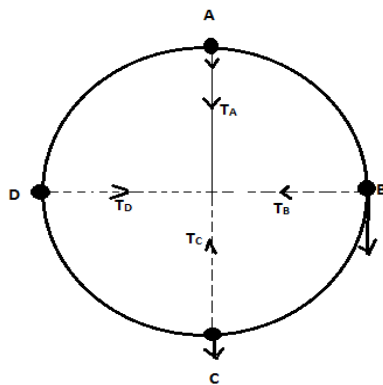
Example:

(a) The figure below shows an object at the end of a light spring balance connected to a peg using a string. The object is moving in a circular path on a smooth horizontal table with a constant speed.



- (i) What provides the force that keeps the object moving in the circular path?
- (ii) Indicate with an arrow on the figure the direction of centripetal force .
- (iii) The speed of the object is constant, why is there acceleration?
- (iv) Although there is force acting on the object, NO, work is done on the object. Explain.
- (v) Given that the mass of the object is 0.5kg and it is moving at speed of 8m/s at a radius of 2m. Determine the reading on the spring balance.
- (vi) State what happens to the reading if the speed of rotation is reduced.

Motion in Vertical Path



Tension on the spring changes its magnitude depending on the position of the ball.

When the ball is at A, the **sum of tension T_A and weight Mg acting in the same direction provide centripetal force.**

$$\frac{MV^2}{r} = T_A + Mg \text{ -----}$$

----- (i)

When the ball is at A it attains minimum speed because $T_A = 0$

$$\frac{MV^2}{r} = mg$$

$$V_{\min} = \sqrt{rg}$$

At B, tensional force T_B provides centripetal force.

$$T_B = \frac{MV^2}{r}$$

At C, tension and weight acts in different direction and hence the resultant force between the two forces provides the centripetal force

$$\frac{MV^2}{r} = T_C - Mg \text{ -----}$$

----- (ii)

$$T_A = \frac{MV^2}{r} - Mg \text{ -----}$$

----- (iii)

$$T_C = \frac{MV^2}{r} + Mg \text{ -----}$$

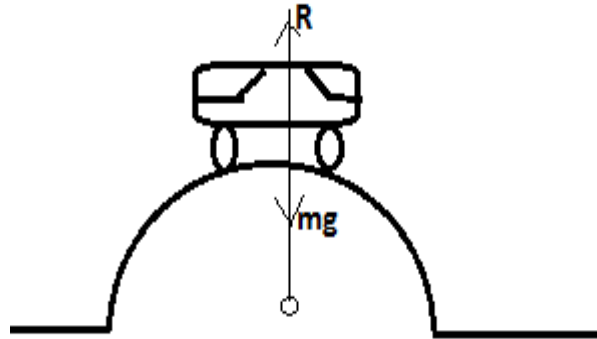
----- (iv)

$$\text{At D, } T_D = \frac{MV^2}{r}$$

1. A pilot not stripped to his seat in a loop manoeuvre without falling.
2. A bucket of water whirled in a vertical without water spilling.
3. A ball bearing 'looping the loop' on a rail lying in vertical plane.

Example

A car travels over a humpback bridge of radius of curvature 40m. Calculate maximum speed of the car if its wt are to staying contact with bridge. $g = 10\text{m/s}^2$



$$\frac{mv^2}{r} = mg - R$$

$$R = 0$$

$$Mv^2 = mg$$

$$V^2 = rg$$

$$V = \sqrt{rg}$$

$$= \sqrt{40 \times 10}$$

$$= 20 \text{ m/s}$$

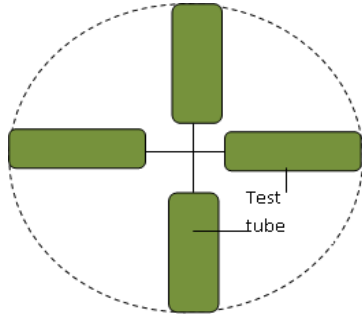
Examples of Centripetal Force

Example	Source(what provides centripetal force)
Cyclist moving along a circular path	Frictional force between the tyre and the road
Car moving along a banked road	Horizontal component of reaction force
Electron orbiting around the nucleus of an atom	Electrostatic force of attraction between the proton and the electron
Electron moving in a magnetic field	Magnetic field
Satellite orbiting around the earth	Gravitational force exerted by the earth
A string whirled in a horizontal track	Tensional force

Application of Circular Motion

1. Centrifuges

It is used to separate particles in suspension in liquids of different densities. It consists of small metal containers tubes that can be rotated.



Centripetal will be too great according to the equation $F = mr\omega^2$

And r will thus be smaller for lighter particles and longer for heavier particles.

2. Satellites

Two bodies with mass m_1 and m_2 at a distance r from each other experience a force of attraction. $F = \frac{GM_1M_2}{R^2}$ G is equal to universal gravitational constant

Attraction between earth and satellite gives centripetal Force $M_1v^2 = \frac{GM_1M_2}{R^2}$

Where M_1 is mass of satellite and m_2 mass of the earth $v^2 = \frac{GM_2}{R^2}$

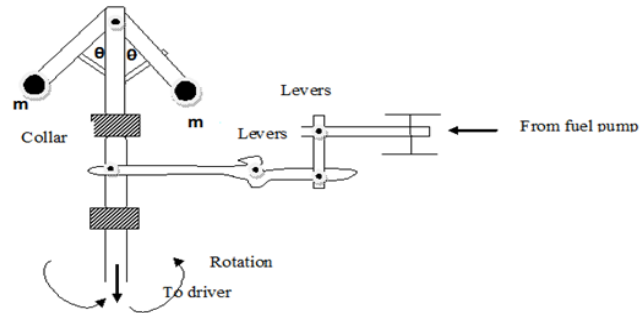
$$v = \sqrt{\frac{GM_2}{r}}$$

The velocity of the satellite increases with decrease in the radius of the orbit.

If periodic time of the satellite is equal to that of the earth the satellite appear stationary as seen from the earth surface such satellite are said to be in **parking orbit and are used in weather forecasting and telecommunications.**

3. Speed Governors

Principle of conical pendulum is used in operating the speed governors.



As the angular velocity of the drive shaft increases the masses m rise and move the collar up as the angle θ increases. The up and down movement of the collar is transmitted through a system of levers to the device that controls the fuel intake. Since the angular velocity of the drive shaft increases with speed of the vehicle, the fuel supply will cut off when the speed exceeds a certain limit.

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SINKING AND FLOATING

Specific objectives

- a) state Archimedes' principle
- b) verify Archimedes principle
- c) state the law of flotation
- d) define relative density
- e) describe the applications of Archimedes' principle and relative density.
- f) Solve numerical problems involving Archimedes' principle.

Upthrust force

Upthrust is an upward force acting on an object floating or immersed in a fluid. An object immersed or floating in a fluid appears lighter than its actual weight due to upthrust force (**force of buoyancy**).

Archimedes principle.

The principle states: When a body is totally or partially immersed in a fluid it experiences an up thrust equal to the weight of displaced fluid.

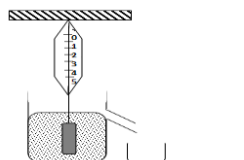
To verify Archimedes' principle

Apparatus

- An overflow can
- A metal block
- A beaker
- A spring balance
- A string
- Water

Procedure

- (i) Weigh the block in air.
- (ii) Note the weight of the block in air as w_1 .
- (iii) **Immerse** the block in water in the overflow can as shown in the diagram below



- Note the weight of the block when fully immersed as w_2
- Measure the volume of water displaced and calculate its weight as w_3
- Apparent loss of weight = $W_1 - W_2$
- The upthrust $U = W_3$
- **Upthrust = apparent loss of weight; $U = W_1 - W_2$**

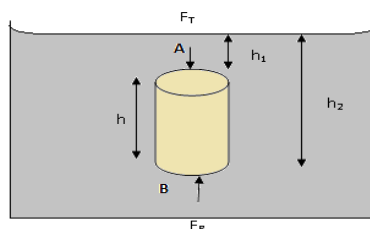
Content

- Archimedes' principle,
- Law of flotation (experimental treatment)
- Relative density
- Applications of Archimedes' principle and relative density.
- Problems on Archimedes' principle
- **Project Work-** Construct a hydrometer.

Precisely: Upthrust = Real weight – Apparent weight.

Cause of upthrust

Consider the figure below.



Pressure at the bottom > pressure at the top

$$P_B = P_a + h_2 \rho g$$

$$P_T = P_a + h_1 \rho g$$

Force = pressure x area

$$F_B = P_B A = (P_a + h_2 \rho g) A$$

$$F_T = P_T A = (P_a + h_1 \rho g) A$$

$$\text{Resultant force} = F_B - F_T$$

$$U = (P_a + h_2 \rho g) A - (P_a + h_1 \rho g) A$$

$$U = (h_2 - h_1) \rho g A$$

$$U = h \rho g A \quad \text{But } A h = v$$

$$\text{Hence, } U = V \rho g$$

Upthrust therefore depends on:

- (i) Volume of fluid displaced.
- (ii) Density of fluid displaced.

Example

A stone of weight 3N in air and 1.2N when totally immersed water. Calculate:

(a) Volume of the stone

(b) Density of the stone

Upthrust = Real weight- Apparent weight

$$= 3\text{N} - 1.2\text{N}$$

$$= 1.8\text{ N}$$

But $U = V\rho g$

$$1.8 = V \times 1000 \times 10$$

$$V = 0.00018\text{ m}^3$$

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

$$= \frac{0.3}{0.00018} \text{ kg/m}^3$$

$$= 1,666.67 \text{ kg/m}^3$$

QUESTIONS

1. A Solid of density 2.5g/cm^3 is weight in air and then when completely immersed in water in a measuring cylinder the Level of water rises from 40cm^3 to 80cm^3 . Determine

(a) Volume of the solid

(b) Its apparent weight.

2 a) State the Archimedes' principle

b) A right angled solid of dimensions 0.02m by 0.02m by 0.2m and density 2700kgm^{-3} is supported inside kerosene of density 800kgm^{-3} by a thread which is attached to a spring balance. The long side is vertical and the upper surface is 0.1m below the surface of kerosene.

(i) Calculate the force due to the liquid on:

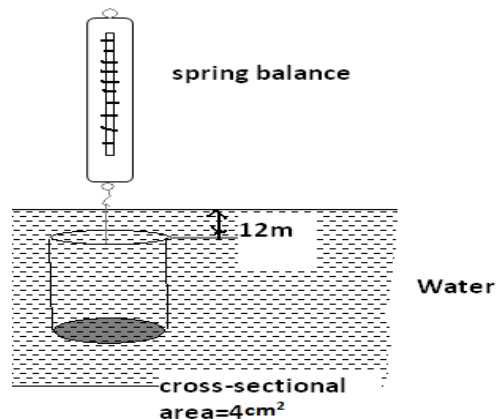
(ii) The lower surface of the solid

(iii) The upper surface of the solid

(iv) Calculate the upthrust and hence or otherwise determine the reading on the spring balance.

3.(a) Distinguish between pressure and up thrust force.

(b) A solid metal block of density 2500kg/m^3 is fully immersed in water, supported by a thread which is attached to the spring balance as shown below.

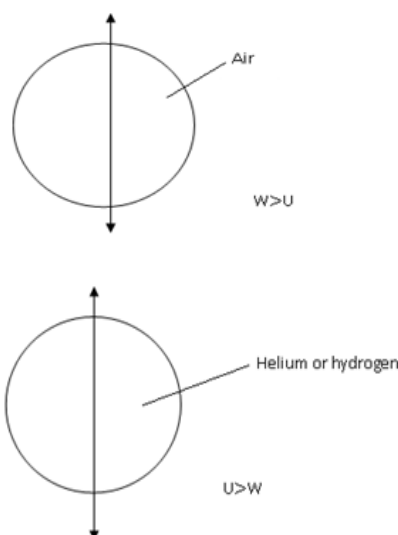


- (i) Calculate the force due to the liquid on the top face of the block.
- (ii) If the upward force on the bottom face is 1.5N , calculate the volume of the block.
- (iii) Calculate the apparent weight of the block in water.

Up thrust in gases

Gases exert small upthrust on objects because of their low density.

A balloon filled with hydrogen or helium rises up because of low density.



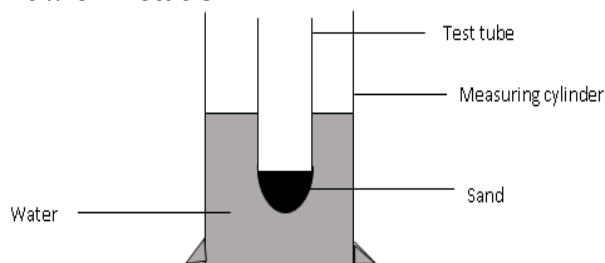
In the figures above the balloon filled with air will not float because the weight of the balloon fabric and air is greater than the weight of air displaced (upthrust) i.e. $w > u$. The balloon filled with helium or hydrogen floats because the weight of the balloon fabric and helium or

weight of block in air. They are equal (same). Therefore we conclude that **a floating object displaces its own weight of the fluid in which it floats. This law of flotation.**

Explanation

hydrogen is less than the weight of the air displaced (upthrust) i.e. $u > w$

Law of Flotation



In this case we consider the floating object and weight of the fluid displaced.

A comparison of the weight of the object and that of fluid displaced.

Experimentally this can be done by:

- $\frac{1}{2}$ fill measuring cylinder with water and record the reading.
- Place a clean dry test tube into the beaker and add some sand in it so that it floats upright.
- Record the new level of the liquid determine the volume of displaced water
- Measure its weight (dried) and content.
- Calculate the weight of displaced water.

It is observed that the weight of the test tube and its content is equal to weight of displaced water.

OR

Apparatus:

A block of wood, A spring balance, Thin thread, Overflow can, A small measuring cylinder and Some water.

Using the apparatus above, describe an experiment to verify the law of floatation.

- Using the spring balance, weigh and record the weight of the block in air
- Fill the eureka completely with water
- Place the measuring cylinder under the spout
- Lower the block of wood slowly into water until the string slackens (the block floats)
- Collect the displaced water using the measuring cylinder
- Repeat the procedure to attain more results
- Compare the weight of displaced water with the

When a body is submerged in water, there are two forces acting on the body;

- (i) The weight of the body acting downwards
- (ii) Upthrust on the body due to displaced liquid acting upwards.

Case 1

If the weight of the body is greater than upthrust, the density of the body is greater than the density of the displaced liquid, the body sinks.

Case2

If the weight of the body is equal to upthrust, the density of the body is equal to the density of the liquid, the body remains in equilibrium.

Case3

If the weight of the body is less than the upthrust, density of the body is less than the density of the liquid, the body floats partially in the liquid.

Example:

A boat of mass 2000kg floats on fresh water. If the boat enters sea water. Determine the volume that must be added to displace the same volume of water as before. (Fresh water = 1000 kg/m^3 , sea water = 1030 kg/m^3)

Weight of fresh water = 2000kg

$$\text{Displaced Volume of fresh water} = \frac{2000}{1000} = 2 \text{ m}^3$$

Mass = Density x Volume

$$= 1030 \times 2$$

$$= 2060 \text{ kg}$$

$$= 2060 - 2000$$

$$= 60 \text{ kg}$$

2. A sphere of radius 3 cm is floating between liquid A and B such that $\frac{1}{2}$ is at A and $\frac{1}{2}$ at B. If of liquids A and B are 0.8 g/cm^3 and 1.0 g/cm^3 respectively determine mass of the sphere.

Mass of sphere= volume x density

$$\text{Volume} = \frac{4}{3}\pi r^3$$

$$= 113.14 \text{ cm}^3$$

Volume of liquid A displaced = $\frac{1}{2} \times 113.14$

$$56.57 \text{ cm}^3$$

Mass displaced of A = 56.57×0.8

$$45.256 \text{ g}$$

Mass of liquid B displaced = 56.57g

Total mass of sphere displaced = $45.256 + 56.57$

101.826g

3. A stone weighs 2N in air and 1.2N when totally immersed in water Calculate

(a) Volume of the stone

(b) Densities of the stone

(a) Up thrust = weight of water displaced

$$= 2 - 1.2$$

$$= 0.8 \text{ N}$$

Mass of water displaced = $0.8/10$

$$= 0.08 \text{ kg}$$

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

$$= \frac{0.08}{1000} \text{ kg m}^{-3}$$

$$1000 \text{ kg/m}^3$$

$$= 0.00008 \text{ m}^3$$

Volume of stone = 0.00008 m^3

$$(b) \text{ Density} = \frac{\text{mass}}{\text{volume}} = \frac{0.2}{0.00008}$$

$$= 2500 \text{ kg/m}^3$$

Upthrust and Relative Density

Relative density is the ratio of the mass of any volume of a substance to the mass of an equal volume of water OR the ratio of the density of a substance to the density of water.

To find relative density of a solid or a liquid several methods or formulas are used.

$$\text{Relative density} = \frac{\text{density of a substance}}{\text{density of water}}$$

Relative density of a solid.

If equal volumes of the substance and water are considered,

$$\text{Relative density} = \frac{\text{Mass of solid}}{\text{Mass of equal volume of water}}$$

Because mass is directly proportional to the weight the relative density of a solid may be given as:

$$\text{Relative density} = \frac{\text{weight of solid}}{\text{weight of equal volume of water}}$$

$$\text{Relative density} = \frac{\text{weight of solid}}{\text{weight of displaced water}}$$

$$\text{Relative density} = \frac{\text{weight of solid}}{\text{up thrust in water}}$$

Relative density of solid which sinks in water

If the weight of the substance in air is W_1 and in water is W_2 , then $R.D = \frac{W_1}{W_1 - W_2}$

Relative density of solid which floats in water

The sinker is used as follows:

Weight of the sinker in water = W_1

Weight of the sinker in water + weight of floating object in air = W_2

Weight of the sinker + weight of floating object in water = W_3

Weight of floating object in air = $W_2 - W_1$

Weight of floating object in water = $W_3 - W_1$

Up thrust of the floating object in water = $(W_2 - W_1) - (W_3 - W_1)$

Up thrust of the floating object in water = $W_2 - W_1 - W_3 + W_1$

Up thrust of the floating object in water = $W_2 - W_3$

$$\text{Relative density} = \frac{\text{weight of solid}}{\text{up thrust in water}}$$

$$\text{Relative density of floating object} = \frac{W_2 - W_1}{W_2 - W_3}$$

Relative density of a liquid

To find relative density of the liquid we determine:

- Weight (w_1) of solid in air.
- Weight (w_2) of the same solid when totally immersed in water.
- Weight (w_3) of the same solid when totally immersed in a liquid whose relative density is to be determined.

R.D of liquids

$$= \frac{\text{mass of liquid}}{\text{mass of equal volume of water}}$$

Or

R.D of liquids

$$= \frac{\text{weight of displaced liquid}}{\text{weight of equal volume of water displaced}}$$

Or

$$\text{R.D of liquids} = \frac{\text{upthrust in the liquid}}{\text{upthrust in water}}$$

$$\text{R.D of liquids} = \frac{w_1 - w_2}{w_1 - w_3}$$

Or

Example

- A solid of mass 800g is suspended by a string is totally immersed in water. If the tension in the string is 4.8N. Calculate

(a) Volume of solid

(b) Relative density of the solid.

Weight of solid = 8N

$w_1 = 8N$

$w_2 = 4.8N$

Up thrust = 3.2N

Volume of water displaced = $\frac{0.32}{1000}$

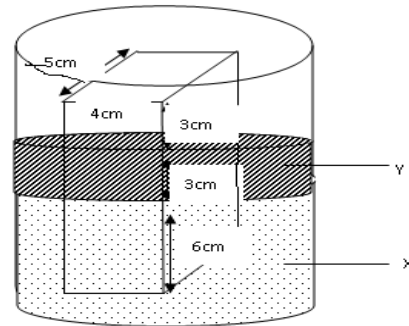
= 0.00032 m^3

Volume of the solid = 0.00032 m^3

- The wooden block below floats in two liquids x and y if the densities of x and y are 1 g/cm^3 and 0.8 g/cm^3 respectively determine:

(i) Mass of the block

(ii) Density of the block



$$\begin{aligned} \text{Volume of y displaced} &= 4 \times 5 \times 3 \\ &= 60 \text{ cm}^3 \\ &= 0.00006 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Up thrust in y} &= v \rho g \\ &= 800 \times 0.00006 \times 10 \\ &= 0.48 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Volume of x displaced} &= 0.04 \times 0.05 \times 0.06 \\ &= 0.00012 \text{ m}^3 \end{aligned}$$

$$\begin{aligned} \text{Up thrust in x} &= v \rho g \\ &= 0.00012 \text{ m}^3 \times 1000 \times 10 \\ &= 1.2 \text{ N} \end{aligned}$$

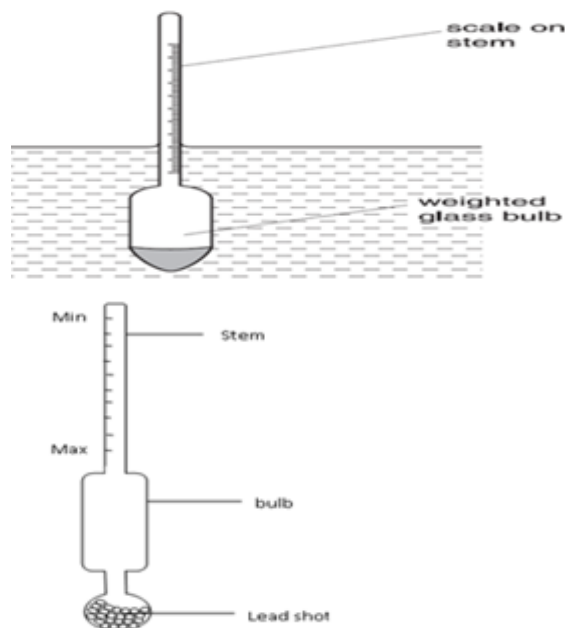
$$\begin{aligned} \text{Total up thrust} &= 1.2 + 0.48 \\ &= 1.68 \text{ N} \end{aligned}$$

$$\begin{aligned} \text{Weight of block} &= \text{total up thrust} \\ &= 1.68 \text{ N} \\ &= 0.168 \text{ kg} \end{aligned}$$

$$\begin{aligned} \text{(b) density} &= \frac{\text{mass}}{\text{volume}} \\ &= 0.168 \\ &= 0.04 \times 0.05 \times 0.12 \\ &= 700 \text{ kg/m}^3 \end{aligned}$$

Applications of Archimedes's Principle and Relative Density

(a) The hydrometer

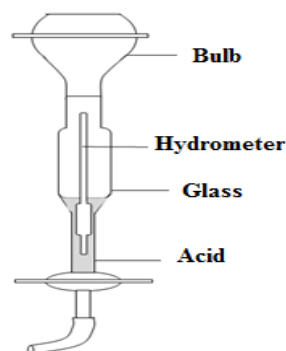


It is an instrument used to find relative densities of density of liquids. It applies the law of flotation in its operation.

It has a wide bulb to displace large volume of liquid that provide sufficient up thrust to keep hydrometer floating.

Lead shots at the bottom- to make hydrometer float upright.

Narrow stem- to make hydrometer more sensitive.



Hydrometers are designed for specific purposes lactometer range 1.015 – 1.0045 so as to measure density of milk.

The bulb is squeezed and released so that the acid is drawn into the glass tube.

Used by metrologists where a gas which is less dense than air like hydrogen is used. The balloon moves upwards because up thrust force is greater than weight of the balloon. It rises to some height where density is equal to that of the balloon. At this point the balloon stops rising because up thrust is equal to weight of the balloon and therefore resultant force is equal to zero.

(c) Ships

They are made of steel which is denser than water but floats because they are hollow thereby displacing a large volume of water than the volume of steel which provides enough up thrust to support its weight.

The average density of sea water is greater than the average density of fresh water. Due to this difference, ships are fitted with primsol lines on their sides to show the level that a ship should sink to when on various waters.

(d) Sub-marine

It can sink or float. It is fitted **with ballast tanks** that can be filled with air or water hence varying its weight .To sink, ballast tanks are filled with water so that its weight is greater than up thrust.

To float compressed air is pumped into the tank displacing water so that up thrust is greater than weight of the submarine.

Examples

1. A hydrometer of mass 20g floats in oil of density 0.7g/cm^3 .with 5cm of its stem above the oil. If the cross sectional area of the stem is 0.5cm^2 . Calculate:-

(a) Total volume of the hydrometer

(b) Length of the stem out of water if it floats in water.

Solutions to questions

$$\begin{aligned} \text{(a) Volume of oil displaced} &= \frac{\text{mass of oil displaced}}{\text{density of oil}} \\ &= \frac{20}{0.8} \\ &= 25 \text{ cm}^3 \end{aligned}$$

$$\begin{aligned} \text{Volume of hydrometer above oil} &= 5 \times 0.5 \\ &= 2.5 \text{ cm}^3 \end{aligned}$$

$$\begin{aligned} \text{Total volume} &= 25 + 2.5 \\ &= 27.5 \text{ cm}^3 \end{aligned}$$

(b) Mass of hydrometer

$$= 2 \times 10 - 2 \text{ kg}$$

$$\text{Weight of hydrometer} = 2 \times 10 - 1 \text{ N}$$

Weight of water displaced

$$= 2 \times 10 - 1 \text{ N}$$

$$\text{Mass of water displaced} = 2 \times 10^{-1}$$

$$= 20 \text{ g}$$

Volume of water displaced

$$= \frac{20 \text{ g}}{1} \text{ g cm}^3$$

$$= 20 \text{ cm}^3$$

Volume of hydrometer above water

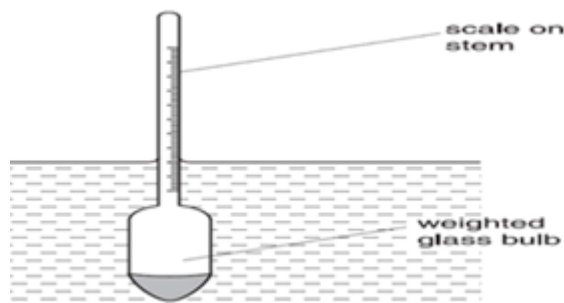
$$= 27.5 - 20$$

$$= 7.5 \text{ cm}^3$$

$$\text{Length} = \frac{\text{volume}}{\text{Area}}$$

$$= \frac{7.5}{0.5} = 15 \text{ cm}$$

The densities of liquids may be measured using hydrometers. The hydrometer in the figure consists of a weighted bulb with a thin stem.



The hydrometer is floated in the liquid and the density is read from a scale on its stem.

The hydrometer in the figure is designed to measure densities between 1.00 g cm^{-3} and 1.10 g cm^{-3} . On the diagram, mark with the letter M the position on the scale of the 1.10 g cm^{-3} graduation. The hydrometer has a mass of 165 g and the stem has a uniform cross-sectional area of 0.750 cm^2 . Calculate;

- (i) The change in the submerged volume of the hydrometer when it is first placed in a liquid of density 1.00 g cm^{-3} and then in a liquid of density 1.10 g cm^{-3} .

Volume of 1.00 g/cm^3 liquid

$$\text{displaced} = m/\rho = 165/1 = 165 \text{ cm}^3;$$

$$\text{Volume of } 1.10 \text{ g/cm}^3 \text{ displaced} = 165/1.1 = 150 \text{ cm}^3;$$

$$\text{Change in volume displaced} = 165 - 150 = \underline{15 \text{ cm}^3} ;$$

$$\text{Volume} = \text{Area} \times \text{Height} ;$$

$$0.75 \times h ; \quad \text{therefore } h = \underline{20 \text{ cm.}}$$

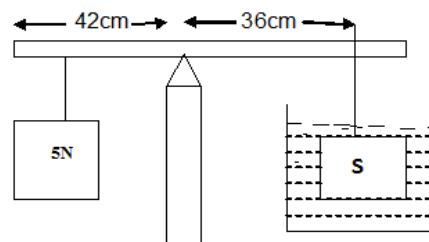
(ii) State two ways of improving the sensitivity of the above hydrometer.

-Using a hydrometer with a narrow stem.

- Using a hydrometer with a large bulb

2. When a body of mass 450 g is completely immersed in a liquid, the upthrust on the body is 1.6 N . Find the weight of the body in the liquid.

3. The figure below shows a lever arrangement with the rod balanced by a knife edged at its centre of gravity. The 5 N weight on one side balances the solid S (volume 100 cm^3) which lies immersed in a beaker of water on the other side.



The beaker of water is then removed and while keeping the 42 cm distance constant, the position of solid S is adjusted to obtain balance conditions again.

- a) Determine the new position of S.
- b) What would be the new position of S if it was immersed in a liquid of relative density 0.8 ?

Specific objectives

By the end of this topic, the learner should be able to:

- Perform and describe simple experiments to illustrate electromagnetic induction
- State the factors affecting the magnitude and the direction of induced emf
- State the laws of electromagnetic induction
- Describe simple experiments to illustrate mutual induction explain mutual induction
- Explain the working of an alternating current (a.c) generator and a direct current (d.c) generator
- Explain the working of a transformer
- Explain the application of electromagnetic induction
- Solve numerical problems involving transformers

Content

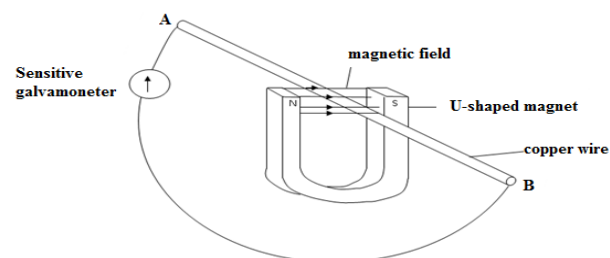
- Simple experiments to illustrate electromagnetic induction
- Induced emf:
 - Faraday's law
 - Lenz's law
- Mutual induction
- Alternating current generator, direct current generator
- Fleming's right hand rule
- Transformers
- Applications of electromagnetic induction
 - Induction coil
 - Moving coil transformers

Introduction

Electric current passing through a conductor has an associated magnetic field. The reverse is also true in that a change in magnetic field induces an electric current in a conductor a phenomenon known as **electromagnetic induction**.

This is attributed to Michael Faraday and has led to production of electrical energy in power station.

Experiment to Show Induced Electromotive Force (Emf)



The galvanometer reflects when conductor AB cuts the magnetic field.

- There is no flow of current when the conductor is stationary.
- The magnitude of induced current increases with the angle of which conductor cuts magnetic field.
- The direction of deflection reverses when the direction of motion is reversed.

FACTORS AFFECTING MAGNITUDE OF INDUCED E.m.f.

- The magnitude or strength of magnetic field.
- The rate of change of flux linkage/rate of relative motion between the conductor and magnetic field.
- The number of turns of coil/length of the conductor
- The nature of the core

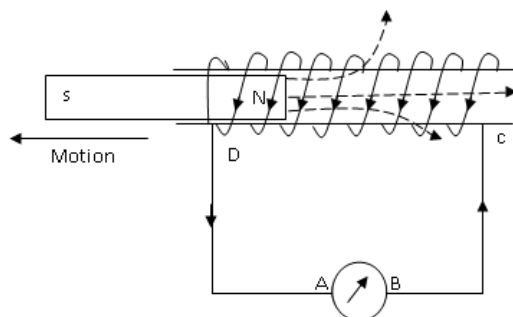
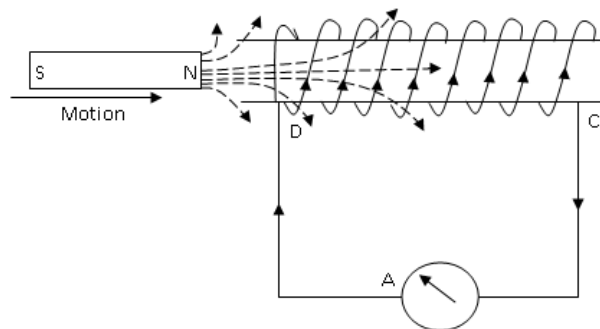
Magnetic Flux

It is the product of magnetic field strength and perpendicular area covered by the field lines.

The direction of induced emf by a conductor is predicted by **two laws of electromagnetic induction**;

Faraday's law-The magnitude of induced e.m.f. is directly proportional to the rate of change of magnetic flux linkage.

Lenz's law – direction of induced e.m.f. is such that the induced current which it causes to flow produces a magnetic effect that opposes the change producing it.



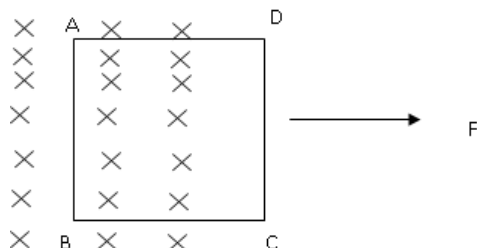
The mechanical energy of a moving magnet inside a coil is converted to electric energy in form of induced current. The person pushing the magnet towards the coil must exert force to do work against repulsion of induced pole of coil magnet.

Fleming Right Hand Rule (Dynamo Rule)

If the thumb and first two fingers of the right hand are held manually at right angle with 1st finger pointing direction of magnetic field, the thumb pointing in the direction of motion then the second finger points in direction of induced current.

Example

(i) A square looped conductor is pulled at speed across a uniform magnetic field as shown below.

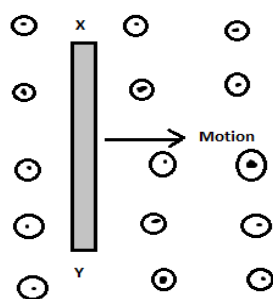


Determine direction of induced current in

- (a) AB – from B to A
- (b) AD - no induced current
- (c) CD-C to D
- (d) BC- no induced current

Question

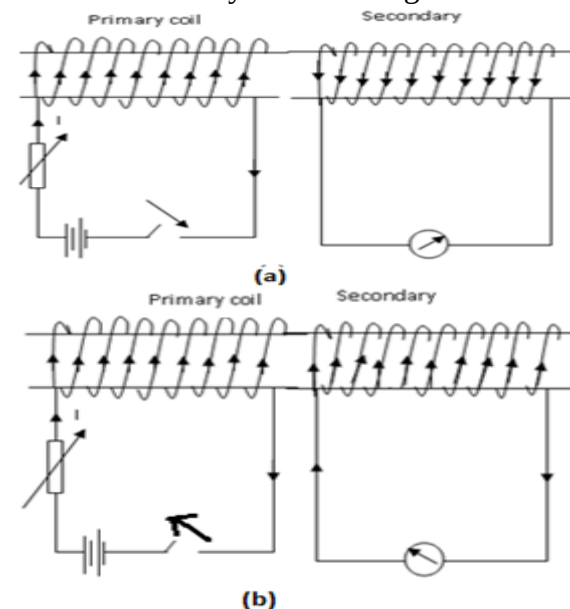
- (a) State Faraday's laws of electromagnetic induction.
- (b) The figure below shows a conductor XY moving in a region of uniform magnetic field.



- (i) State the direction of the induced current in the conductor and the rule used in arriving at the answer.
- (ii) Suggest one way of increasing the magnitude of the induced current in the conductor.

Mutual Induction

It occurs when change of current in one coil induces a current in another coil placed close in to it. The **changing magnetic flux** in the first coil (Primary) links to secondary coil inducing an EMF in it.



When a switch is closed, current in the primary coil increases from zero to a maximum current within a very short time. The magnetic flux in the primary coil linking with the secondary coil increases from zero to a maximum value in the same interval of time inducing an e.m.f. in the secondary coil. Current flows hence the reflection on the galvanometer.

Likewise when the switch is opened the current in the primary takes a very short time to fall from maximum value to zero. The magnetic flux in primary coil linking secondary also falls from maximum value to zero inducing an **e.m.f.** on the secondary coil.

The induced e.m.f. in the secondary coil is higher when current in the primary coil is switched off than when it is switched on because the current in the circuit takes a much shorter time to die off than build up. The above explanation is called **mutual induction**. The induced e.m.f. in the secondary coil can be increased by:

- (i) Having more turns in the secondary coil.
- (ii) Winding the primary and secondary coils on a soft iron rod.
- (iii) Winding both primary and secondary coils on a soft iron ring in order for the magnetic flux in the primary to form concentric loops within it thus reaching the secondary point. Soft iron concentrates magnetic flux in both coils that is why it is used.

Application of Electromagnetic Induction

It is applied in many areas some of these are:

(i) Transformer

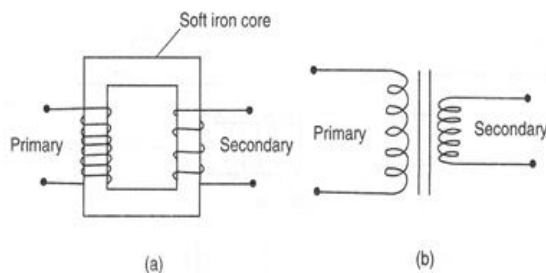
A transformer transfers electrical energy from one circuit to another by mutual induction.

It consists of a primary coil where an alternating current is the input and secondary coil forming the output.

The coils are wound on a common soft iron.

Types of Transformers

Step down transformers



It has more turns in primary coil (N_p) than in the secondary coil (N_s)

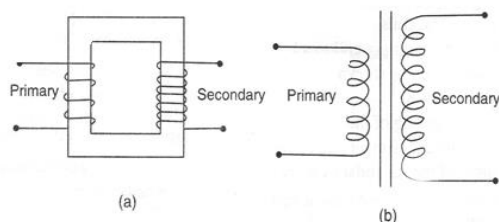
$$\frac{V_s}{V_p} = n(\text{Turns ratio})$$

Turns ratio is less than one

Step up transformer

It has less turns in primary coil and more in the secondary coil.

The turn's ratio is greater than one.



NOTE – In a step-down transformer current in the secondary coil is greater than in the primary coil while in the step-up transformer current in the primary coil is greater than in the secondary coil.

Useful transformer equations

From experiment; $\frac{\text{Secondary voltage}}{\text{Primary voltage}} = \frac{\text{no. of secondary turns}}{\text{no. of primary turns}}$

This is called **turns rule**.

Mathematically;

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

Assuming negligible resistance

Power = Voltage x current

$$P = VI$$

Power input

= Primary voltage x primary current

$$P_{\text{input}} = V_p I_p$$

Power output = secondary voltage x secondary current

$$P_{\text{output}} = V_s I_s$$

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

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

For ideal transformer there is no energy lost and therefore efficiency is 100%

$$100 = \frac{V_s I_s}{V_p I_p} \times 100$$

$$V_p I_p = V_s I_s$$

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

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

Examples

1. A transformer is to be used to provide power of 24V ceiling bulb from a.c. supply of 240. Find the number of turns in secondary coil if the primary coil has 1000 turns.

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

$$\frac{24}{240} = \frac{N_s}{1000}$$

$$1000$$

$$= 100 \text{ turns}$$

2. A power station has an output of 10KW at a p.d of 500v. The voltage is stepped up to 15 KV by transformer T_1 , for transmission along a grid of resistance 3 k and then stepped down to p.d 240v by transformer T_2 at the end of grid for use in a school. Given that efficiency of T_1 is 95% and T_2 90%, find:
- The power output of T_1
 - The current in the grid.
 - The power loss in grid.
 - The input voltage of T_2
- (a) The maximum power and current available for use in school
- (b) Why is it necessary to step up the voltage at power station?
3. Power station has an output of 33K at a p.d of 5k V a transformer with a primary coil of 2000 turns is used to step up the voltage of 132 KV for transmission along a grid. Assuming there is no power loss in the transformer calculate
- Current in the primary coil
 - Number of turns of secondary coil
 - Current in the secondary coil.

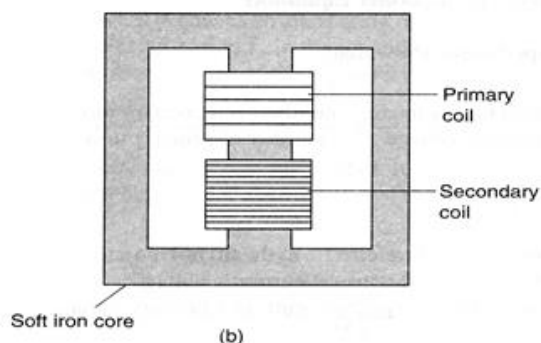
Energy Losses in a Transformer

There are four main causes of energy losses in a transformer.

Flux Leakage

All magnetic flux produced by the primary may not link up with the secondary coil hence reducing e.m.f induced in secondary. Flux leakage is reduced by efficient design of transformers to ensure maximum flux linkage.

The secondary coil is wound over the primary coil or coils are wound next to each other on a common core.



Resistance of Coils (Copper Losses)

This can be prevented by use of thick copper wire to reduce heating effect.

Eddy Currents in the Core

Eddy currents have associated fluxes that tend to oppose the flux change in primary. This reduces power transfer to the secondary. To reduce eddy currents the core is laminated (using thin sheets of insulated soft iron plates) causes minimal heating effect.

Hysteresis Loss

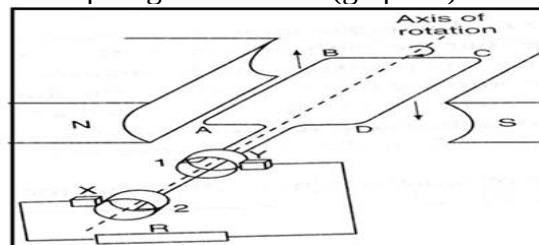
It is energy losses in form of heat in magnetizing and demagnetizing the soft iron core every time the current reverses. It can be minimized by using a core of soft magnetic material which magnetizes and demagnetizes easily.

Practical Transformer

A transformer used in power stations and along transmission lines generates a lot of heat. **They are therefore cooled by oil which does not easily evaporate.** Small transformers are cooled by use of air. A well-designed transformer can have an efficiency of up to 99%. However; the presence of air reduces its efficiency.

(i) Alternating current generator

It converts mechanical energy into electrical energy. It has a rectangular curved permanent magnet poles, two slip rings and carbon (graphite) brushes.



The poles of the magnet are curved so that magnetic field is radial. Induced current enters and leaves the coil through the brushes which press against the slip-rings. The brushes are made of graphite because:

- It is a good conductor of electricity-
- It is slippery and therefore can act as a lubricant.

When coil rotates in clockwise direction side AB moves up and CD downwards. The two sides are cutting the magnetic field perpendicularly and produce maximum induced e.m.f (E) when the coil is horizontal.

Applying Fleming's right hand rule, the flow of induced current is in the direction ABCD

The current flow through the external circuit via the slip – ring 2 and brush x. Brush Y and slip-ring 1 complete the circuit. Brush x is thus positive terminal which Y is negative. When coil rotates from horizontal to vertical position the angle at which the sides of the coil cuts magnetic field reduces from 90° to 0°

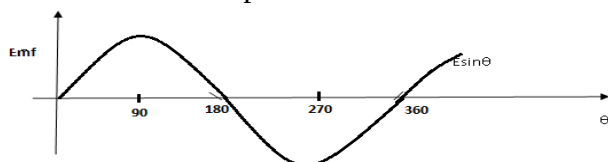
Likewise the induced emf reduces from maximum to zero. When the coil rotates past the vertical position side AB moves downwards as side CD moves upwards. The angle θ at which the sides of the coil cuts the magnetic field increases from 0° to 90° when coil is horizontal. The induced emf increases from zero to maximum value and direction of current in the coil reverses from D C B A brush Y now becomes positive and X negative.

The magnitude of induced e.m.f obeys the sinusoidal equation

$$E = E_0 \sin \theta$$

Where E_0 is maximum e.m.f and θ is the inclination of the coil to the vertical.

The graph below shows the variation of induced emf with time for one revolution of the coil starting with the coil in vertical position.



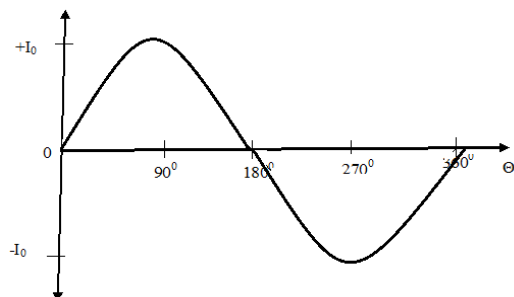
$$\text{By Ohm's law } I = \frac{E}{R}$$

$$E = E_0 \sin \theta$$

$$IR = I_0 \sin \theta$$

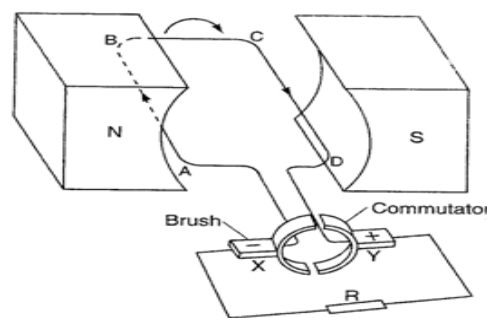
$$I = I_0 \sin \theta$$

The graph of induced current against the angle of inclination is similar to one above.



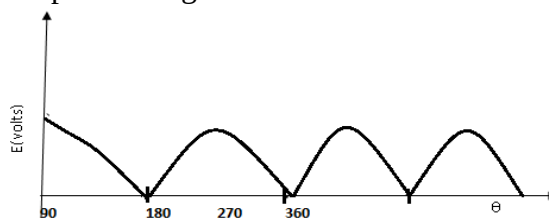
(ii) Direct Current Generator

Direct current (d.c) generator differs from an a.c generator in that it has a split-ring (commutator) while in ac generator has slip-ring.



If the coil rotates into the vertical position induced current and e.m.f though resistor R decreases from maximum value to zero. The polarity of brush Y is **positive** and X is **negative**. The brushes touch the gaps within the commutators

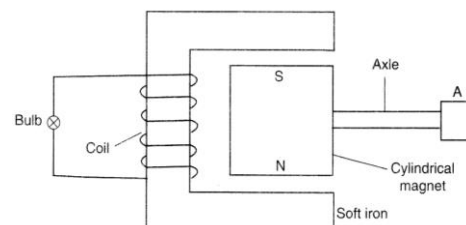
The vertical position ensures that rings exchange brushes since the induced current change direction but direction of current through the external resistor remains the same. The polarity does not change and output of d.c generator is shown below.



The induced e.m.f or current of both a.c and d.c generator can be increased by;

- i) Increasing speed of rotation of coil.
- ii) Increasing no of turns of coil.
- iii) Increasing the strength of the magnetic field.
- iv) Winding the coil on a laminated soft iron core.

In a bicycle dynamo the magnet rotates while coil remains stationary. It has advantages over other generators because there are no brushes which get worn out.



(iv) Moving Coil Microphone

Sound waves from the source set diaphragm in vibration which in turn causes the coil to move to and from cutting the magnetic field.

Induced e.m.f of varying magnitude sets up varying current in coil so that coil is perpendicular to it for maximum flux linkage.

An amplifier is used to increase the amplitude of this current before it is fed into the loudspeaker to be converted back to sound.

(iv) The Induction Coil

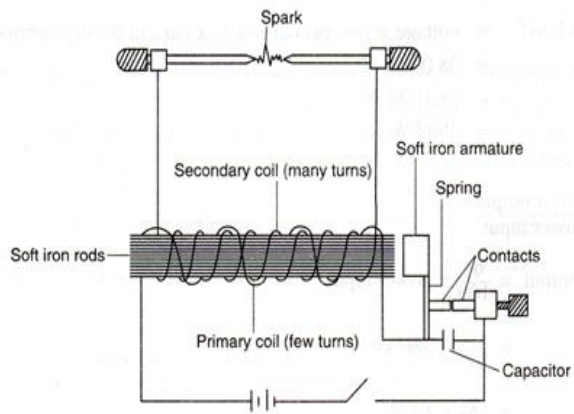
It is used to ignite petrol-air mixture in a car engine.

When the switch is closed the soft iron rod is magnetized due to current on the primary coil and attracts the soft iron armature.

The armature opens the contact and cuts off primary currents reducing magnetic field to zero. This in turn induces a large emf in the secondary coil by mutual induction. The spring pulls the armature back to make the contact again and process repeats itself.

The induced emf in the secondary coil is higher when primary current is switched off than when it is switched on. This is because current takes a longer time to increase from zero to maximum than to decrease from maximum to zero.

Sparking occurs at the contact due to magnetic field of the primary. A capacitor is therefore connected across the contacts to minimize sparking effects by decaying magnetic flux to zero. Sparks form across gap between the ends of secondary coil and can be used to ignite petrol-air mixture in a car engine.



Assignment to the student.

Do the exercise at the end of the topic in KLB.

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