OPTICS (LIGHT)

Definition:

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

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

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

Sources of light.

(i) *Luminous light sources*:

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

(ii) *Non – luminous light sources:*

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

Transmission of light:

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

(i) Transparent Medium

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

(ii) Translucent Medium

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

(iii) Opaque Medium

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

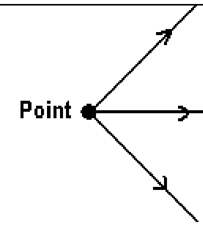
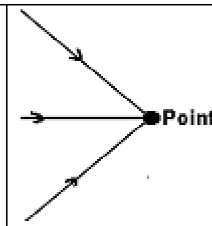
N/B: incandescent bodies give off light because they are hot while fluorescent bodies give off light without being hot.

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

RAYS AND BEAMS

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

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

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

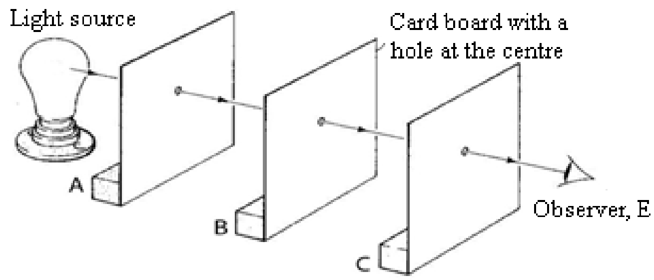
RECTILINEAR PROPAGATION OF LIGHT

Definition:

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

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

Experiment to show that light travels in a straight line



Procedures

Arranging cardboards

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

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

Observation

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

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

Conclusion

This shows that light travels in a straight line

SHADOWS

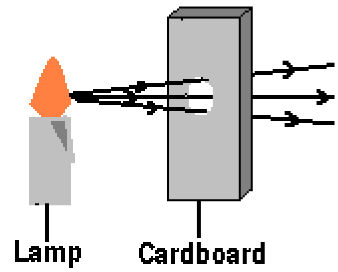
A shadow is a region of darkness formed when an opaque object obstructs the path of light.

Shadows are formed because light travels in a straight line.

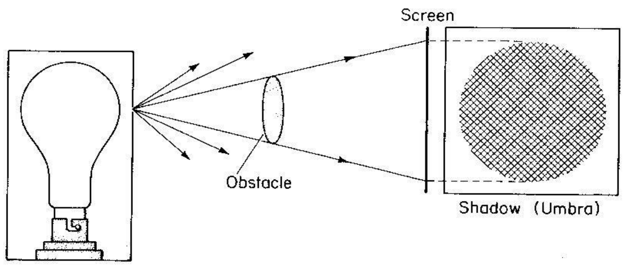
Shadow formation

a) Point Source:

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



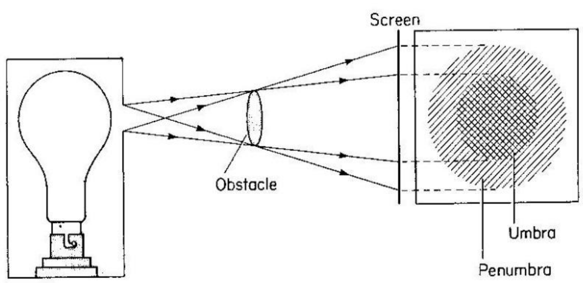
A shadow is formed by a point source



For a point source, a sharp shadow is formed, i.e. the shadow is also equally dark all over.
For a point source: When the opaque object is moved near the source, then the size of the shadow increases. However, when the object is moved near the screen, the size of the shadow is decreased.

b) Extended Source

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



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

Umbra

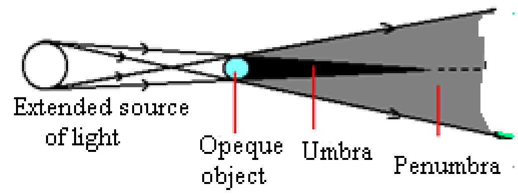
A region of shadow where no light reaches at all.

Penumbra

A region of the shadow where some light reaches.

Note:

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



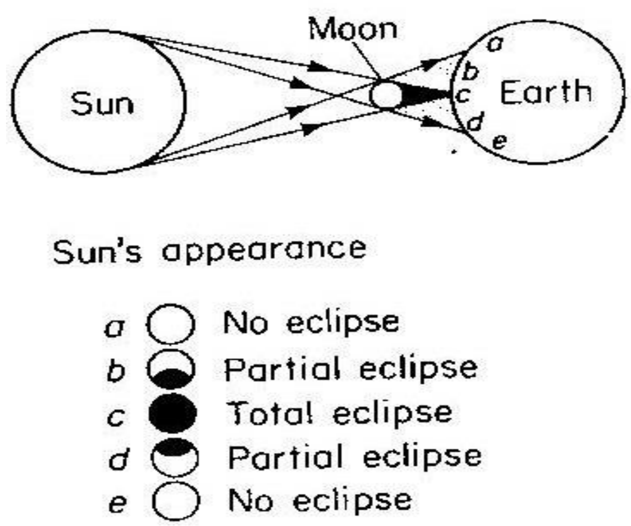
The umbra may fail to reach the screen if the opaque object is very far away from the screen

ECLIPSE:

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

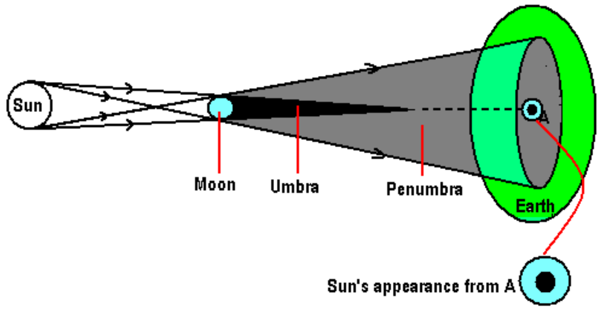
a) Solar Eclipse:

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



❖ ***Annular Eclipse:***

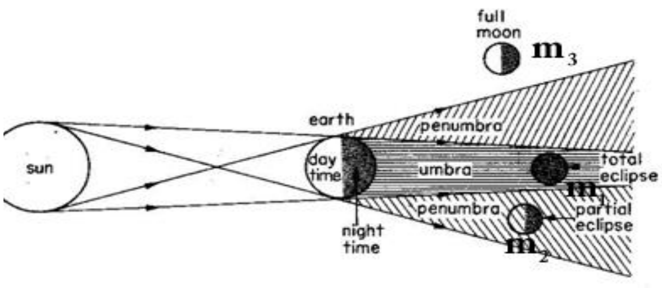
Annular eclipse of the sun occurs when the sun is very far from the earth and the moon is between the earth and the sun, such that the tip of the umbra is the one that reaches the earth's surface. From one place on the earth, the sun is represented by the appearance of a ring of light.



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

b) Lunar Eclipse:

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



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

Flourescence and phosphorence substance

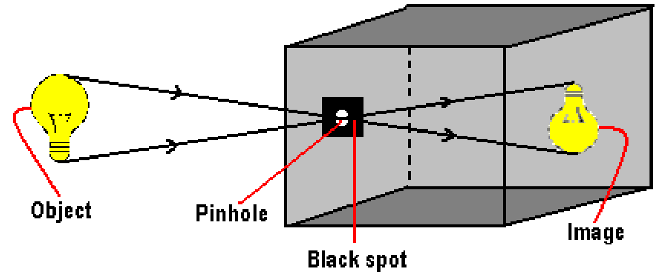
i. *Fluorescence Substance:*

A substance which absorbs energy and immediately release the energy in the form of light e.g. zinc sulphide. The screen of a T.V and C.R.O are made of a fluorescent substance.

ii. *Phosphorescence Substance:*

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

THE PIN HOLE CAMERA



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

Description of Image Formation:

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

Effect of image formation for pin hole camera if;

(i) Pin hole is enlarged; image become blurred and brighter

Explanation:

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

Note:

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

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

Explanation:

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

MAGNIFICATION

Definition:

Magnification is the ratio of image height to object height or image distance to object distance.

Mathematically, magnification is given by:

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

OR

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

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

Example: 1

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

Solution

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

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

$\frac{h}{H} = \frac{V}{U}$ $\frac{5\text{ cm}}{H} = \frac{10\text{ cm}}{150\text{ cm}}$ $10H = 5 \times 150$ $H = 75\text{ cm}$ Alternatively, you can first calculate magnification using first equation and then substitute in second equation to obtain object height; i.e.	From $M = \frac{\text{Image distance, V}}{\text{Object distance, U}}$ $M = \frac{10\text{ cm}}{150\text{ cm}} = \frac{1}{15} \ldots\ldots(i)$ But also; $M = \frac{\text{Image height, h}}{\text{Object height, H}}$ $M = \frac{5\text{ cm}}{H} \ldots\ldots(ii)$ Equating (i) and (ii) $\frac{5\text{ cm}}{H} = \frac{1}{15}$ $H = 5 \times 15$ $H = 75\text{ cm}$

$= 75\ cm$

Example: 2

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

Solution:

Given; Image distance = 25 cm = 0.25 m Object height = 2 m Object distance = 10 cm = 0.1 m Image height=?	
From definition of magnification; $M = \frac{\text{Image distance, V}}{\text{Object distance, U}}$ $M = \frac{10\text{ cm}}{150\text{ cm}}$ $M = 2.5$	$\frac{h}{H} = \frac{V}{U}$ $\frac{h}{2} = \frac{0.25}{0.1}$ $0.1h = 2 \times 0.25$ $h = 0.5\text{ cm}$

See UNEB Paper I

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

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

2. UNEB 1992 Qn. 1

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

3. . UNEB 1997 Qn. 4

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

4. . UNEB1998 Qn.7

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

REFLECTION OF LIGHT

Definition:

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

Types of Rays

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

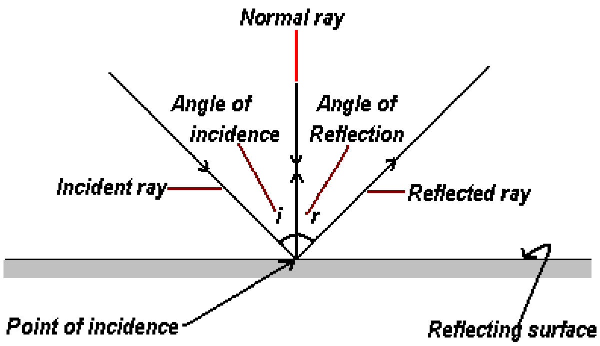
(ii) Reflected rays*;* is a ray leaving/bouncing off the reflecting surface at the point of incidence.

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

Types of Angle:

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

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



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

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

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

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

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

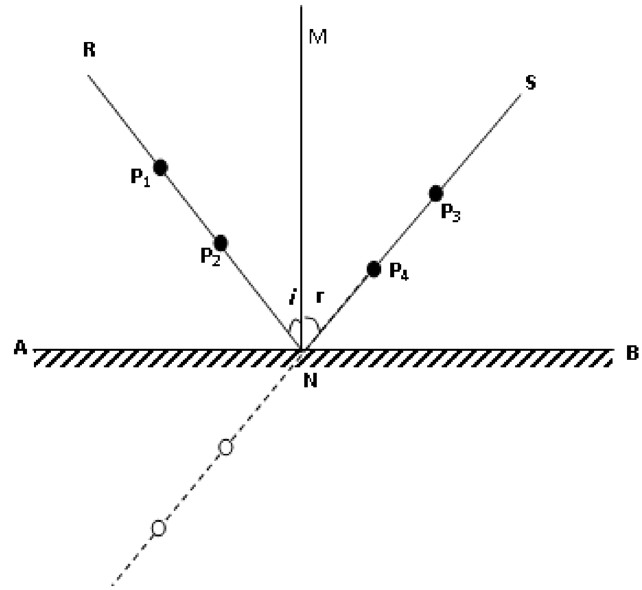
✓ Angle of reflection (r)
This is an angle between the reflected ray and the normal at the point of incidence.

The Laws of Reflection
The laws of reflection state that:

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

Experiment to verify the laws of reflection of light
A white sheet of paper is fixed on a soft board and a plane mirror is placed vertically on the paper with its reflecting surface facing the object.

The mirror line is traced and the mirror is removed and the line is drawn and labeled AB.
A normal MN bisecting the mirror line AB is drawn.



A line RN is drawn at an angle θ to the normal. e.g $\theta = 30^0$

Pins P_1 and P_2 are fixed along line RN

The mirror is placed back on the board so that its reflecting surface coincides exactly with the mirror line AB.

The images of P_1 and P_2 are viewed in the mirror and other pins P_3 AND P_4 are fixed such that they are in line with the images of P_1 and P_2 .

The pins P_3 and P_4 are removed and a line NS is drawn.

Angle r is measured and recorded.

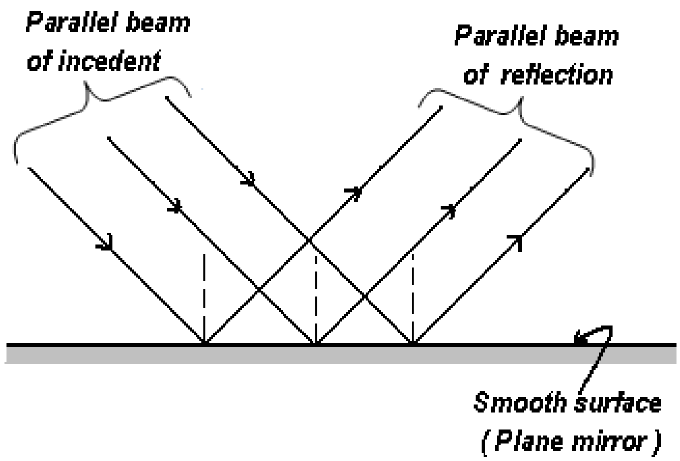
Observation:
✓ Angle **i** = angle **r.**
✓ The incident ray, the normal and the reflected ray at the point of incidence all in the same plane.

Conclusion: hence verifying the laws of reflection

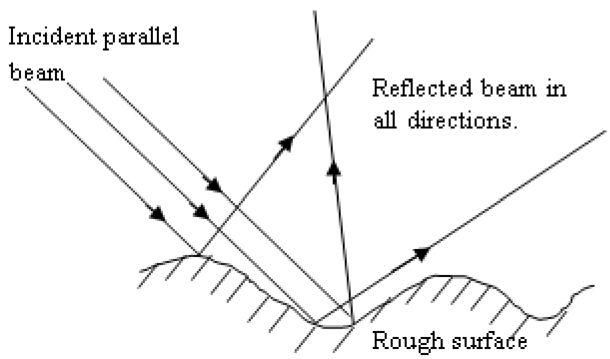
Types of Reflection

1. **Regular Reflection:**

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

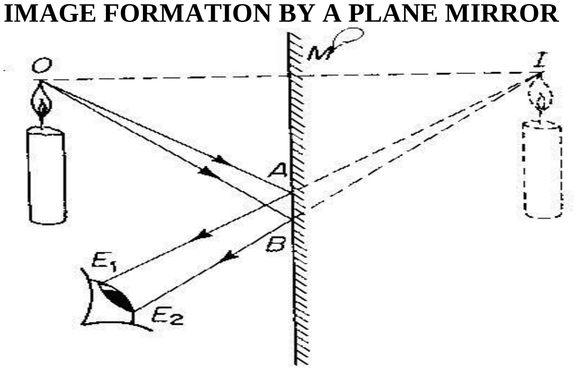


2. **Irregular or Diffused Reflection:**



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

IMAGE FORMATION BY A PLANE MIRROR



Characteristics of the image formed

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

Definition:

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

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

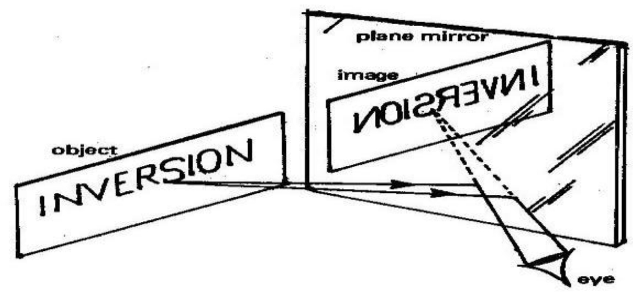
Explanation of virtual image in plane mirror:

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

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

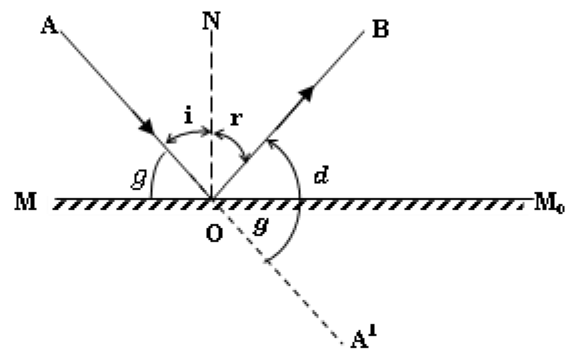
Lateral Inversion:

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



The glancing angle and the angle of deviation.

Deviation of light at a plane surface



g – **Glancing angle**

The angle between the incident ray and the reflecting surface.

d- **Angle of deviation**

it is the angle between the initial direction of the incident ray (extended incident ray) and the reflected ray.

Angle of Deviation, d;

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

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

$d = g + (90 - r)$

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

$d = g + (90 - i)$

But;

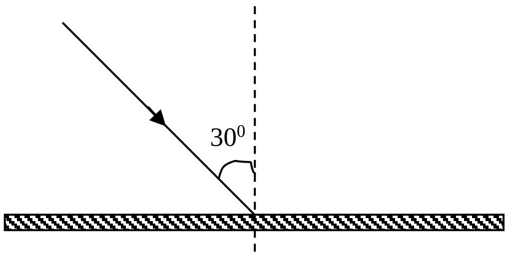
$(90 - i) = g$ (Vertically opposite angles)

$d = g + g$

$$d = 2g$$

Example

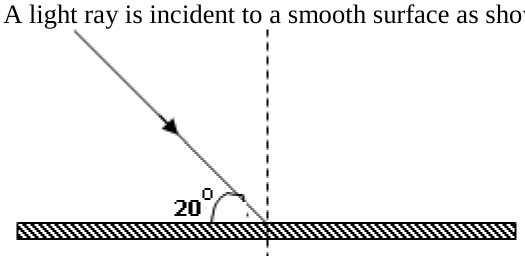
1. A light ray is incident to a smooth surface as shown below



Find the:

(i) Angle of reflection
(ii) Glancing angle
(iii) Angle of deviation

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



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

More questions about a plane mirror and characteristics of its image.

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

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

Inclined mirrors

Image formed by an inclined mirror at an angle θ

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

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

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

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

Questions

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

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

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

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

Solution

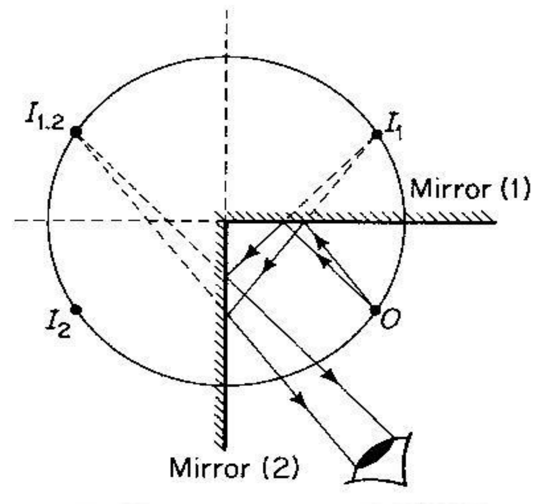
$$n = \left(\frac{36}{\theta} - 1\right)$$

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

$$\theta = 4.5^0$$

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

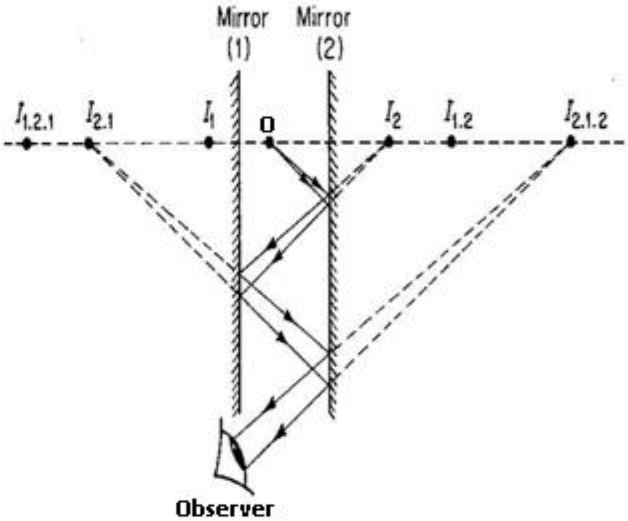
(a) Image formed in two plane mirrors inclined at 90^0



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

(b) Image formed in parallel mirrors

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



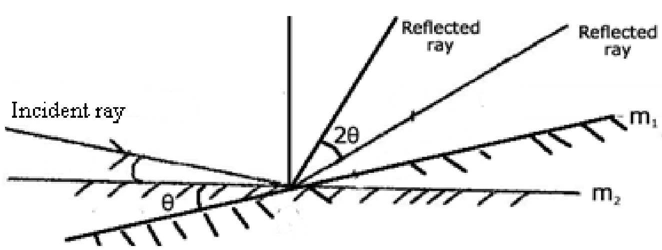
-The object O, gives rise to image I_1, on mirror m_1 and I_2 on m_2 .I_1 acts as virtual object to give an image $I_{(1,2)}$ in mirror m_2 just as I_2 gives an image $I_{(2,1)}$ in mirror $m_{1.}$ $I_{(1,2)}$ in mirror m $I_{(1,2)}$ gives $I_{(1,2,1)}$ after reflection in m_1 while $I_{(2,1,2)}$ after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

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

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

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

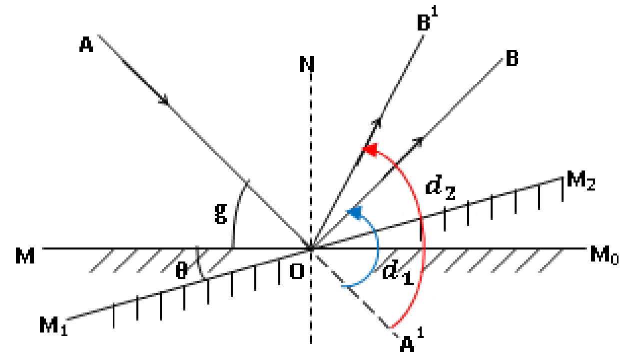
ROTATION OF REFLECTED RAY BY ROTATING THE MIRROR



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

Required angle = 2θ = 2 x 20 = 40^0

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



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

$d_1 = \text{Angle BO } A^1 = 2g \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots..(i)$

Deviation produced by mirror in position $M_1M_{2,}$ is twice the glancing angle

$d_2 = \text{Angle } B^1O\ A^1 = 2(g+\theta) \ldots\ldots..\ldots\ldots.(ii)$

Angle of rotation of reflected ray $= \text{Angle } B^1O\ B$

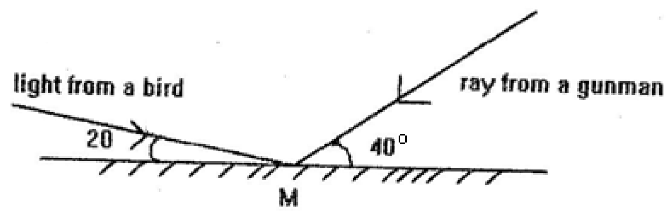
But;

$\text{Angle } B^1O\ B = \text{Angle } B^1O\ A^1 - \text{AngleBO } A^1$

$\text{Angle } B^1O\ B = 2(g+\theta) - 2g$

$\mathbf{Angle\ B^1O\ B = 2\theta}$

Questions



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

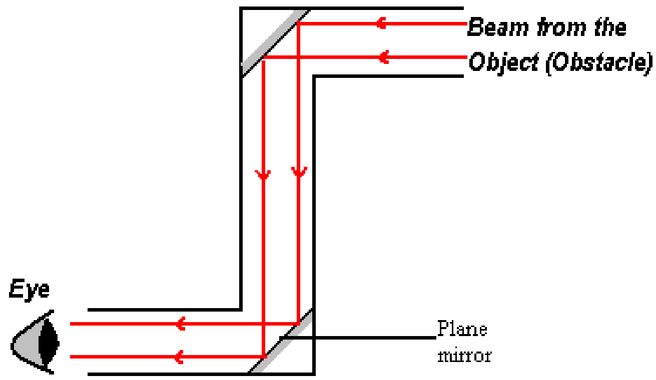
a) What will the angle of reflection be if the mirror is rotated through 6^0 to position m2 while direction of incident ray remains the same?
b) An object is placed 6cm from a plane mirror. If the object is moved further, find the distance between the object and its image.

Application of reflections

Uses of Plane Mirrors

(a) Periscope

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



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

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

(c) They are attached to optical lever such as galvanometer to reflect light falling on the mirror over the galvanometer scale as it rotates.
Used in optical lever instruments to magnify angle of rotation.

(d) Inclined mirrors are used in kaleidoscope for producing different patterns of objects placed between them.
A kaleidoscope consists of two plane mirrors inclined at an angle of 60^0 to each other in a tube.
When one looks through the tube, five images of the same object are seen, which together with the object form a symmetric pattern of six sectors.

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

Exercise See UNEB Paper I

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

CURVED MIRROR

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

Terms used in mirror

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

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

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

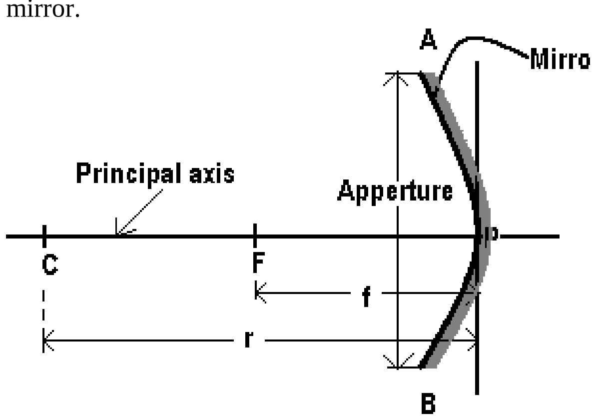
Radius of Curvature, r.
The radius of curvature is the distance from the pole to the centre of curvature.

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

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

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

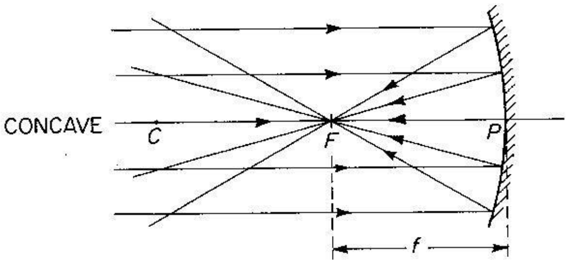
Summary for terms used in curved mirrors i.e. Concave mirror.



Types of curved mirrors

CONCAVE MIRROR

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



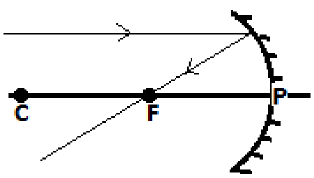
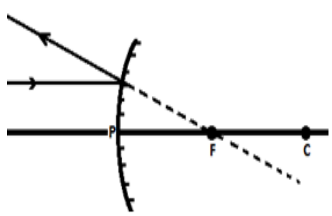
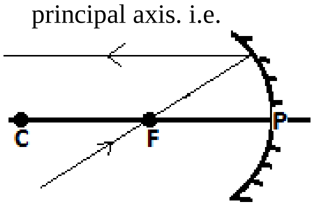
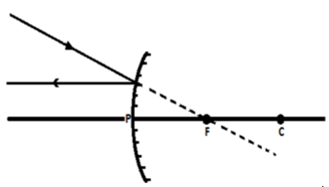
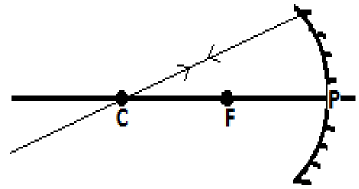
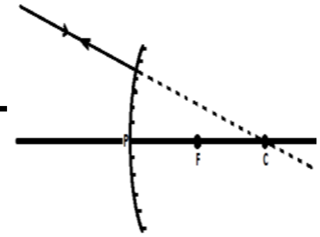
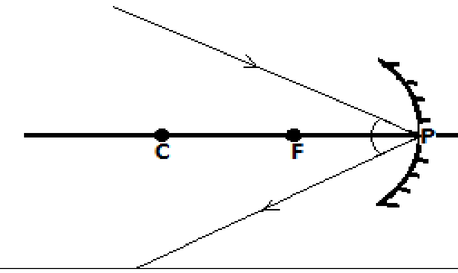
Uses of concave mirror

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

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

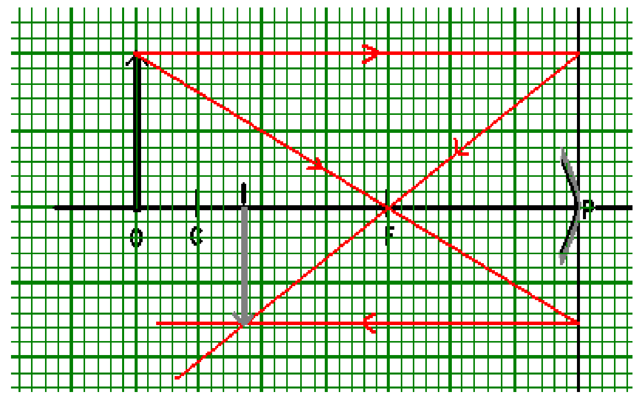
N.B Caustic curve is an illusory curve that is seen to touch the reflected rays when a wide parallel beam of light falls on a concave mirror.

Useful rays used in construction of ray diagrams.

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

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

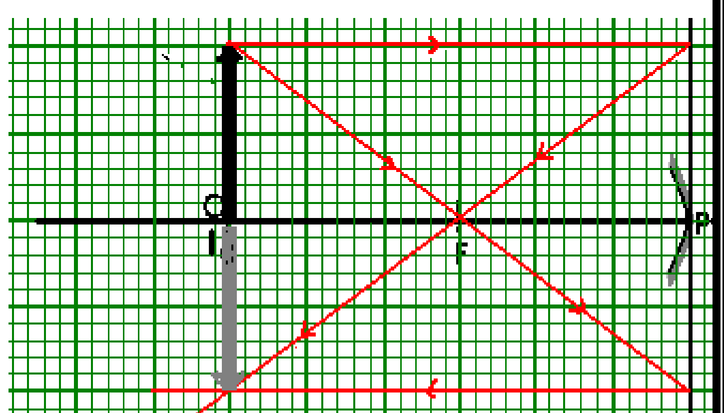
(i) Object, O beyond the center of curvature, C.



The image, I formed is;

- ❖ Position: Between F and C
- ❖ Nature : Real and Inverted
- ❖ Size : Diminished

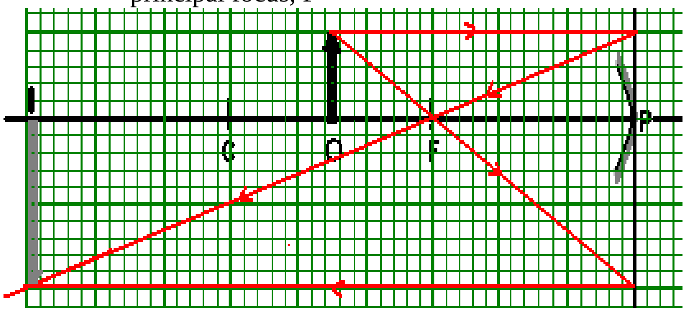
(i) Object, O at centre of curvature, C.



The image, I formed is;

- Position: At C
- Nature : Real and Inverted
- Size : Same size as the object

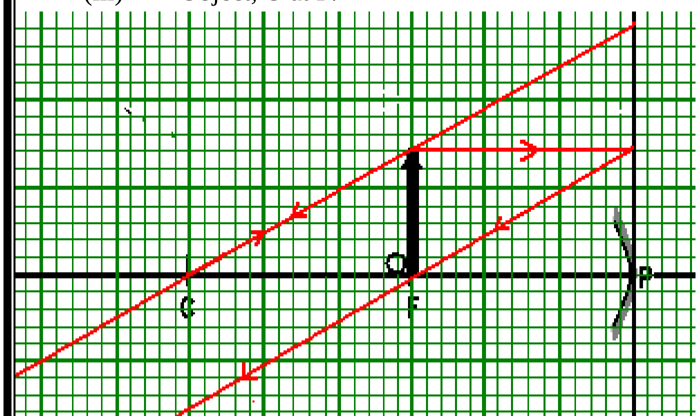
(ii) Object, O between centre of curvature, C and the principal focus, F



The image, I formed is;

- Position: Beyond C
- Nature : Real and Inverted
- Size : Magnified

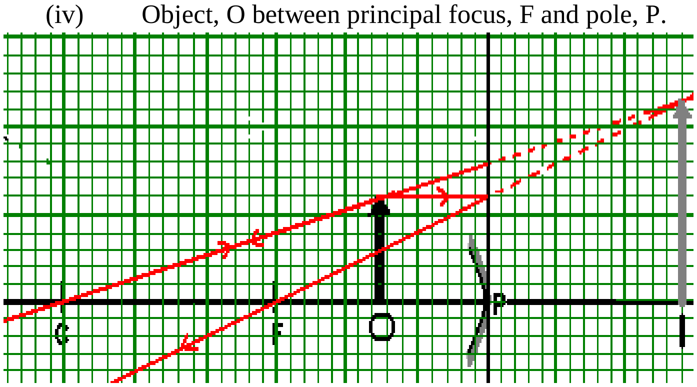
(iii) Object, O at F.



The image, I formed is;

- Position: At infinity
- Nature : Real and Inverted

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



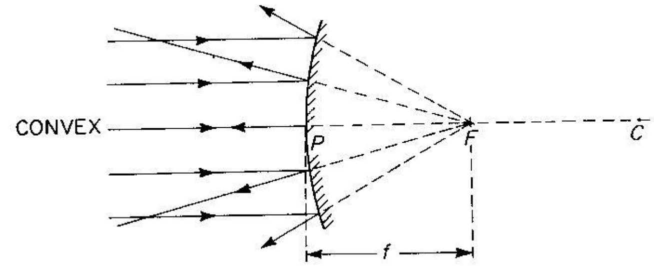
The image, I formed is;

- Position: Behind the mirror
- Nature : Virtual and Upright (erect)
- Size : Magnified

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

CONVEX MIRROR

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



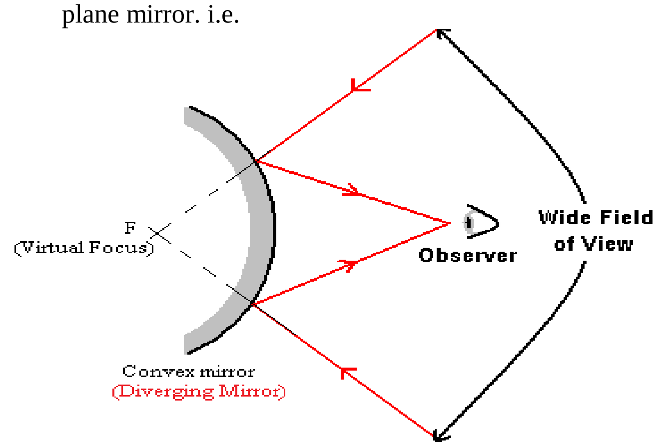
Uses of convex mirror

Convex mirrors are used as;

i) security mirrors in supermarket
ii) driving mirrors

This is **because** a convex mirror;

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

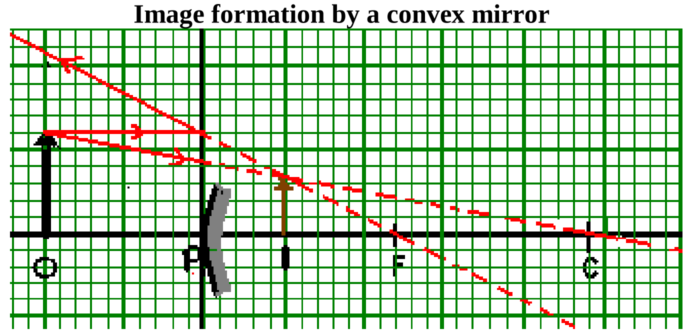


Disadvantage of convex mirrors:

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

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

Image formation by a convex mirror



Characteristics of the image, I formed by convex mirror.
Irrespective of the position of the object, the images formed in convex mirrors are;

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

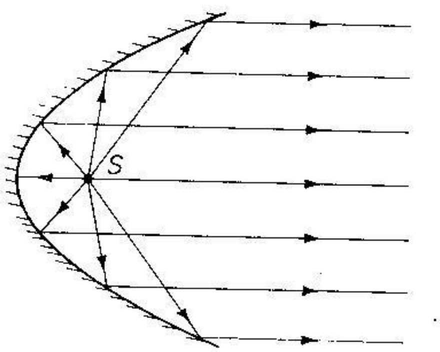
NOTE: 1. Magnified images are the images which are larger than the objects.
2. Diminished images are the images which are smaller than the objects.

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

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

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

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



Magnification
Definition:
Magnification is defined as;

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

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

- ❖ The ratio of image distance to object distance.

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

- ❖ The ratio of image height to object height.

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

Construction of accurate ray diagrams on graph paper

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

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

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

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

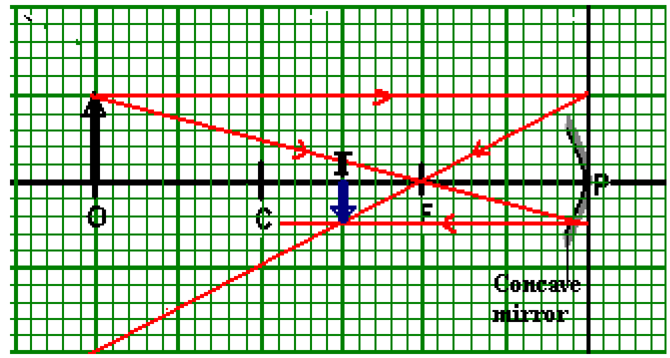
Step 5: Measure the position (distance) and the size (height) of the image and multiply by the corresponding scale.

Example 1:
An object of height 10cm is placed at a distance of 60cm from a concave mirror of focal length 20cm. Find by scale drawing the;

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

Solution

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



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

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

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

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

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

Magnification:

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

Or

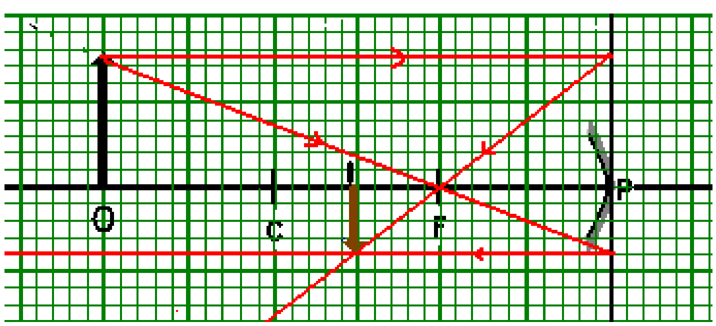
$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{5}{10} = 0.5$$

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

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

Solution

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



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

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

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

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

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

(iii) Magnification:

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

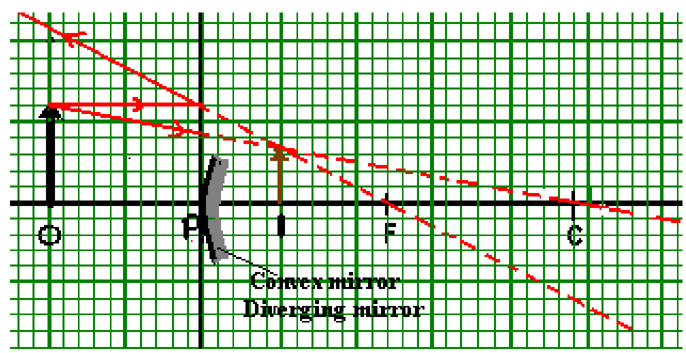
Or

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

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

Solution
Let 5 cm be represented by 1 cm

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



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

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

The image 5.0cm behind the mirror.

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

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

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

(iii) Magnification:

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

Magnification and the image size of the object.

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

THE MIRROR FORMULA

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

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

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

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

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

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

Example 1:
An object is placed 20cm in front of a concave mirror of focal length 12cm. Find the nature and position of the image formed.
Solution
u = 20cm; f = 12cm ; v = ?

Using the mirror formula;

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

$$\frac{1}{12} = \frac{1}{20} + \frac{1}{\mathrm{v}}$$

$$\frac{1}{12} - \frac{1}{20} = \frac{1}{\mathrm{v}}$$

$$\frac{1}{\mathrm{v}} = \frac{5-3}{60} = \frac{2}{60} = \frac{1}{30}$$

$$\frac{1}{\mathrm{v}} = \frac{1}{30}$$

$$\mathrm{v} = 30 \text{ cm}$$

A real image was formed 30cm from the mirror on the same side as the object.

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

Using the mirror formula;

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

$$\frac{1}{15} = \frac{1}{20} + \frac{1}{\mathrm{v}}$$

$$\frac{1}{15} - \frac{1}{20} = \frac{1}{\mathrm{v}}$$

$$\frac{1}{\mathrm{v}} = \frac{4-3}{60} = \frac{1}{60}$$

$$\frac{1}{\mathrm{v}} = \frac{1}{60}$$

$$\mathrm{v} = 60 \text{ cm}$$

A real image was formed 60cm from the mirror on the same side as the object.

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

Using the mirror formula;

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

$$\frac{1}{-10} = \frac{1}{15} + \frac{1}{\mathrm{v}}$$

$$\frac{1}{-10} - \frac{1}{15} = \frac{1}{\mathrm{v}}$$

$$\frac{1}{\mathrm{v}} = \frac{-3-2}{30} = \frac{-5}{30}$$

$$\frac{1}{\mathrm{v}} = \frac{-1}{6}$$

$$\mathrm{v} = -6 \text{ cm}$$

A virtual image was formed 6 cm from the mirror on the opposite side as the object.(i.e behind the convex mirror)

Example 4:
A convex mirror of focal length 18cm produces an image of on its axis 6cm from the mirror. Calculate the position of the object.
Solution
u =?; f = -18cm (for convex mirror); v = -6cm

Using the mirror formula;

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

$$\frac{1}{-18} = \frac{1}{\mathrm{u}} + \frac{1}{-6}$$

$$\frac{1}{-18} + \frac{1}{6} = \frac{1}{\mathrm{u}}$$

$$\frac{1}{\mathrm{u}} = \frac{-1+3}{18} = \frac{2}{18} = \frac{1}{9}$$

$$\frac{1}{\mathrm{u}} = \frac{1}{9}$$

$$\mathrm{u} = 9 \text{ cm}$$

A real object was 9cm in front of the convex mirror.

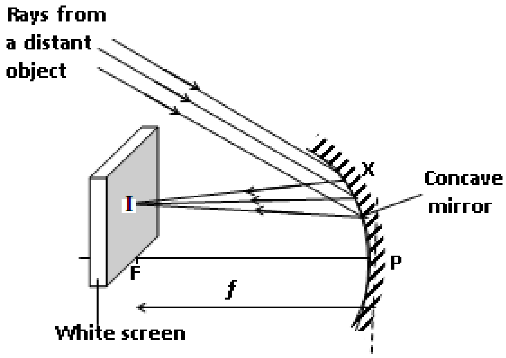
Exercise

1. Find the distance of the image from the concave mirror of focal length 10cm if the object is 5cm from the mirror.
2. A concave mirror of focal length 15cm has an object placed 25cm from it. Find the position and nature of the image.
3. An object is 32cm in front of a convex mirror of focal length 16cm. Describe the image and give its position.
4. When an object is 42cm from a concave mirror, the object and the image are of the same height. What is the focal length of the mirror?

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

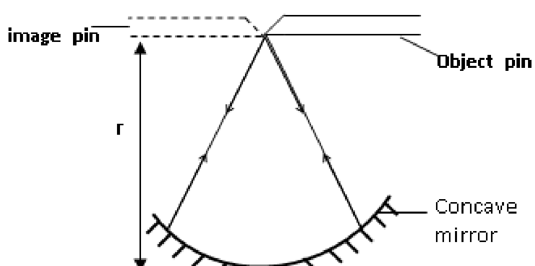
NOTE: Currently, the use of the mirror formula and lens formula is out of the O- level syllabus. Therefore students are encouraged to practice the use of accurate ray diagram (graphical) method to find the position of images and objects or the focal length of the mirror.

Determining the focal length of Concave mirrors
i) Focusing distant object (Approximate Method)



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

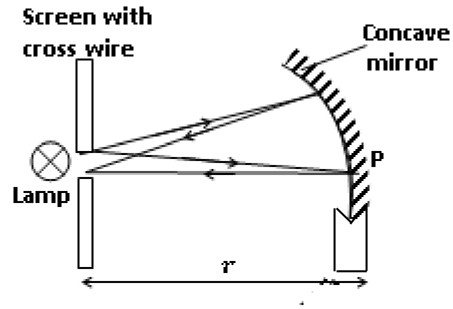
ii) **By determining first the radius of curvature.**
(Self conjugate method) or the no parallax method.



A concave mirror is placed horizontally on a bench. An optical pin is clamped horizontally on a retort stand so that the tip lies along the principal axis of the mirror.
The position of the pin is adjusted until the position is obtained where it coincides with its image and there is no parallax between the two, i.e. there is no relative motion between the object and the image when the observer moves the head from side to side or up and down.
The distance r of the pin from the pole is measured and focal length determined,

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

iii) Using an illuminated object at C



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

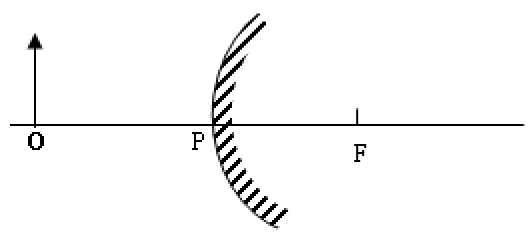
$$\boldsymbol{f} = \frac{\boldsymbol{r}}{2}$$

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

Exercise: See UNEB Paper I:
1.

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

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



(b) State two applications of convex mirrors.

3. UNEB 1997 Paper 2 Qn. 4
(c) An object 10cm high is placed at a distance of 25cm from a convex mirror of focal length 10cm.
(i) Draw a ray diagram to locate the position of the image.
(ii) Calculate the magnification.
(d) State the reasons for use of convex mirrors in vehicles.

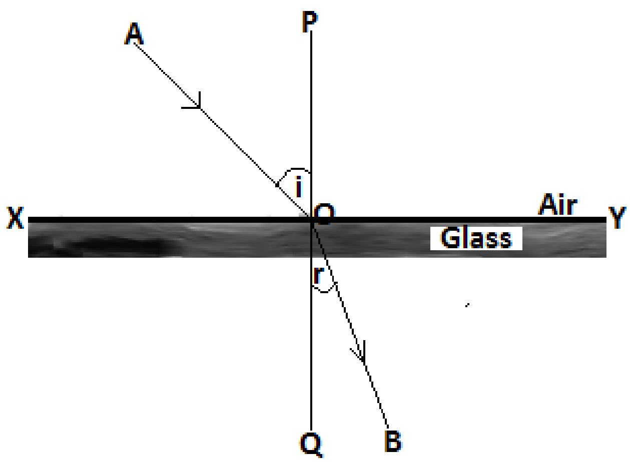
4. UNEB 2002 Paper 2 Qn. 5
(c) With the aid of a diagram, explain why a parabolic mirror is most suitable for use in car head lights.
(d) List **three** uses of concave mirrors

REFRACTION OF LIGHT

Definition:
Refraction is the bending of light ray(s) as it passes from one transparent medium to another of different densities.

Refraction is the change in speed of propagation of light due to change in optical density.
When light propagating in free space is incident in medium, the electrons and protons interact with the electric and magnetic fields of the light wave. This result in the slowing down of a light.

Illustration.



Refraction occurs because light travels at different speed in the different media.

Description

(a) **Rays and lines**

Ray AO is called incident ray.
This is the ray that fall/strikes the boundary at the normal in the first medium.

Ray OB is called the refracted ray.
Refracted ray is the ray that leaves the boundary at the normal in the second medium and o the opposite side of the incident ray.

Line PQ is called the normal.
The normal is an imaginary line at right angle to the boundary and separates the incident ray and the refracted ray.

Line XY is called the boundary.
The boundary is the line that separates the two media. It is the line where refraction occurs.

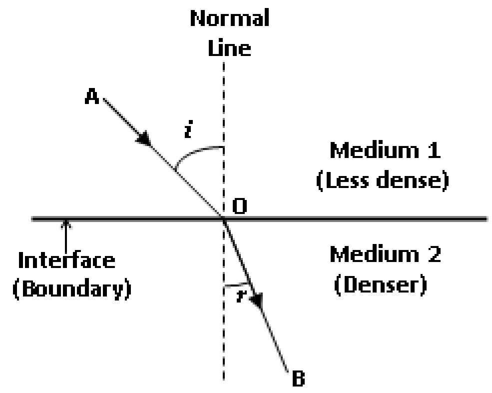
(b) **Angles**

Angle, i is the angle of incidence.
This is the angle formed between the incident ray and the normal.
Angle, r is called angle of refraction.
The angle of refraction is the angle formed between the refracted ray and the normal.

NOTE: The light ray is refracted towards the normal when it travels from a less dense medium to a denser medium and then refracted away from the normal if it travels from a denser medium to a less dense medium.

Principle of Reversibility of light
It states that if a light ray (path) after suffering a number of refractions is reversed at any stage, it travels back to the source along the same path with the same refraction.

Law of refraction
When light passes from one medium to another, say from air glass part of it is reflected back into the previous medium and the rest passes through the second medium with its direction of travel changed.



AO = **Incident ray**

i = **Angle of incidence**

OB = **Refracted ray**

r = **Angle of refraction**

Generally, if light is incident from a less dense medium, to a more optically dense medium, its speed reduces and it is refracted towards the normal at the point of incidence.
However, if light travels from a denser to a less dense medium, its speed increases and it is refracted away from the normal.

Laws of Refraction
Law 1. The incident ray, refracted ray and the normal at point of incidence all lie on the Same plane.

Law 2. For any two particular media, the ratio of the sine of angle of incidence to sine of angle of refraction is constant.

i.e.$\frac{\sin i}{\sin r} = \textbf{aconstant}(\cap)$

The constant ratio $\frac{\sin i}{\sin r}$ is called the refractive index for light passing from the first to second medium.

Hence; ${}_1\cap_2 = \frac{\sin i}{\sin r}$

Definition:
Refractive Index is the ratio of sine of angle of incidence to the sine of angle of refraction for a ray of light traveling from one medium to another of different densities. i.e.
If light travel from air to glass, then the refractive index of glass with respect to air is given by;

$$_{air}\cap_{glass} = \frac{\sin i}{\sin r}$$

It can also be defined as the ratio of the speed of light in one medium to the speed of light in another medium.

$$\text{Hence; } {}_1\cap_2 = \frac{v_1}{v_2} = \frac{\text{Speed of light in medium 1.}}{\text{Speed of light in medium 2}}$$

If medium 1 is a vacuum, we refer to the ratio as the **absolute refractive index of medium 2**, denoted by **n_2**.

If medium 1 is a vacuum, then;

$$\cap_2 = \frac{C}{v_2} = \frac{\text{Speed of light in vacuum.}}{\text{Speed of light in medium 2}}$$

$$Where, \boldsymbol{C} = 3.0 \times 10^8 \boldsymbol{ms}^{-1}$$

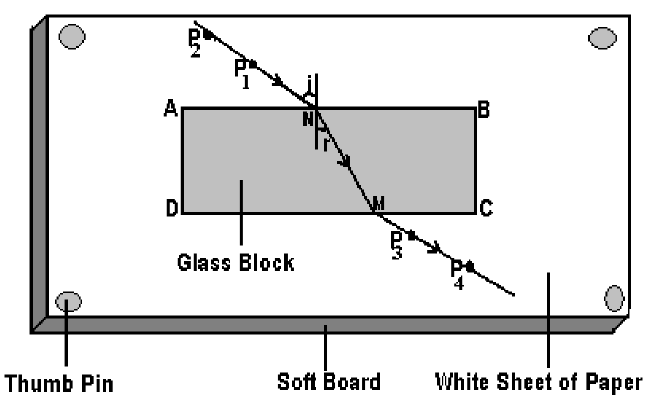
Note: For practical purposes, $\cap_{\mathbf{Vacuum}} = \cap_{\mathbf{Air}} = 1$

DETERMINATION OF REFRACTIVE INDEX

Apparatus:

- Rectangular Glass Block
- Four Optical Pins and 4 thumb pins
- Soft Board
- White Sheet of Paper
- Mathematical Set

Set up



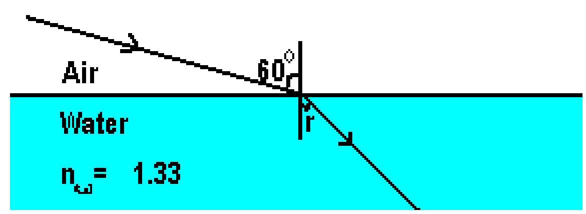
Procedure
a) Place the rectangular glass block on the white sheet of paper stuck on the soft board.
b) Trace the outline of the glass block on the white sheet of paper.
c) Remove the glass block and draw a normal at N.
d) Using a protractor, measure from the normal the angle of incidence, i = 20° to draw the incident ray of the angle measured and pin two optical pins P_1 and P_2 on the ray drawn.
e) Replace the glass block back to its outline and aim from face DC to fix pins P_3 and P_4 such that they appear to be in line with the images of P_1 and P_2.
f) Remove the glass block and draw a line through P_3 and P_4 to face DC.
g) Draw a line from normal to meet the line trough P_3 and P_4 to measure the angle of refraction, r.
h) Repeat the procedure d) to g) for i = 30°, 40°, 50°, 60° and 70°.
i) Tabulate your result in a suitable table including values of sin i and sin r.
j) Plot a graph of sin i against sin r and determine the slope n of the graph.

Conclusion

- The graph sini against sinr is a straight line this verifies Snell's law.
- The slope of the graph is the refractive index of the glass block.

Example 1:
A ray of light travels from air into water at angle of incidence of 60°. Calculate the angle of refraction given that the refractive of water is 1.33.

Solution
Given; i = 60° n = 1.33 r = ?
Ray Diagram



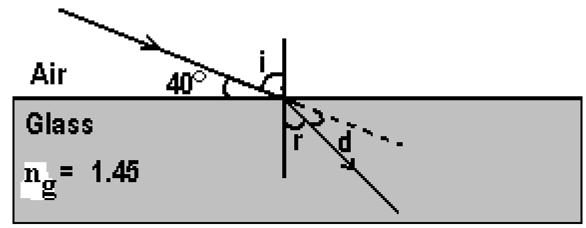
From Snell's law

$$\cap_{air}\sin i_{air} = \cap_{water}\sin i_{water}$$
$$1 \sin 60 = 1.33 \sin r$$
$$\sin r = \left(\frac{0.866}{1.33}\right)$$
$$r = \sin^{-1}\left(\frac{0.866}{1.52}\right)$$
$$r = 41.7^0$$

Example 2:
A ray of light traveling through air strikes glass at an angle of 40° to the surface. Given that the refractive index of glass is 1.45, find the;

(i) Angle of refraction
(ii) Angle of deviation (angle through which the ray is bent from its original direction).

Solution
Given; ϴ = 40° n = 1.45 r = ?
Ray diagram

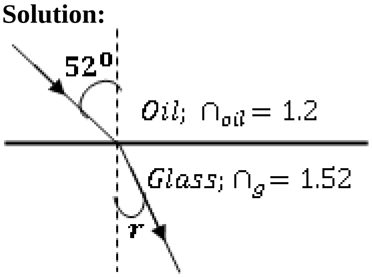


Where; r = angle of refraction
d = angle of deviation

From the angle properties $40^0 + i = 90^0$ $i = 90^0 - 40^0$ $i = 50^0$ From Snell's law $\cap_{air} \sin i_{air} = \cap_{water} \sin i_{water}$ $1 \sin 50 = \quad 1.45 \sin r$ $\sin r = \left(\frac{0.766}{1.45}\right)$ $r = \sin^{-1}\left(\frac{0.766}{1.45}\right)$ $r = 31.9^0$	Angle of deviation, d *From the diagram,* $r + d = i$ $31.9^0 + d = 50^0$ $d = 18.1^0$

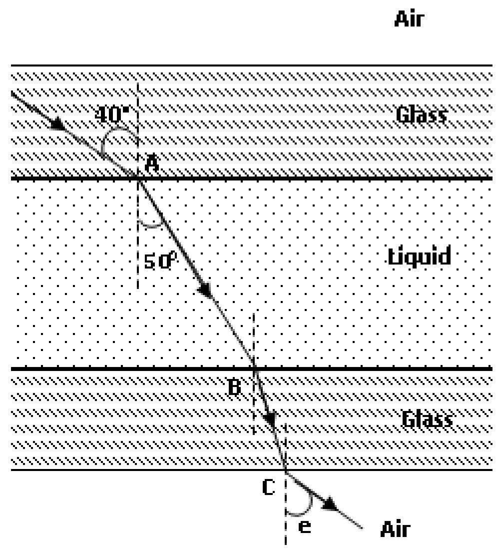
Examples 3:
If the angle of incidence in oil is52^0, find the angle of refraction in glass for a ray of light travelling from oil to glass. ($\cap_{oil} = 1.2$ and $\cap_{glass} = 1.52$)

Solution:



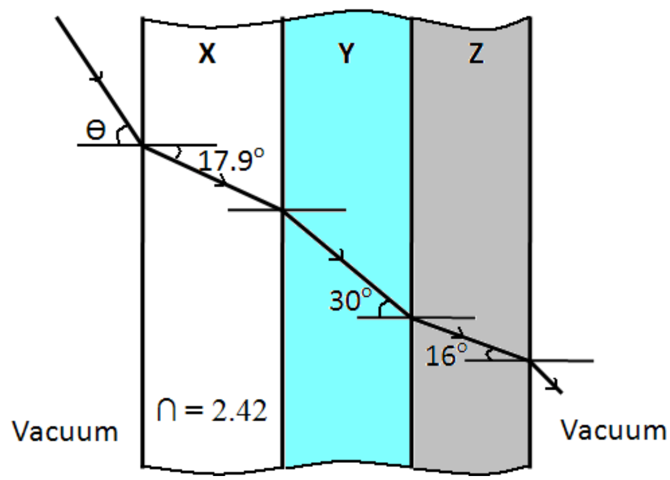
Using Snell's law;
$\cap \sin i = \text{constant}$
$\cap_{oil} \sin i_{oil} = \cap_{glass} \sin i_{glass}$
$1.2 \sin 52 = \quad 1.52 \sin r$
$\sin r = \left(\frac{0.9456}{1.52}\right)$
$r = \sin^{-1}\left(\frac{0.9456}{1.52}\right)$
$r = 38.47^0$

Examples: 4
The diagram bellow shows a liquid sandwiched between two glass slabs of refractive index 1.5. A ray of light begins from the upper glass slab and it latter emerges into air.



Find the;
(i) Refractive index of the liquid.[$n_L = 1.26$]
(ii) Angle of emergency in air. [e = 74.6^0]

Example 5:
White light was observed to travel from vacuum through multiple boundaries of transparent media X, Y and Z, parallel to each other as shown below. Calculate the;
(i) Angle Ɵ
(ii) Refractive index of Y
(iii) Speed of light in X
(iv) Refractive index of Z with respect to X



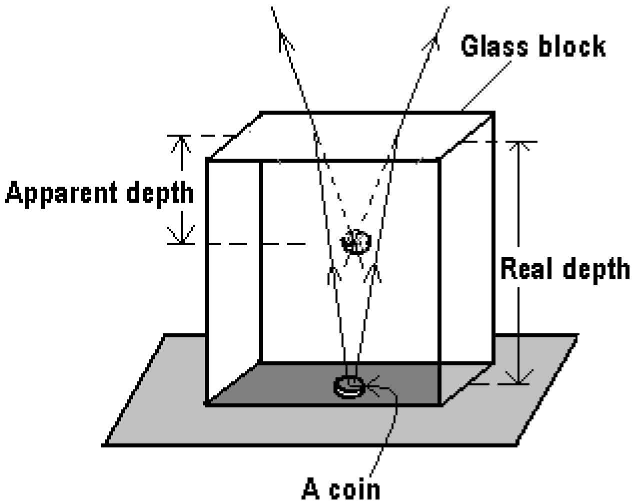
Real and Apparent Depths

Real depth
Real depth is the depth where the object is actually placed or laying under the transparent medium of different optical density to the surrounding medium. i.e. Real depth is the actual height of the medium in its desired dimension.

Apparent depth
Apparent depth is the depth where the object appears to be when observed through the transparent medium of different optical density to the surrounding medium.

The real and apparent depth of an object viewed through a transparent material can be used to determine the refractive index of the transparent material.

Illustration of real depth and apparent depth

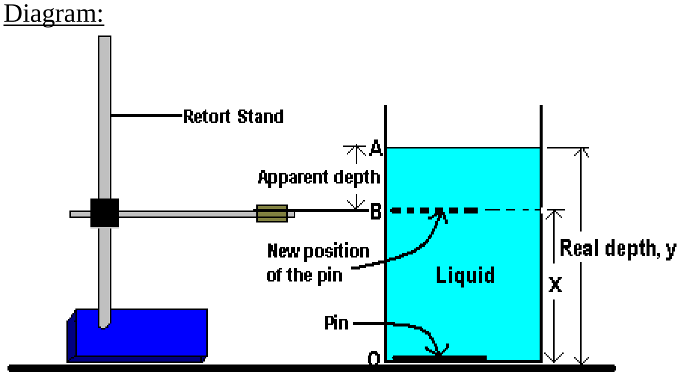


Determination of refractive index of Liquid using real depth and apparent depth.

Apparatus:

Beaker, Retort stand, Pins, Liquid, Half metre rule

Diagram:



Procedure:

Pour liquid in a beaker and measure the height, y (real depth) of the liquid in the beaker

Place a pin at the bottom of the beaker with its point touching the side of the beaker.

Support another pin on the clamp at the side of the beaker using plasticine.

Observe from the edge of the beaker and adjust the pin on the clamp until it appears to be on the same level with the pin in the beaker.

Now measure the height, x from the bottom of the beaker where the pin in liquid appears to determine the apparent.

Divide the real depth of the pin in liquid by the apparent depth of the same pin to determine the refractive index, n of the liquid.

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{y}{y - x}$$

Example: 1

A pin placed at the bottom of the liquid appears to be at a depth of 8.3 cm when viewed from above. Find the refractive index of the liquid if the real depth of the liquid is 11 cm.

Solution

Given, Real depth = 11 cm

Apparent depth = 8.3 cm

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{11}{8.3}$$

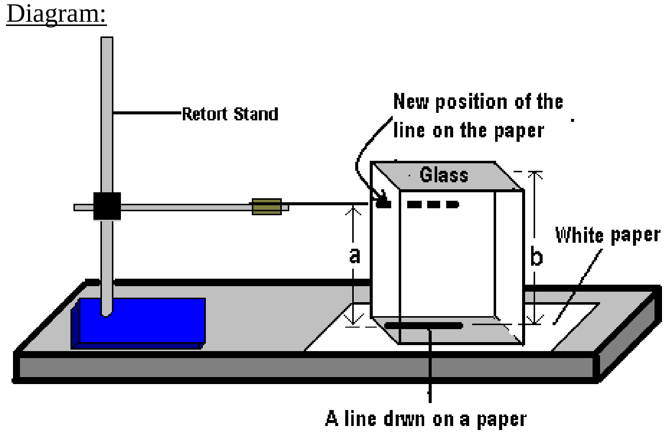
$$n = 1.33$$

Determination of refractive index of glass using real depth and apparent depth.

Apparatus:

Glass block, Retort stand, optical Pin, White sheet of paper Half metre rule

Diagram:



Procedure:

Draw a line on a white sheet of paper and place a glass block a above it as shown.

Look down at the edge of the glass perpendicular to the tip of the line drawn on the paper.

Adjust the search pin on the clamp until it is at the same level as the line drawn on the paper. Ensure no parallax i.e. the pin and the image of the line should appear to be one on moving the head to and fro the line of observation.

Measure the distance, a and b respectively to determine the apparent depth of the line

Refractive index of the glass block is then obtained from;

$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{b}{b - a}$$

Example: 2

A glass block of height 9 cm is placed on a coin of negligible thickness. The coin was observed to be at 3 cm from the bottom of the glass block when viewed from above. Find the refractive index of the glass.

Solution

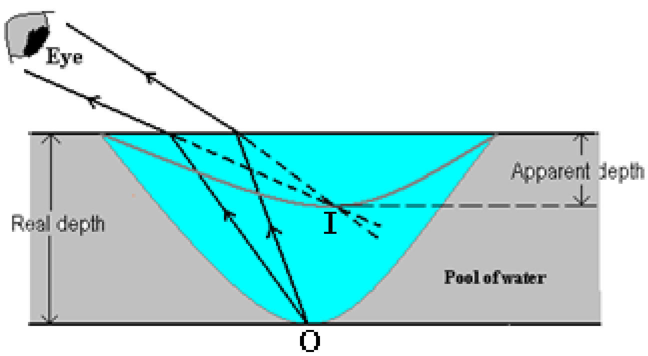
$$\text{Refractive index, n} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

$$n = \frac{9}{9-3} = \frac{9}{6}$$

$$n = 1.5$$

Effects of refraction:

(i) <u>A swimming pool appears shallower that its actual depth</u>

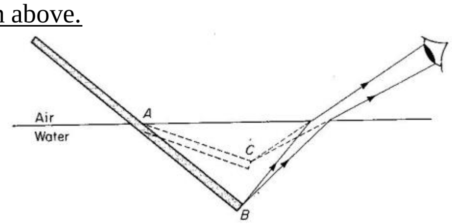


Explanation

This is because light rays from the bottom are refracted away from the normal at the water to air boundary.

These rays appear to come from the point I not O, so at the point I the pool appear shallower than it is.

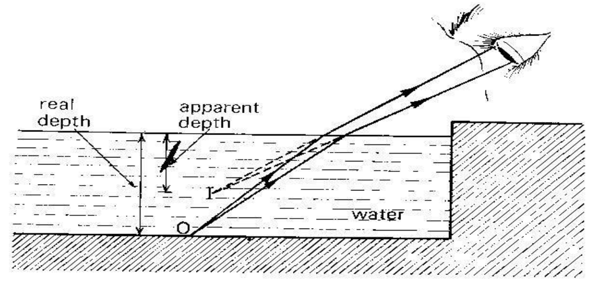
(ii) <u>A ruler placed in a glass of water appears bent when viewed from above.</u>



Explanation

Rays of light from the point V of the ruler pass from water to air and are bent away from the normal as it emerges to the less dense medium. As it enters the eye, it appears to be coming from the point I above V.

(iii) <u>A coin or even written mark placed at the bottom of water in a beaker or basin appears to be on top when viewed from above.</u>



Explanation

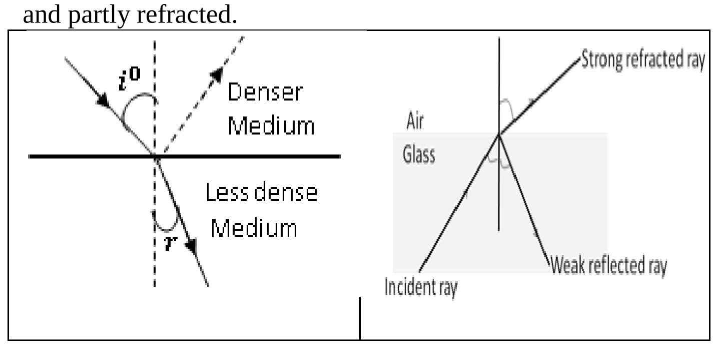
This is due to refraction of light from the coin at O. As light passes through the water to air boundary, the ray is refracted away from the normal in air and appear to be originating from the point I (apparent depth) above the actual point O (Real depth) at the bottom of the container.

This effect and explanation is also factual for an object or mark under other medium like glass block and even glass prism.

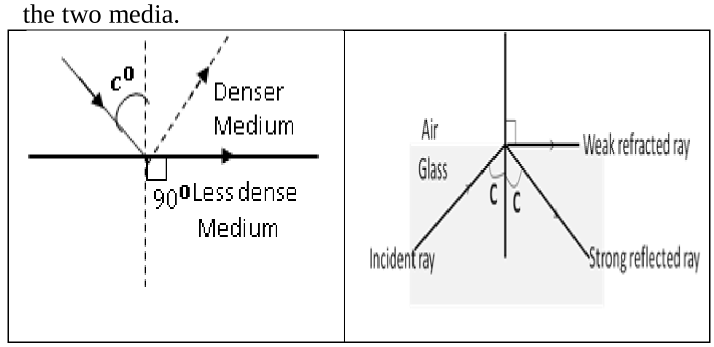
(iv) <u>Twinkling of the stars in the sky at night.</u>

TOTAL INTERNAL REFLECTION AND CRITICAL ANGLE

Consider monochromatic light propagating from a dense medium and incident on a plane boundary with less dense medium at a small angle of incidence. Light is partly reflected and partly refracted.



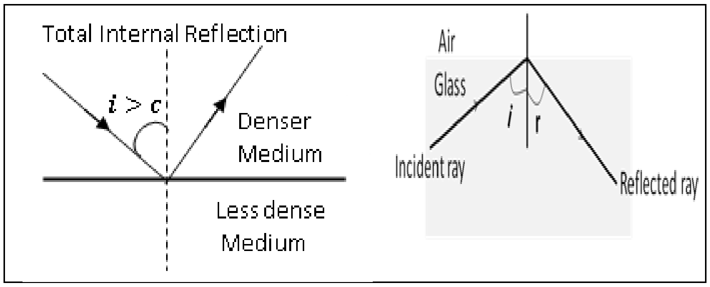
As the angle of incidence is increased gradually, a stage is reached when the refracted ray grazes the boundary between the two media.



The angle of incidence **c** is called the <u>critical angle.</u>

Hence **critical angle** is the angle of incidence in a denser medium which makes the angle of refraction in a less dense medium 90°.

When the angle of incidence is increased beyond the critical angle, the light is totally internally reflected in the denser medium. Total internal reflection is said to have occurred.



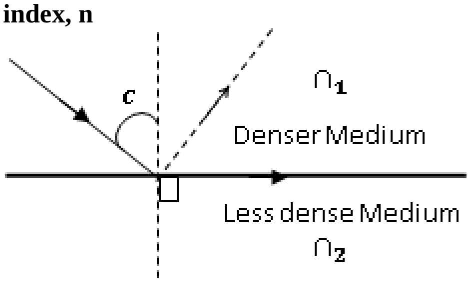
Hence **Total Internal Reflection** is the process where all the incident light energy is reflected back in the optically denser medium when the critical angle is exceeded.

Conditions for Total Internal reflection to occur.

(i). Light must be moving from an optically denser medium (e.g glass) to a less dense medium (e.g air).

(ii). The angle of incidence in the optically denser medium must exceed (greater than) the critical angle. **[$i > c$].**

Relationship between critical angle, c, and refractive index, n



Using Snell's law:

$\cap_1 \sin i_1 = \cap_2 \sin r_2$

$\cap_1 \sin c = \cap_2 \sin 90$

$$\sin c = \frac{\cap_2}{\cap_1}$$

If the lens dense medium is air or a vacuum;

$$\mathbf{\sin c} = \frac{1}{\cap_1}$$

Calculation involving critical angle and refractive index

At critical angle, the angle of refraction is 90° i.e. r = 90°. And the ray is from more optically dense medium i.e glass to a less optically dense medium i.e. air. So,

From Snell's Law:

$\cap_g \sin i_g = \cap_{air} \sin r_{air}$

$\cap_g \sin C = \sin 90^o$; But $\sin 90^o = 1$

$\cap_g \sin C = 1$

$$\cap_g = \frac{1}{\sin C}$$

Where $\cap_g =$ Refractive index of the glass and C is the critical angle.

Example: 1

Calculate the refractive index of the glass if the critical angle of the glass is 48°.

SOLUTION:

Give; C = 48o , $\cap_g = ?$

$From; \cap_g = \frac{1}{sin\mathbf{C}}$

$\cap_g = \frac{1}{sin 48^o}$

$\cap_g = \frac{1}{0.669}$

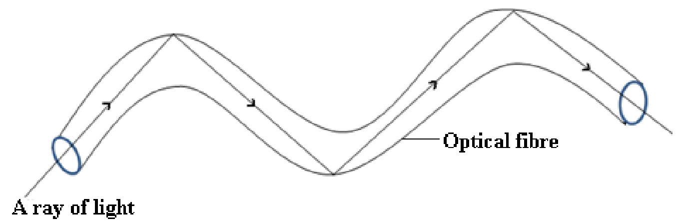
$\cap_g = 1.5$

Applications of total internal reflection

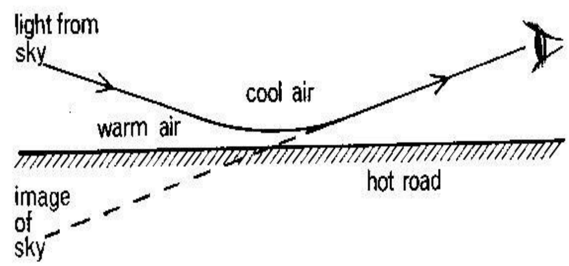
(i) Light pipes and Optical fibres

Light can travel and can be trapped by total internal reflection inside a bend glass tube and pipe along a curved path.

If several thousand rays are trapped together, a flexible light pipe is obtained that can be used to light up some awkward spot for inspection.



(ii) Mirage



Explanation

✓ Gradual refraction:

On a hot day light from the sky is gradually refracted away from the normal as it passes through layers of warm but less dense air near hot road.

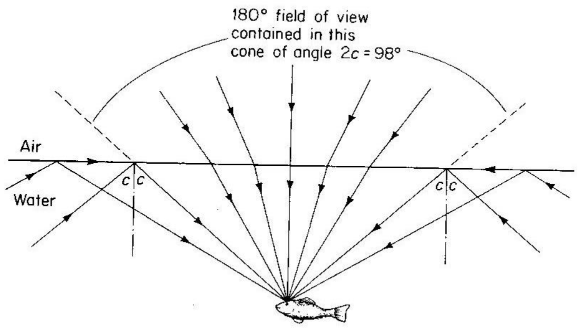
✓ Total internal reflection:

The refractive index of warm air is slightly smaller than that of cool air, so when light meets a layer at critical angle, it suffers total internal reflection thus to the observer the road appears to have a pool of water.

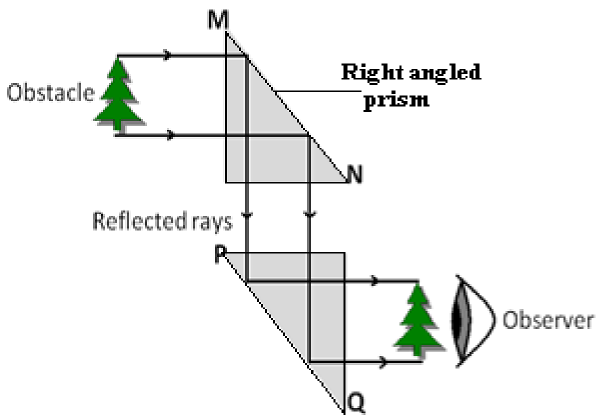
(iii) Fish's view:

The fish in water enjoys a wider field of view in that it views all objects under water and those above the water surface

Objects above the water surface are viewed as a result of refraction while those under the water surface are viewed as a result of total internal reflection. However this is only true if the water surface is calm.



(iv) Submarine periscope:

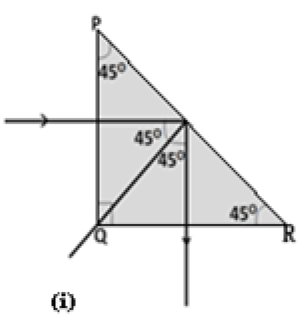


Light from a distant object meets the surface MN at 45°; so light is totally internally reflected downwards.

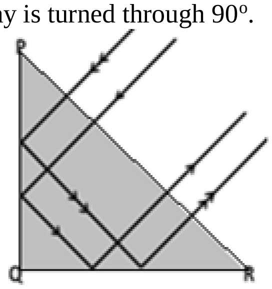
The reflected light is incident to the surface PQ where it is totally internally reflected to give the emergent light to the observer.

(v) Totally reflecting prism

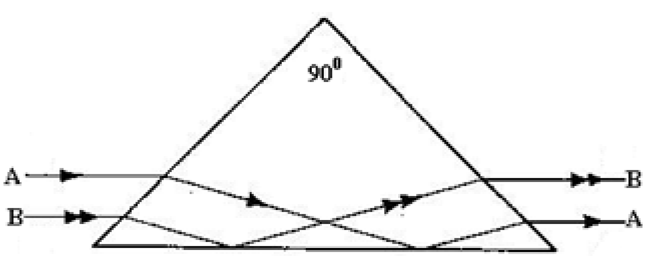
The critical angle of a glass prism is **42°** and a ray is normally incident on face PQ thus un deviated i.e. not refracted. Total internal reflection occurs and a ray is turned through 90°.



(i)



(ii) Turning a ray through 90^0



(iii) Turning a ray through 180^0

The critical angle of glass is 42° and rays are incident normally on face PR. At face PQ, the rays are incident at 45° so total internal reflection occurs.

The use of prisms are preferred to plane mirror

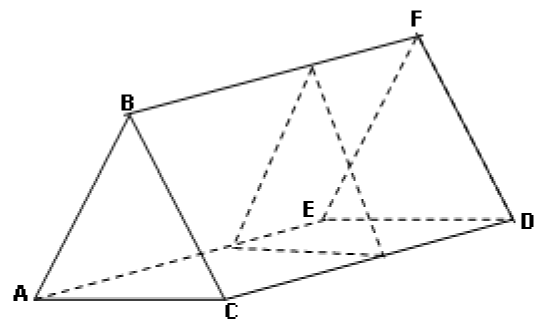
- ✓ Prisms produce clear image
- ✓ Prisms do not tarnish and deteriorate as mirror.

However, plane mirrors are not used in submarine periscope because:

- Several images of one object are formed at the back by plane mirror due to multiple reflection inside the glass i.e. plane mirror produces blurred images.
- Plane mirrors absorbs more light than prisms so the image produced is fainter.

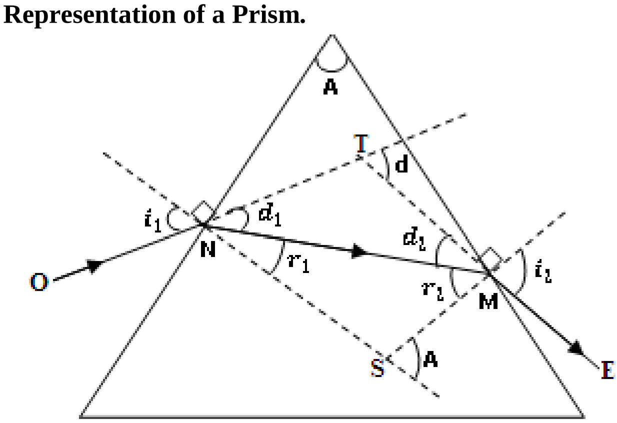
REFRACTION THROUGH A TRIANGULAR PRISM

Refraction by glass prism



BF= Refracting edge
AB and BC = Refracting surface
AC and ED = Base
ABC and DEF = Principle section (or any other plane perpendicular to the refracting edge).
Angle ABC = Refracting angle or angle of the prism.

Representation of a Prism.



Rays: ON = Incident ray; Angle i_1 = angle of incidence
NM = Refracted ray; Angle r_1 = angle of refraction
ME = Emergent ray; Angle i_2 = angle of emergence
Lines: NS and MS = Normal lines on either sides.
Angle A = angle of the prism or refracting angle.

Deviation of light by a prism

Considering Deviation at N,

$i_1 = r_1 + d_1 \Leftrightarrow d_1 = i_1 - r_1 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (i)$

Considering Deviation at M,

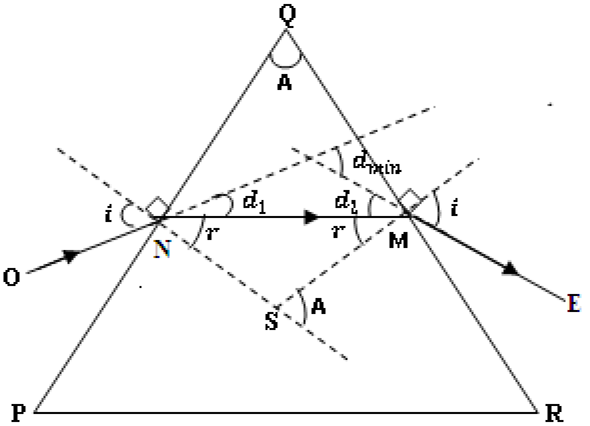
$i_2 = r_2 + d_2 \Leftrightarrow d_2 = i_2 - r_2 \dots\dots\dots\dots\dots\dots\dots\dots\dots\dots (ii)$

From Triangle NMT:
$d = d_1 + d_2$ … ....(iii)
Putting equations (i) and (ii) into Equation (iii) gives:
$d = (i_1 - r_1) + (i_2 - r_2)$
$d = (i_1 + i_2) + (-r_1 - r_2)$
$d = (i_1 + i_2) - (r_1 + r_2)$ .... … … … … … … … … … … … … ….(iv)

From Triangle NMS:
$A = r_1 + r_2$ … … … … … … … … … … … … … … … … … .. … . … (v)
$\boldsymbol{d = (i_1 + i_2) - A}$ … … … … … … … … … … .. … … … .... … (vi)

Minimum Angle of Deviation

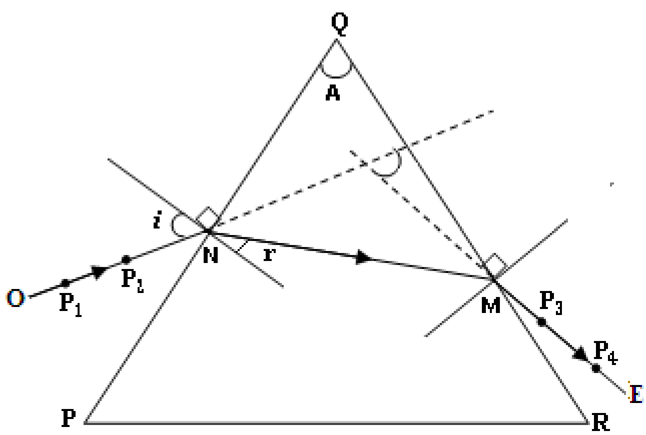
Definition: is the smallest angle to which angle of deviation decreases when the angle of incidence is gradually increased.



Condition for minimum deviation position:

- ✓ Ray of light MN in the prism is parallel to the base of the prism.
- ✓ Incidence angle and emergency angles are equal.
- ✓ Light passes symmetrically rough the prism.
  The angle of incidence, i = angle of emergency, e

Experiment to measure the refractive index of a triangular glass prism.



✓ Outline of the prism

The prism is placed on a paper and its outline ABC is drawn and then the prism is removed. Draw the normal at M and measure the angle of incidence, i. Place the pins P_1 and P_2 on the incident ray.

✓ Obtaining the refracted ray.

Replace the prism to its outline. By looking through the prism from side QR, pins $\mathbf{P_3}$ and P_4 are placed such that they are in a straight line with images of P_1 and P_2 in the prism.
Draw a line to join point N to M from which the angle of refraction on AC is measured.

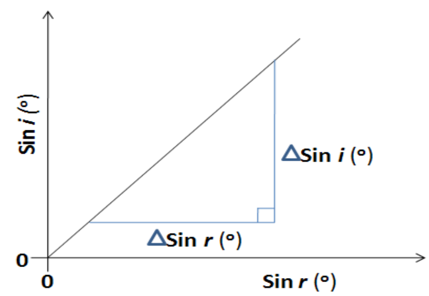
✓ Repeating the procedures and tabulating the results

Repeat the procedures for different values of i and obtain different values of r.
Record the results in a suitable table including values of sin i and sin r as shown below
Table of result:

$i(^0)$	$r(^0)$	Sini	Sinr

✓ Plotting the graph

Plot a graph of sin i against sin r to determine the slope of the graph. Slope is the refractive index of the prism.



Note: For a light ray travelling in a medium like water to glass, then the refractive index of glass with respect to water is calculated from:

$$_w\cap_g = \frac{\cap_g}{\cap_w} = \frac{\sin r_2}{\sin i_2}$$

In general, the refractive index of any medium X with respect to another first medium Y is given by:

$$_Y\cap_X = \frac{\cap_X}{\cap_Y}$$

Where; $\cap_X =$ refractive in dex of X
$\cap_Y =$ refractive index of Y
For calculation, your are required to use;

$$\cap_Y \sin i_Y = \cap_X \sin r_X$$

Example 1:

A ray of light is incident on water – glass boundary at 41o. Calculate r if the refractive indices of water and glass are 1.33 and 1.50 respectively.

Solution:

Given; $\cap_g = 1.5$, $\cap_w = 1.33$, $\mathbf{i_w} = 41^o$ and $\mathbf{r_g} = ?$

From ;$\cap_Y \sin i_Y = \cap_X \sin r_X$

$\cap_w \sin i_w = \cap_g \sin r_g$

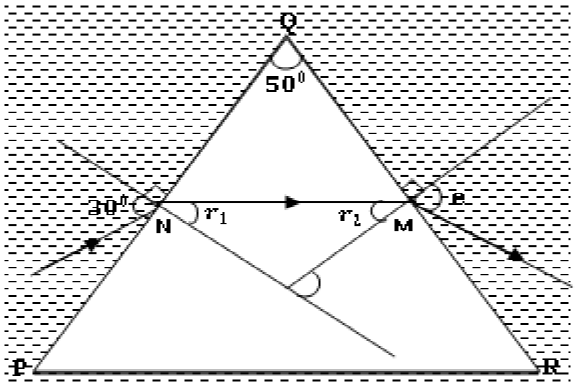
$1.33 \sin 41^o = 1.50 \sin r$

$$\sin r = \frac{1.33\sin 41^o}{1.50}$$

$$r = \sin^{-1}\left(\frac{1.33\sin 41^o}{1.50}\right)$$

$$r = 35.5^o$$

Example:1
A ray of light propagating in a liquid is incident on a prism of refractive angle 50^0 and refractive index 1.6, at an angle of 30^0 as shown below.



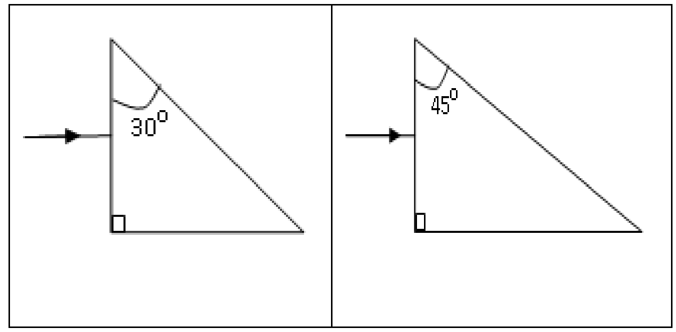
If light passes through the prism symmetrically, calculate the;
(i). Refractive index of the liquid.
(ii). Angle of deviation.

Solution.

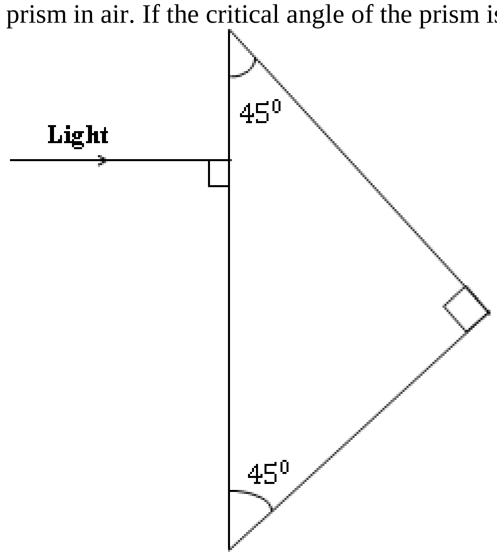
(i) Applying Snell's law at N: $\cap_L \sin i = \cap \sin r_1$ $\cap_L \sin 30 = 1.6 \sin r_1 \ldots (i)$ Applying Snell's law at M: $\cap \sin r_2 = \cap_L \sin e$ $1.6 \sin r_2 = \cap_L \sin e \ldots (ii)$ But, also; $\mathrm{r_1 + r_2 = A}$ $\mathrm{r_1 + r_2} = 50 \ldots\ldots\ldots (iii)$ But since light passes through the prism symmetrically, then;	❖ $\mathrm{r_1 = r_2 = r}$; Thus $2\mathrm{r} = 50 \Leftrightarrow \mathrm{r} = 25^0 \Leftrightarrow \mathrm{r_1 = r_2} = 25^0$ ❖ $e = i \Leftrightarrow e = 30^0$ Thus from equation (i); $\cap_L \sin 30 = 1.6 \sin r_1$ $\cap_L \sin 30 = 1.6 \sin 25^0$ $\cap_\mathrm{L} = \dfrac{1.6 \sin 25^0}{\sin 30}$ $\cap_\mathrm{L} = 1.35$

(ii).
$\mathrm{d} = (i_1 + i_2) - \mathrm{A}$
$\mathrm{d} = (i + \mathrm{e}) - 50$
$\mathrm{d} = (30 + 30) - 50$
$\mathrm{d} = 10^0$

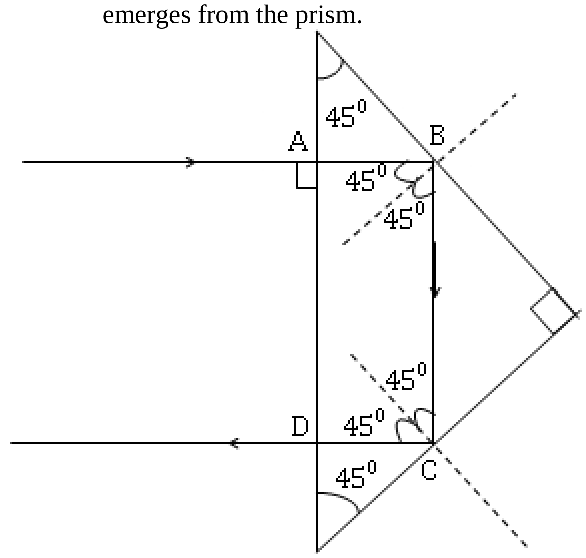
The figures below show two right angled prisms of refracting angles 30^0 and 45^0respectively. Rays of light are incident normally on the faces of the prisms below. Complete the diagrams to show the path taken by the incident ray through each prism hence explain why light takes the path shown.



The figure below shows light incident normally on a glass prism in air. If the critical angle of the prism is 42^0,



(i) Complete the diagram t o show the path of light as emerges from the prism.



At points B and C, light is moving from a denser to a less dense medium and angle of incidence is greater than the critical angle. [$45^0 > 42^0$]. Thus, total internal reflection occurs.
At points A and D, the incident light is not deviated because it is incident normally to the surface.

(ii) Calculate the refractive index of the glass prism
Applying Snell's law at B

$$\cap_Y \ sin\ i_Y \quad = \quad \cap_X \ sin\ r_X$$

$$n \sin C = 1x \sin 90$$
$$n \times \sin 42 = 1 \times \sin 90$$
$$n = 1.49$$

Trial Questions

1. A prism of refractive 1.5 and refractive angle 60^0 has an angle of refraction of 28^0 on the 1^{st} face. Determine
   a) angle of incidence i [44.7^0]
   b) angle of refraction on 2^{nd} face r_2 [$r_2 = 32^0$]
   c) angle of emergency i_2 [$i_2 = 52.6^0$]
   d) angle of deviation d [37.34^0]

2. Critical angle of a certain precious stone is **27^0**. Calculate the refractive index of the stone.

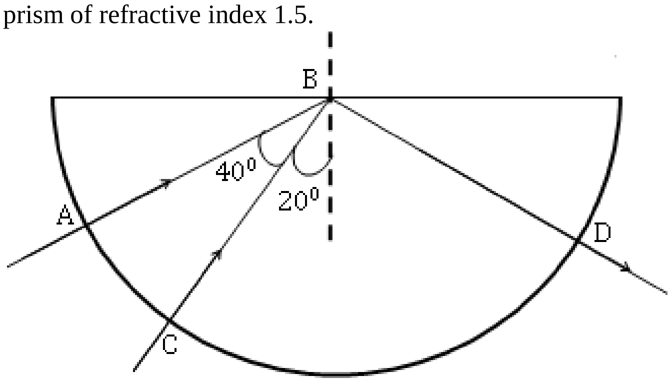
3. **See UNEB Paper I**

1994 Qn.40	1995 Qn.24	1996 Qn.1	1996 Qn.35

4. **UNEB 1990 Qn. 4**
(a) (i) State the laws of refraction.
(ii) What is meant by refractive index?
(b) Describe a simple experiment to determine the refractive of the glass of a triangular prism.
(c) The angle of refraction in glass is 320. Calculate the angle of incidence if the refractive index of glass is 1.5.

5. **UNEB 1996 Qn. 3 PII**
(a) What is meant by the following terms;
(i) Critical angle
(ii) Total internal reflection
(b) State; (i) two conditions for total internal reflection to occur.
(ii) One application of total internal reflection.

6. **UNEB 1993 Qn. 9**
The diagram below shows rays of light in a semi-circular glass prism of refractive index 1.5.



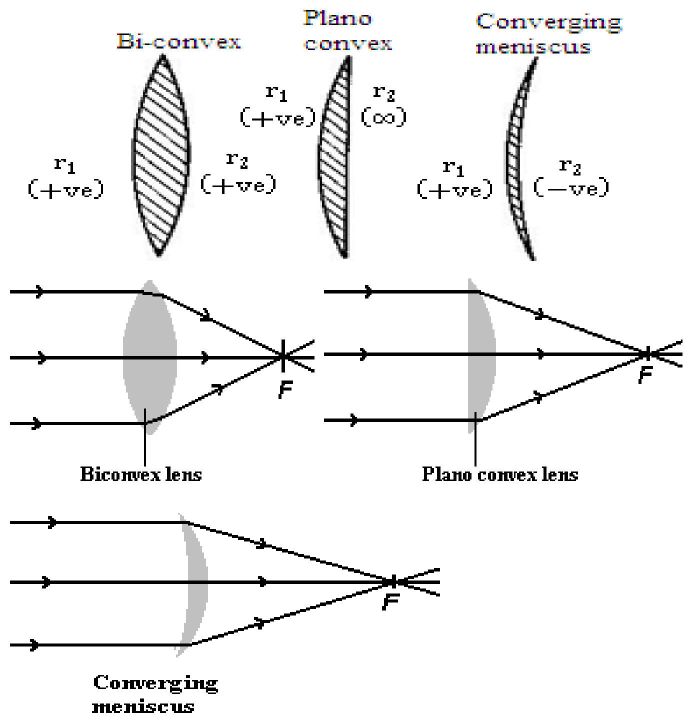
(a) Explain why ray AB;
(i) Is not refracted on entering the block at A.
(ii) Takes path BD on reaching B.
(b) Ray CB is refracted at B. Calculate the angle of refraction.

7. UNEB 1996 Qn. 4; UNEB 1987 Qn. 7; UNEB 2001 Qn.46

LENSES

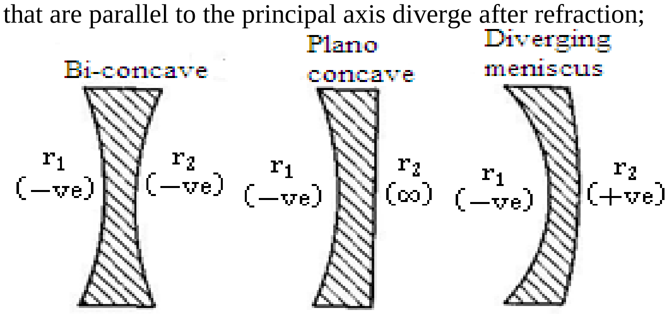
Definition:
Lenses are spherical surfaces of transparent materials. The materials may be glass, plastics, water, etc.

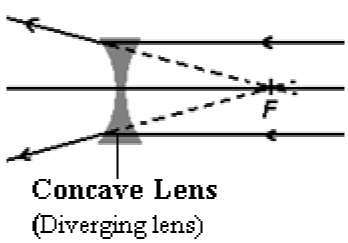
Types of Lenses:
(i) Converging Lenses (Convex Lens):
A convex lens is thick in the center. It is also called a converging lens because it bends light rays inwards. There are three examples if convex lenses, namely:

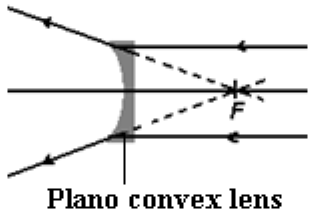


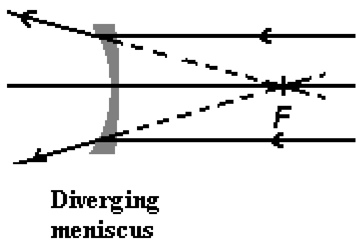
A converging lens (Convex lens) is one in which all parallel beams converge at a point (principle focus) after refraction.

(ii) Diverging Lens (Concave Lens):
A concave lens is thinnest in the central and spreads light out. A concave lens is also called a divergent lens because all rays that are parallel to the principal axis diverge after refraction;



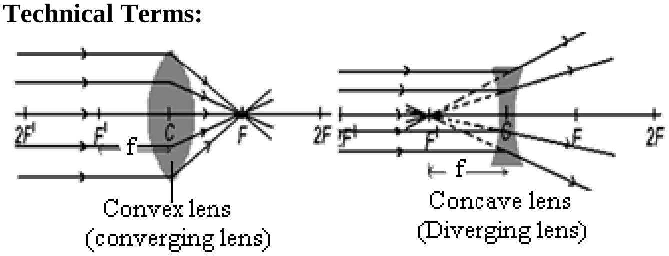






In a diverging lens, refracted ray seems to come from the point after refraction.

Technical Terms:



- Pole of a lens:

Is the centered point of the surface of the lens through which the principal axis passes.

- Optical Centre: (C)

Is the point on the principle axis mid way between the lens surfaces. It is the centre of the lens at which rays pass un deviated.

- Principal Axis:

Is the line through the optical center of the lens on which the principal focus lies.

- Principal Focus, F:

Convex lens.
Is the point on the principal axis at which all rays parallel and close to the principal axis meet after refraction thru the lens.
Concave lens.
This is the point on the principal axis of a concave lens at which all rays parallel and close to the principal axis appear to diverge from after refraction thru the lens.

- Focal Length, f:

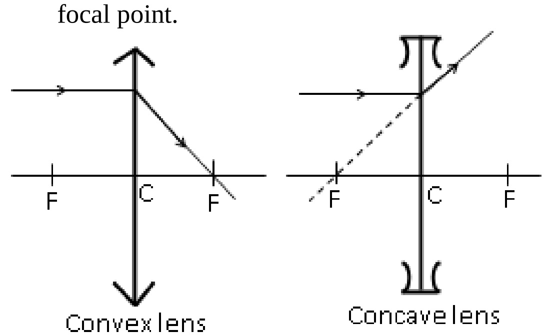
Is the distance between the optical center and the principal focus.

Note: The principal focus of a converging lens is real while that of a diverging lens is virtual.
Real principal focus is one at which actual rays meet after refraction.

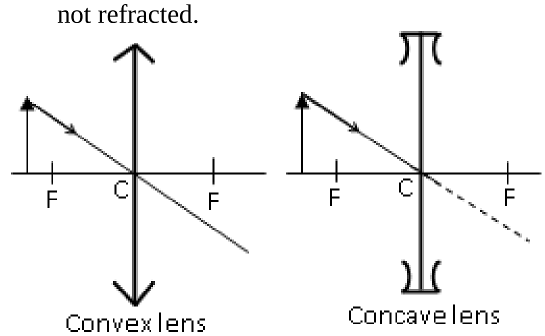
1. Centers of curvature, 2F: Is the centre of the sphere of which the lens surfaces form part. OR It is a point on the principle axis where any ray through it hits the lens at right angles.
2. Radius of curvature: Is the radius of the sphere of which the lens forms part. OR It is the distance between the optical centre and the centre curvature of the lens.

Ray Diagram for a Convex (Converging) Lens.
In constructing ray diagram, 2 of the 3 principal rules are used.

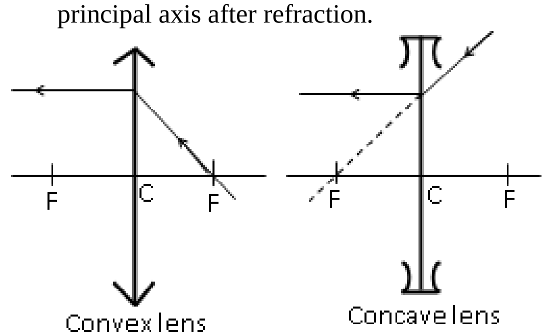
1. A ray parallel to the principal axis is refracted through the focal point.



2. A ray through the optical centre passes un deviated i.e. is not refracted.

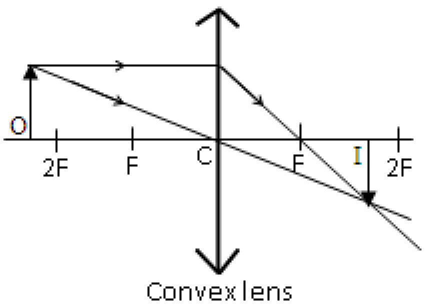


3. A ray through the principal focus emerge parallel to the principal axis after refraction.



Images formed by convex lenses:
The nature of the image formed in a convex lens depends on the position of the object from the lens.

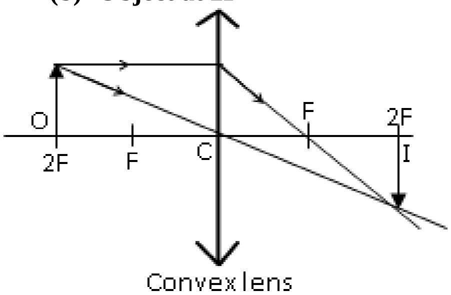
(a) **Object beyond 2F**



Characteristics of the image:

- Nature: Real and Inverted.
- Position: Between F and 2F.
- Magnification: Diminished

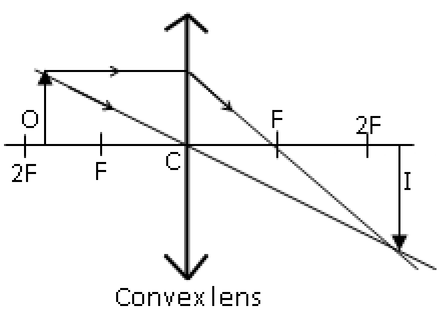
(b) Object at 2F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: At 2F.
- Magnification: Same size as object.

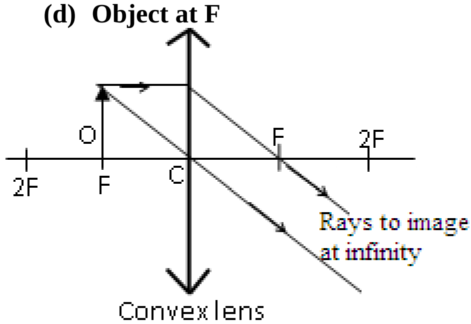
(c) Object between F and 2F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: Beyond 2F.
- Magnification: magnified.

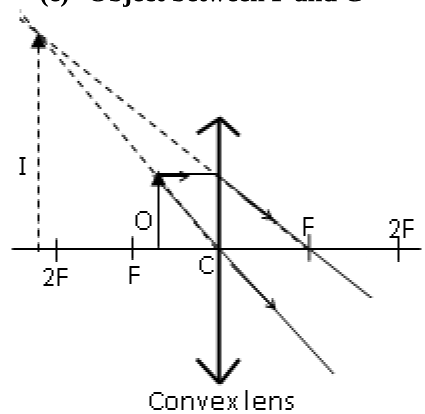
(d) Object at F



Characteristics of the image:

- Nature: Real and Inverted.
- Position: At infinity.
- Magnification: magnified.

(e) Object between F and C



Characteristics of the image:

- Nature: Virtual and Upright or erect.
- Position: On the same side as the object.
- Magnification: magnified.

When the object is placed between F and C, the image is magnified and this is why the convex lens is known as a magnifying glass.

Summary of the useful rays

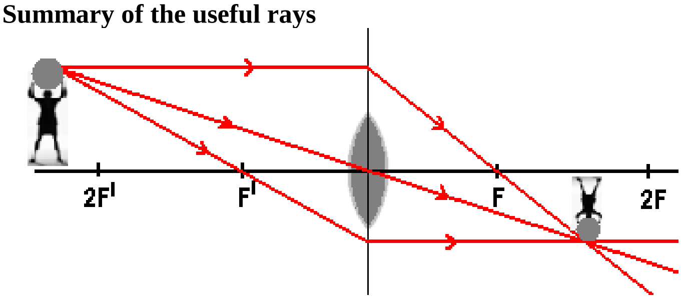
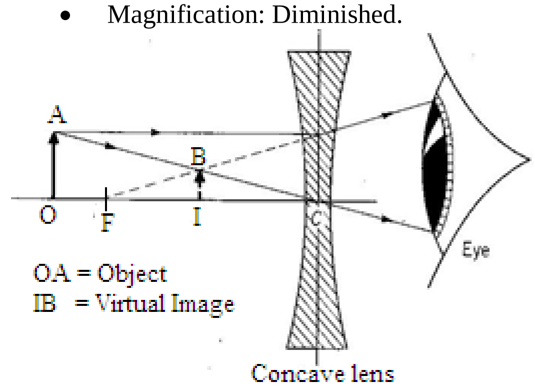
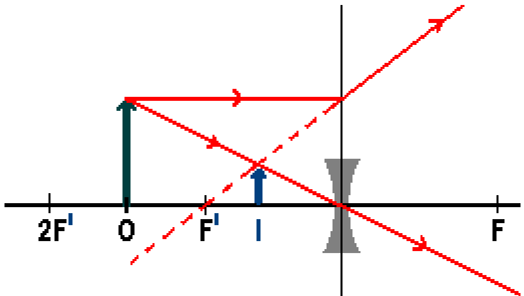


Image Formation in a Concave Lens

Irrespective of the position of the object, a concave lens forms an image with the following characteristics:

- Nature: Virtual and Upright or erect.
- Position: Between F and C.
- Magnification: Diminished.





Magnification of lens:

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

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

The lens formula:
If an object is at a distance, u forms the lens and image, v distance from the lens, then focal length, f is given by:

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

This applies to both concave and convex.

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

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

Example 1:
An object of height 10cm is placed at distance 50cm from a converging lens of focal length 20cm. Calculate the;
(i) Image position.
(ii) image height
(iii) magnification

Solution:
Given, H = 10 cm, u = 50 cm, f = 20 cm
v = ? h = ?

Using the mirror formula; $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ $\frac{1}{20} = \frac{1}{50} + \frac{1}{v}$ $\frac{1}{20} - \frac{1}{50} = \frac{1}{v}$	$\frac{1}{v} = \frac{5-2}{100} = \frac{3}{100}$ $\frac{1}{v} = \frac{3}{100}$ v = 33.33 cm A real image was formed 33.33cm from the lens.
Using the definition of magnification, $M = \frac{h}{H} = \frac{V}{U}$ $\frac{h}{10} = \frac{33.33}{20}$ h = 6.67 cm	Magnification: $M = \frac{h}{H} = \frac{V}{U}$ $M = \frac{(\frac{100}{3})}{20}$ M = 0.67

Questions: (Students' Exercise)
1. An object is placed: a) 20 cm b) 5 cm, from a converging lens of focal length 15 cm. Find the;
   (i) nature of the image in each case .
   (ii) position, v of the image in each case. (Va = 60cm ; Vb = 7.5)
   (iii) Magnification, M of the image in each case. (Ma = 3 ; Mb = 1.5)

2. A four times magnification virtual image is formed of an object placed 12cm from a converging lens. Calculate the;
(i) position of the image (v = 48 cm)
(ii) focal length of the lens (f = 10 cm) .

3. Find the nature and position of the image of an object placed 10cm from a diverging lens of focal length 15cm. (Virtual : v = 6cm).

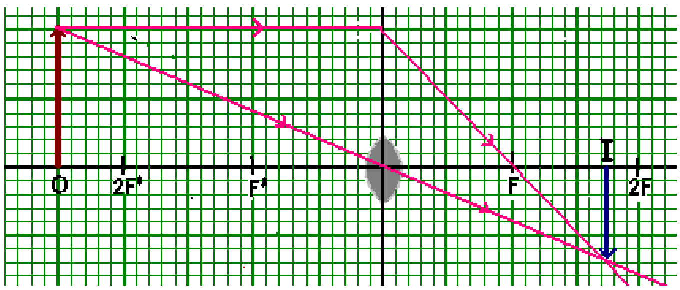
Finding position by graph (scale drawing):
Step I: Select a scale for drawing
Step II: Make a sketch of the drawing; this should include two major rays from a point on the object i.e.

- ✓ A ray parallel and closed to the principal axis should be refracted through the focal point for a converging lens while for a diverging lens, the ray parallel and closed to principal axis is refracted in such a way that is appears to come from the focal point.
- ✓ A ray through the optical center should be drawn un deviated.

Examples:
An object of height 10cm is placed at a distance of 50cm from a converging lens of focal length 20cm. Find by scale drawing the;
(i) Image position
(ii) Image height
(iii) Nature of the image formed

Solution

Axis	Scale	Conversion
Vertical axis	**1 : 5 cm**	❖ 10 cm → $\frac{10}{5}$ → 2cm
Horizontal axis	**1 : 10 cm**	❖ 50cm → $\frac{50}{10}$ → 5cm ❖ 20cm → $\frac{20}{10}$ → 2cm



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

$$Image\ distance = (3.4\ x\ 10)\ cm$$
$$= 34cm$$

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

$$Image\ height = (1.4\ x\ 5)\ cm$$
$$= 7\ cm$$

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

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{34}{50} = 0.68$$

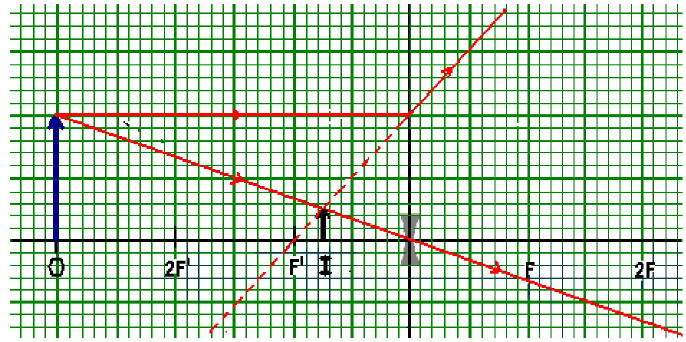
Or

$$\text{Magnification} = \frac{\text{Image Height}}{\text{Object Height}} = \frac{7}{10} = 0.7$$

Example: 2
An object of the height 10cm is placed at a distance of 60 cm from a diverging lens of focal length 20cm. Find by scale drawing, the;
- (i) Image position, v
- (ii) Height, h of the image
- (iii) Nature of the image
- (iv) Magnification, M

Solution

Axis	Scale	Conversion
Vertical axis	**1 : 5 cm**	❖ 10 cm → $\frac{10}{5}$ → 2cm
Horizontal axis	**1 : 10 cm**	❖ 60cm → $\frac{60}{10}$ → 6cm ❖ 20cm → $\frac{20}{10}$ → 2cm



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

$$Image\ distance = (1.5\ x\ 10)\ cm$$
$$= 15cm$$

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

$$Image\ height = (0.5\ x\ 5)\ cm$$
$$= 2.5\ cm$$

(ii) Nature:
The image formed is; Virtual, Upright and Diminished.

(iii) Magnification:

$$\text{Magnification} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{15}{60} = 0.25$$

Students' Exercise
1. An object 1cm tall stands vertically on principal axis of a converging lens of, focal length, f = 1cm, and at a distance of 1.7cm from the lens. Find by graphical construction, the position, size, magnification and nature of the image.

2. An object is 32.5 cm from a diverging lens of focal length 12 cm. by scale drawing;
   - (i) Locate the numerical position and the height of the image formed.
   - (ii) Calculate the ratio of image magnitude to object height.
   - (iii) Describe the image formed using the result in (ii) above.

3. An object is placed 10 cm in front of a concave lens of focal length 20 cm to form an image. Determine the position, nature and magnification of the image using a ray diagram.

4. An object 5cm tall is placed 15 cm away from a convex lens of focal length 10cm. By construction, determine the position size and nature of the final image.

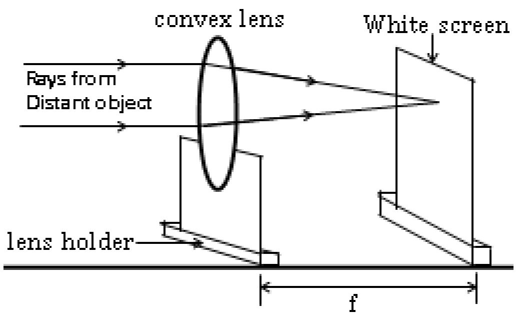
5. An object 5cm high is placed 20cm in front of a converging lens of focal length 15cm. Find the power of the lens and the magnification of the lens.

6. An object of height 20cm is placed vertically on the axis of a convex lens of focal length 10cm at a distance of 30cm from the lens. Use the graphical method to find the position, nature and magnification of the image.

Experiments to measure focal length of convex lens (Converging lens)

1. **Rough method**

(Using a distant object, e.g window)



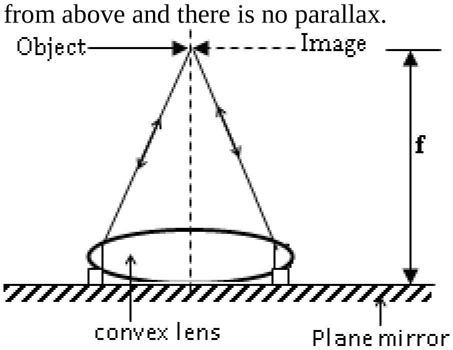
Position the lens and a white screen on a table as shown above.
Move the lens towards and away from the screen until a sharply focused image of the distant object is formed on the screen.
Measure the distance, f between the lens and the screen. It is approximately equal to the focal length of the lens used.

Note:
To improve the accuracy of the results, it is advisable that the experiment is repeated at least three times and the average focal length calculated.

f_1(cm)	f_2(cm)	f_3(cm)	f(cm)
a	b	c	$\frac{(a+b+c)}{3}$

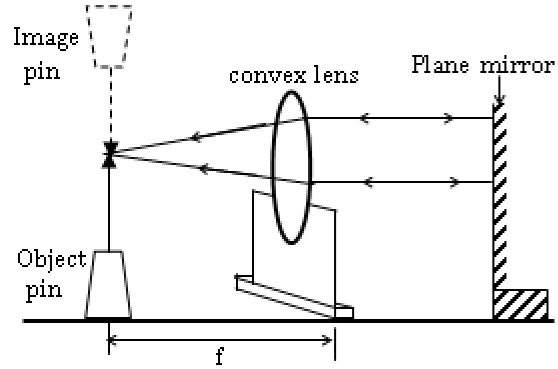
2. **Plane mirror method and no parallax**

A plane mirror M is placed on a table with its reflecting surface facing upwards. The lens L is placed top of the mirror. An optical pin, O is then moved along the axis of the lens until its image I coincide with the object O, when both are viewed from above and there is no parallax.



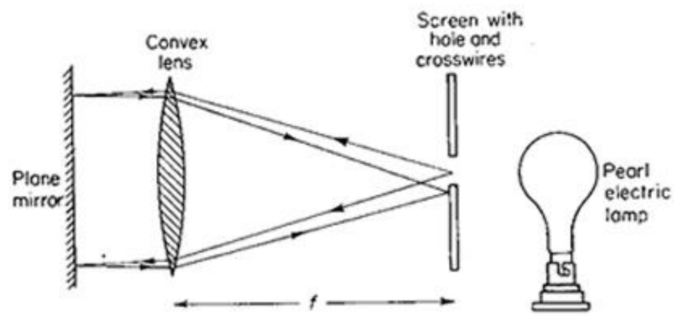
The distance from the pin O to the lens is thus measured and it is equal to the focal length, f, of the lens.

Alternatively, the set up bellow may be used.



NOTE: Rays from O passing through the lens are reflected from the plane mirror M and then pass through the lens a gain to form an image. When O and I coincides the rays from O incident on the mirror must have returned a long their incident path after reflection from the mirror. This happens if the rays are incident normally on the plane mirror, M. The rays entering the lens after reflection are parallel and hence the point at which they converge must be the principle focus.

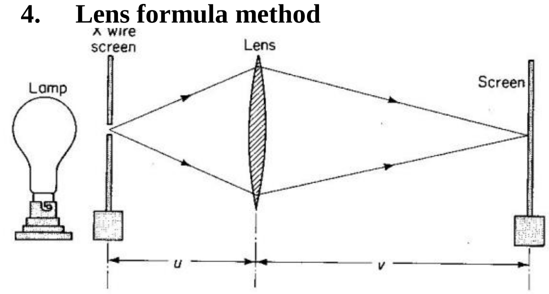
3. **Using illuminated object and plane mirror**



The position of the lens holder is adjusted until a sharp image of the object is formed on the screen alongside the object itself. The object will now be situated at the focal point (focal plane). The distance between the lens and screen is measured and this is the focal length f.

Note: The focal point or focal plane of a lens is a point or a plane through the principal focus at right angle to the principal axis. At this point, rays from any point on the object will emerge from the lens as a parallel beam and are reflected back through the lens.

4. **Lens formula method**



Using an illuminated object, O at a measured distance, u, move the screen towards and away from the lens until a clear image of the cross wires is obtained on the screen.
The image distance, *v* is measured and recorded.

The procedure is repeated for various values of u and the corresponding values of v measured and recorded.

The results are tabulated including values of $\frac{1}{u}\ and\ \frac{1}{v}$.

u(cm)	v(cm)	$\frac{1}{u}(\text{cm}^{-1})$	$\frac{1}{v}(\text{cm}^{-1})$
-	-	-	-

The focal length can be calculated from the equation $\frac{1}{\mathbf{f}} = \frac{1}{\mathbf{u}} + \frac{1}{\mathbf{v}}$ and the average of the values obtained .

Power of a lens:

Power of a lens is the reciprocal of its focal length expressed in meters. The S.I of power of lens is dioptres (D).

Note: The Focal length of convex les is real so it's positive and hence its power is positive.

The focal length of a concave lens is virtual so it's negative hence its power is negative.

The power of the combination of lenses can be calculated from:

The power of the lens; $\mathbf{P} = \frac{\mathbf{1}}{\textbf{focal length in metres}} = \frac{\mathbf{1}}{\mathbf{f}}$

$$\left(\begin{matrix}\text{Power of}\\ \text{combination,}\end{matrix}\right) = \left(\begin{matrix}\text{Power of}\\ \text{first lens}\end{matrix}\right) + \left(\begin{matrix}\text{Power of}\\ \text{second lens}\end{matrix}\right)$$

$$\text{P}_{\text{combination}} = \frac{1}{\begin{matrix}\text{focal length, f}_1\\ \text{of first lens}\end{matrix}} + \frac{1}{\begin{matrix}\text{focal lenth, f}_2\\ \text{of second lens}\end{matrix}}$$

$$\text{P}_{\text{combination}} = \frac{1}{\text{f}_1} + \frac{1}{\text{f}_2}$$

Examples:

1. Two converging lenses of focal lengths 15cm and 20cm are placed in contact, find the power of combination.

Solution

Given, $\text{f}_1 = 15\text{ cm} = 0.15\text{ m};\ \text{f}_2 = 20\text{ cm} = 0.20\text{ m}$

$$\text{P}_{\text{combination}} = \frac{1}{\text{f}_1} + \frac{1}{\text{f}_2}$$

$$\text{P}_{\text{combination}} = \frac{1}{0.15} + \frac{1}{0.20}$$

$$\text{P}_{\text{combination}} = 11.67\text{ D}$$

2. A convex lens of focal length 20cm is placed in contact with concave lens of focal length 10cm. Find the power of the combination (Ans: -5D).

Solution

Given, $\text{f}_1 = 20\text{ cm} = 0.20\text{ m};\ \text{f}_2 = 10\text{ cm} = 0.10\text{ m}$

$$\text{P}_{\text{combination}} = \frac{1}{\text{f}_1} + \frac{1}{\text{f}_2}$$

$$\text{P}_{\text{combination}} = \frac{1}{0.20} + \frac{1}{-0.10}$$

$$\text{P}_{\text{combination}} = -5\text{ D}$$

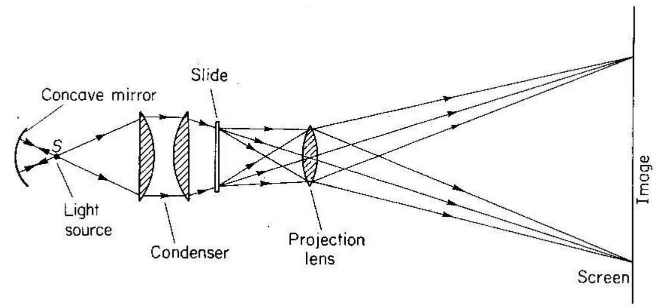
Uses of lenses

- The eye uses it to focus images on the retina
- In spectacles to correct eye defects.
- In lens cameras to focus images on the screen or film.
- In slide projectors to magnify/focus images on the screen.
- In compound microscopes to magnify/ focus images of tiny near objects.
- As simple magnifying glasses, to magnify images of smaller objects without inverting them.

Simple Optical Instruments:

(i) Projector (or Projection Lantern)

A projector is used for projecting the image of a transparent slide onto the screen. Thus the image formed is real.



Mode of Operation

The powerful **source of light (lamp):** is placed at the principal focus of a concave mirror so as to illuminate the slide if the image is to be bright.

Concave mirror: reflects back light which would otherwise be wasted by being reflected away from the film.

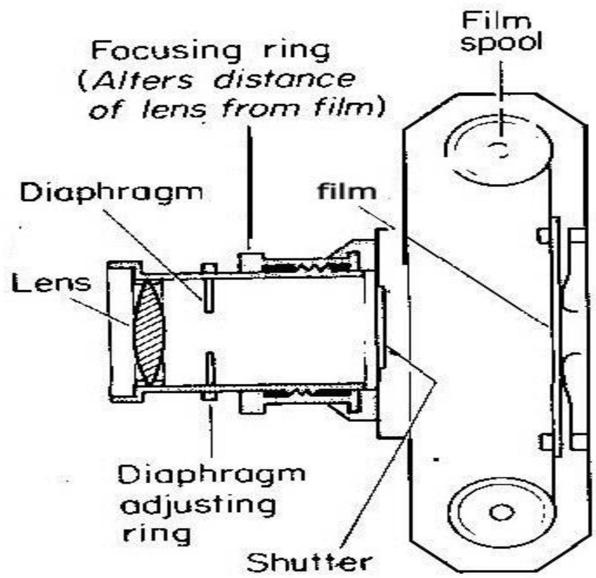
Condenser; this is the combination of two Plano convex lenses. The main function is to collect the rays from the light source and concentrate them onto the slide.

Slide: It contains the object whose image is to be projected on the screen.

Projector lens: is mounted on a sliding tube so that it may be moved to and fro to focus a sharp real image on the screen.

(ii) Lens Camera

A camera is alight tight box in which a convex lens forms a real image on a film.



The film contains chemicals that change on exposure to light. It is developed to give a negative. From the negative the photograph is printed.
The inner surface of the camera is **painted black** in order to prevent reflection of stray rays of light.
A camera is fitted with the provision for adjusting the distance between the film and then lens so that the object can be focused on the film by the convex lens.

(i) **Converging lens**; is to focus the object on the film.

(ii) **Shutter;** It controls the amount of light entering the camera by the length of times the shutter is open. Fast moving objects require short exposure.

The brightness of the image on the film depends on the amount of light passing through the lens. The shutter opening is controlled by the size of the hole in the diaphragm.

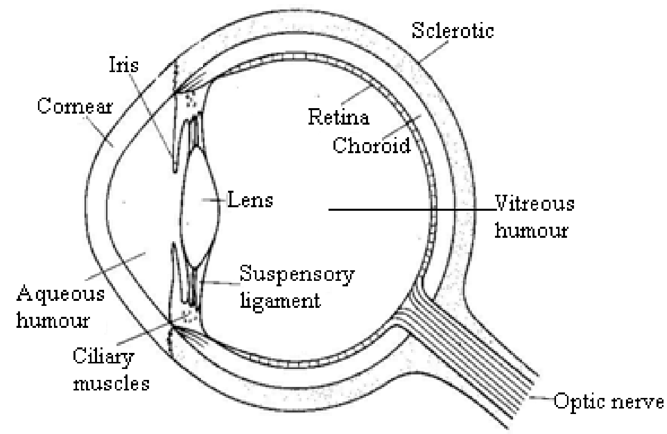
(iii) **Diaphragm**, this changes the size of the aperture. The stop is made of a sense of metal plates which can be moved to increase the aperture size.

Thus it controls the amount of light entering the camera by its size.
***Note:** The correct setting of the lens for an object at any given distance from the camera is obtained from a scale engraved on the lens mount.

(iv) **Film:** It is a light sensitive part where the image is formed.

THE HUMAN EYE

Light enters the eyes through the cornea, the lens and then is focused on the retina. The retina is sensitive to light and sends messages to the brain through optic nerves. The iris changes in size to vary the amount of light entering through the pupil. The size of the pupil decreases in bright light and increases in dim light.



Functions of the parts of the eye.

1. **Lens**

The lens inside the eye is convex. It's sharp; it changes in order to focus light.

2. **Ciliary muscle**

These alter the focal length of lens by changing its shape so that the eye can focus on image on the retina.

3. **The iris**

This is the coloured position of the eye. It controls the amount of light entering the eye by regulating the size of the pupil

4. **The retina**

This is a light sensitive layer at the back of the eye where the image is formed.

5. **The optic nerve**

It is the nerve that transmits the image on the retina to the brain for interpretation.

6. **The cornea:** It is the protective layer and it also partly focuses light entering the eye .

Accommodation

This is the process by which the human eye changes its size so as to focus the image on the retina. This process makes the eye to see both near and far objects.

Note: Accommodation is the process by which objects at different distances are focused by the ciliary muscles changing shape, so that the focal length of the lens changes.

Accommodation can also be the ability of the eye to focus objects at various distances.
Near point: this is the closest point at which the eye can accommodate a most clear vision. Its 25m for a normal eye.

Far point: this is the most distant point at which the eye can accommodate a clear vision. It's at infinity since rays travel in a straight line.

Defects of vision and their corrections

a) **Long Sightedness. (Hypermetropia)**

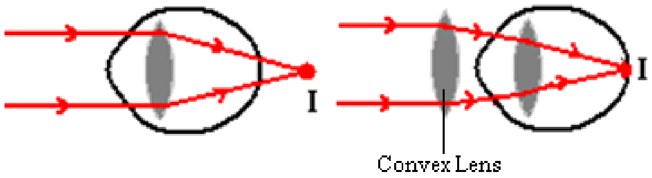
This is an eye defect where a person can see distant objects clearly but near objects are blurred.
It is due to either;

(i) Too long focal length, or

(ii) Too short eye ball.

Because of these effects, the ciliary muscles have weakened and cannot make the eye lens fatter (i.e. decrease its focal length) to focus near object on the retina.

Thus, the image is formed behind the retina.



This defect is corrected by using spectacles containing converging lens which increase the convergence of the rays and brings it to focus on the retina.

b) Short Sightedness: (Myopia)

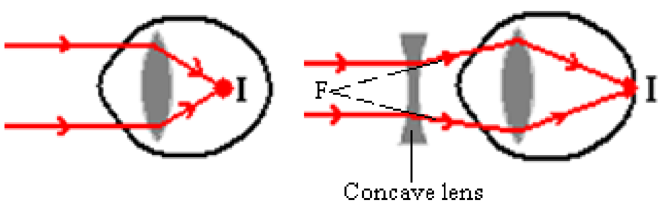
This is an eye defect where person can see near objects clearly but distant ones are blurred.

It is due to either;

(i) Too short focal length, or

(ii) Too long eye ball.

Because of these effects, the ciliary muscles do not relax sufficiently and consequently, distant objects are focused in front of the retina.



This defect is corrected by using spectacles containing diverging lens which increase the divergence of the light rays before they enter the eye and brings them to focus on the retina.

Similarities between the camera and the eye

- Both the eye and camera have light sensitive parts i.e. the retina for an eyes and film for camera.
- Both the eyes and camera have lenses.
- Both have a system which regulates the amount of light entering them i.e. iris for the eye and the diaphragm for the camera.
- The camera has black light proof inside the camera while the eye has a black pigment inside.

Differences between the human eye and camera:

Human eye	Camera
Lens: - Is biological. - Is flexible	-Lens is artificial - Is a rigid glass or plastic
Focal length: f of lens for the eye is variable.	-focal length of lens the for camera is fixed.
Distance: The distance between the lens and retina is fixed.	-The distance between the lens and film is variable.
Focusing: By changing the shape of the lens.	-By moving the lens relative to the film.
Aperture: Controlled by the iris.	-Controlled by the diaphragm.
Exposure: Is continuous.	- Controlled by shutter.
Light sensitive surface: film	-Retina

Exercise:

1. See UNEB Paper I

1993 Qn.7	2000 Qn. 21	2001 Qn. 30	2004 Qn. 14	2007 Qn. 10

2. Section B

1993 Qn.7 PII	1994 Qn. 2	1998 Qn.6	2000 Qn.8

COLOURS AND DISPERSION OF LIGHT

Colours of objects we see depend on the colours of the light which reach our eyes from them.

Its by experiments conducted that we can prove that white light is made up of a mixture of seven colours called a **spectrum.**

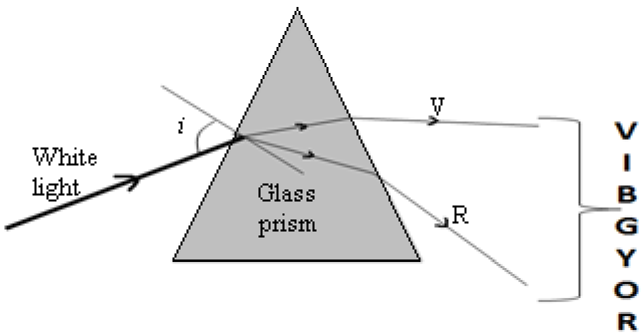
A spectrum is a range of seven colours that form white light. (Day light)

DISPERSION OF LIGHT

Definition:

Dispersion of light is the separation of white light into its component colours.

When white light is passed through a prism, it is deviated and separated into seven colours.



This is because of the refractive index of glass being different for each colour which makes the different colours to move at different speeds.

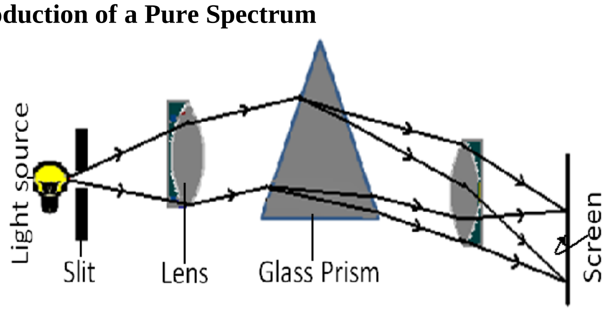
An object colour depends on:

- Colour of light falling on it.
- Colour it transmits or reflects i.e. green light appears green because it absorbs all other colours of white light and reflects green

Impure spectrum: this is the type of spectrum in which the boundaries between the different component colours are not clearly defined. i.e when there is overlapping of colours of white light.

Pure spectrum: this is a spectrum in which light of one colour only forms on the screen without over lapping.

Production of a Pure Spectrum



An illuminated slit is placed at the principle forces of a converging lens so that a parallel beam of white light emerges and falls on the prism.

Refraction through the prism splits up the light into separate parallel beams of different colours each of which is brought to its own focus.

Note: the combination of the slit and first lens is called the **collimator** (To collimate means to make parallel).

Note: The slit should be made narrow to reduce the overlapping of colours to a minimum so as to produce a fairly pure spectrum.

COLOURS

Colour is the appearance of an object that results from their ability or capacity to reflect light.

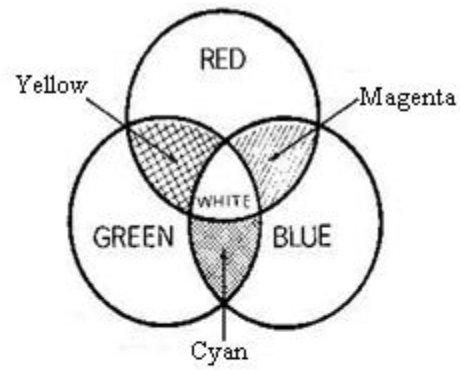
Types of Colour

(i) Primary Colours:

Colours that can't be obtained by mixing any other colours. Examples: Red, Green, Blue

(ii) Secondary Colours:

Colours obtained by mixing any two primary colours.
Examples: Yellow, Magenta, Cyan (Peacock Blue)



Colour Addition:

When two colours of light are projected on a screen, they overlap to give a different colour. The new colour is said to be formed by colour addition.

(iii) Complementary Colours:

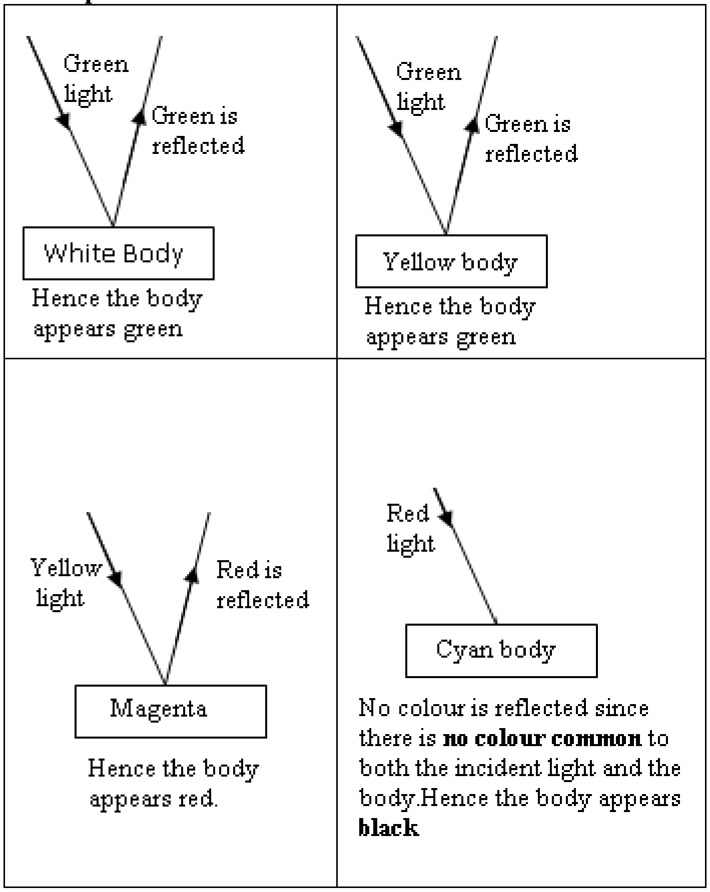
This is a pair of one primary colour and one secondary colour which when mixed gives white light. Examples:

$$\text{Red} + \text{Cyan} = \text{White}$$
$$\text{Blue} + \text{Yellow} = \text{White}$$
$$\text{Green} + \text{Magenta} = \text{White}$$

Coloured objects in white light

An object coloured because it reflects and transmits its own colour and absorbs all other colours incident on it.

Examples:



Question

Describe and explain the appearance of a red tie with blue spots when observed in.

a) Red light

b) Green light – the whole tie appears black because both colours are primary colours and none is reflected back.

c) Red light – in the red light the tie appears red and blue spots blacks.

This is because the red reflects the red colour and observes blue colour.

Question2

A plant with green leaves and red flowers is placed in

a) green b) blue c) Yellow

d) what colour will the leaves and flowers appear in each case . Assume all colours are pure

a) green -: the leaves remain green but the flower black

b) blue -: the leaves will appear black and flowers black

c) Yellow -: the leaves appear green and flowers appear red.

Colour subtraction.

When light falls on a surface of an object, three things may happen to it in varying proportions. Some light may be;

(i) Reflected,

(ii) Transmitted,

(iii) Absorbed.

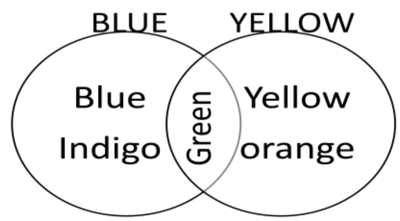
The light which is absorbed disappears. The absorption of light is known as **subtraction of coloured light.**

Mixing pigments;

Is a phenomenon when a impure colour reflects more than one colour light. Mixing coloured pigment is called mixing by subtraction and mixing coloured light is called mixing by addition.

When two pigments are mixed, they reflect the colour which is common to both and absorb all the other e.g. yellow paint reflects orange, yellow and green. While blue paint reflects green, blue and indigo.

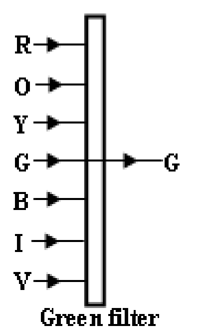
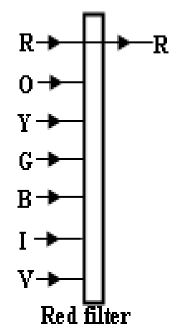
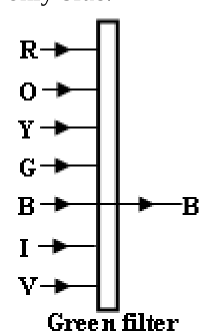
Yellow and blue reflect green but absorb orange, yellow, blue and indigo.

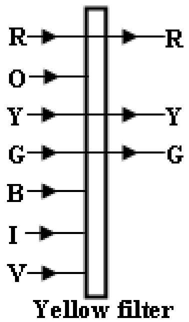
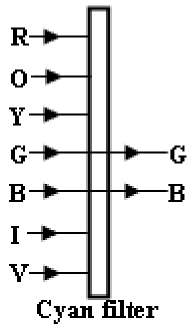
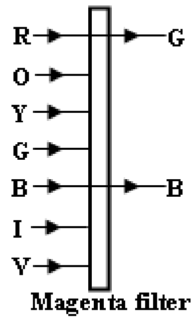


FILTERS

Definition:

A filter is a coloured sheet of plastic or glass material which allows light of its own type to pass through it and absorbs the rest of the coloured lights i.e. a green filter transmits only green, a blue transmits only blue, a yellow filter transmits red, green and yellow lights.

Effect of filters of primary colours on white light		
A green filter absorbs all other colours of white light and transmits only green. 	A red filter absorbs all other colours of white light and transmits only red. 	A blue filter absorbs all other colours of white light and transmits only blue. 

Effect of filters of secondary colours on white light		
A yellow (R+G) filter absorbs all other colours of white light and transmits only Red green and yellow.	A Cyan (G + B) filter absorbs all other colours of white light and transmits only Green and Blue.	A magenta (R + B) filter absorbs all other colours of white light and transmits only Red and blue.
		

Infrared and Ultra-violet light

The spectrum from the sun has both the visible and invisible spectrum. The invisible spectrum consists of ultra-violet at the extreme end of the violet light and the Infra red found just beyond the red light.

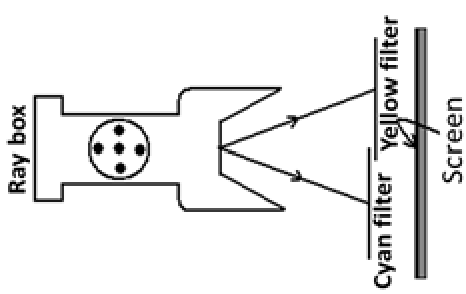
Ultra-violet	VIBGYOR	Infra-red
Invisible spectrum	Visible spectrum	Invisible spectrum

The invisible spectrum can be detected by;

(i) A thermopile connected to a galvanometer which shows a deflection on its detection.

(ii) A photographic paper which darkens when the invisible spectrum falls on it.

Mixing Coloured Filters and Pigments



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

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

Explanation:

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

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

Exercise:

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

Section C

UNEB 1994 Qn. .4 PII;

UNEB 1994 Qn. .4 PII;