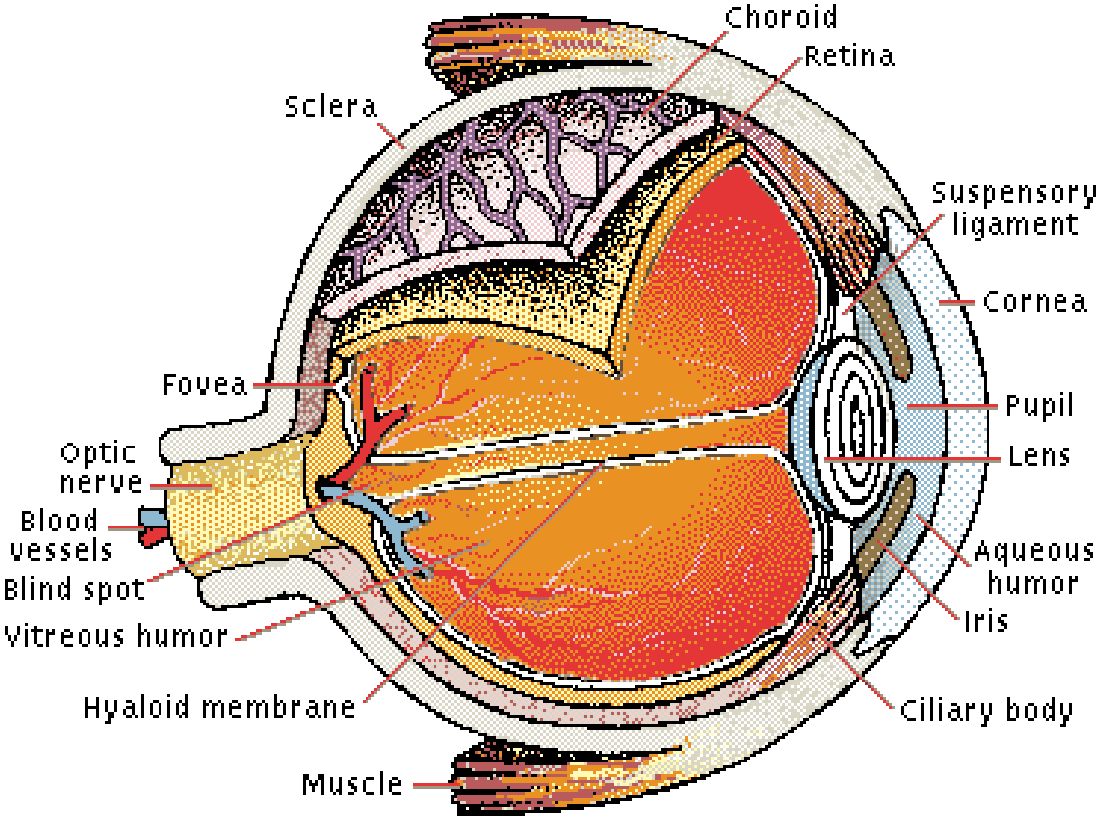
# O’ LEVEL PHYSICS

# LIGHT

## LIGHT

**TIRAGANA GR**




*Light is a form of energy that enables us to see and travels in a straight line*

# LIGHT

## (A) INTRODUCTION

Light is a form of energy which enables us to see. In order to see objects, light must travel from them to our eyes.
Light travels in vacuum at approximate speed of $3.0 \times 10^8 ms^{-1}$.
Objects that produce light on their own are called *self luminous*.
Examples include sun, stars, torch, candle, lamp lightning, glowing insects.
Objects that produce light on by reflection are called *non luminous*.
Examples include moon, books, pen, wall, dresses, desks, trees etc.

***Terms used***

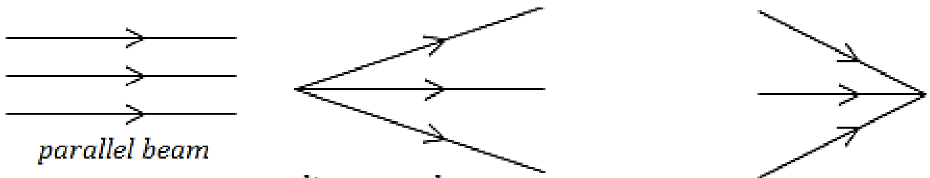
1. A *ray*: this is the direction of path taken by light. It is represented by a single line with an arrow.

The arrow shows the direction of light.

2. *Beam*: this is the collection of light rays

***Types of beams***

They are; parallel, convergent and divergent beams



*parallel beam* *divergent beam* *convergent beam*

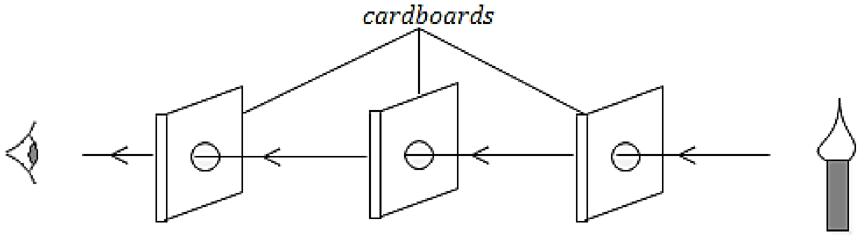
***Rectilinear propagation of light***

When light is produced and sent outwards (propagates), it travels in a straight line.

***Experiment to show that light travels in a straight line***

*Apparatus: three cardboards with central hoes, lit candle.*

(a) Cardboards are arranged in such way that holes, lit candle and the observer are in a straight line.




(b) The observer is able to see light.
(c) If one cardboard is lifted upwards, the observer is unable to see light.
This shows that light travels in straight line.

***Obstacles of light***

These are opaque, translucent and transparent objects
Opaque objects do not allow light to pass through them e.g. walls, wood, thick paper etc.
Translucent objects allow some light to pass through them e.g. coated bulbs, tracing papers, frosted glass, cloth, dirty water mist, colourless polythene bag.

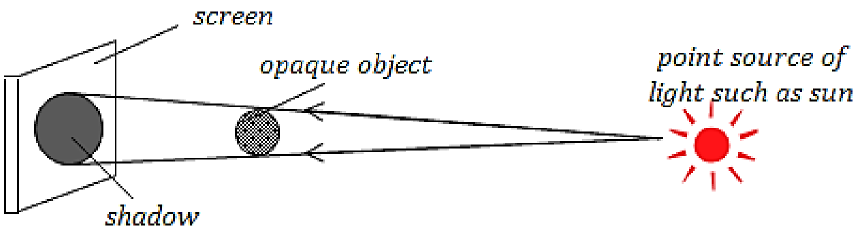
Transparent objects allow most light to pass through them e.g. clean water, uncoated bulb, uncovered glass, clean air.

***Shadows and eclipses***

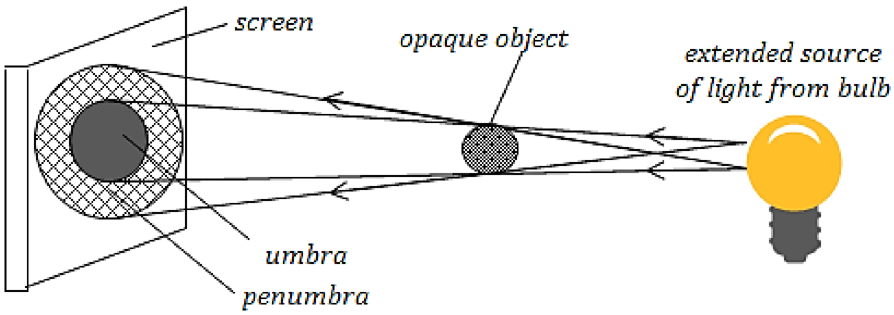
1. ***Shadows:*** When an opaque object is placed between the screen and the source of light, a shadow is formed on the screen.

The shadow formed depends on the source of light

(a) If a point source used, a very sharp shadow is formed. The shadow formed has only the darkest part called *umbra*.



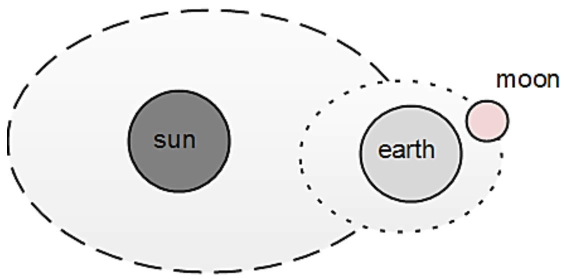

(b) If an extended source is used the shadow formed has two regions – *umbra* and *penumbra*. Penumbra is a region where some light reaches.




Note: The size of penumbra depends on the nearness of the object to the screen i.e. the near the screen the bigger the penumbra.

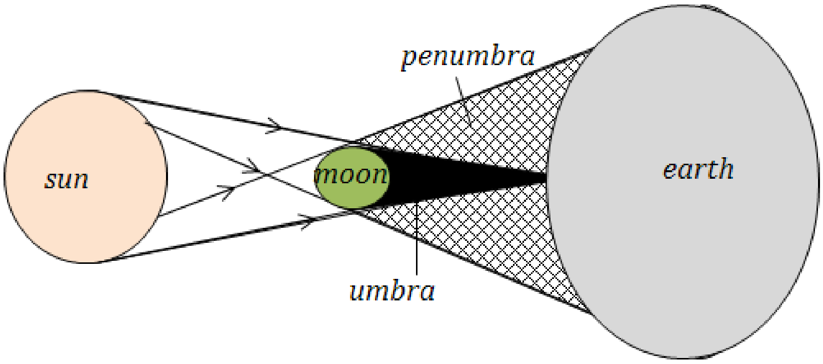
2. ***Eclipses***

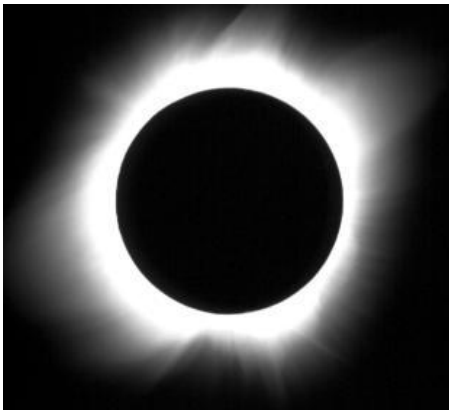
An eclipse is formed when the sun, moon and earth are in straight line




There are two types of eclipse – *solar and lunar eclipses.*

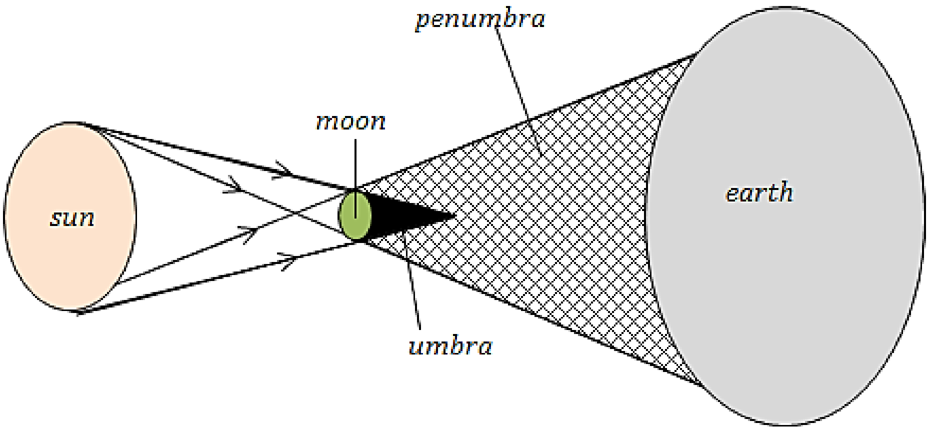
(i) ***Solar eclipse*** is the eclipse of the sun. It occurs when the moon is between the sun and earth (SME) and its shadow moves across the face of the earth.
With the moon near the earth, umbra and penumbra are formed on earth.



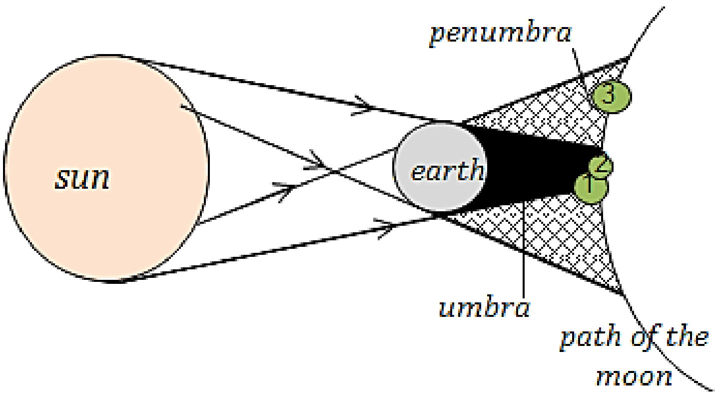



*The light from the outer part of the sun's atmosphere, called the corona, became visible during a total solar eclipse on July 11, 1991, in La Paz, Baja California, Mexico. The moon's shadow on earth appeared only as a thin band not more than 269 km wide.*

If the moon is far from the earth, umbra does not reach the earth. This eclipse of the sun is called *annular eclipse*.




(ii) ***Lunar eclipse*** is eclipse of the moon and it occurs when the earth is between the sun and the moon (SEM) and its shadow darkens the moon.



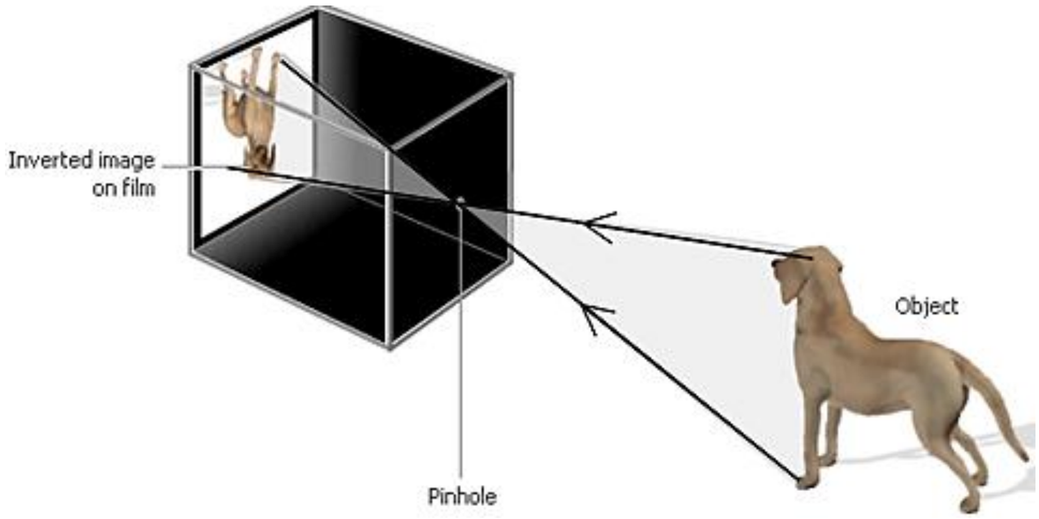

The moon moves in the earth's shadow and

- when it reaches in position 1, partial eclipse occurs where part of the moon is seen.
- when it is in earth's umbra (position2), it becomes dark and total eclipse occurs.
- no eclipse is seen when it reaches position3.

***Pinhole camera***

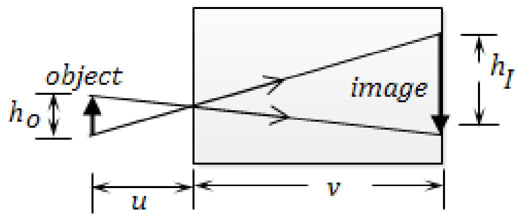
*Construction:* It is made up of a closed box with a hole on one face and a tracing paper as a screen on the opposite side.

*Action*: It works on the principal that light travels through a straight line.
Rays from various parts of the object pass through the hole and form an inverted real image o the screen.




***Factors affecting image formed in a pinhole camera***

(a) Image distance from the pinhole,($v$) (length of pinhole camera): the larger the camera the larger the image formed.




(b) Object distance from the pinhole ($u$): a large and less bright image is formed when the object is near the pinhole.

(c) Size of the pinhole: irrespective of object distance, a small hole acts as a point source forming a sharp image on the screen. If the hole is large, a blurred image is formed. This is because a large hole is considered as a number of tiny holes each forming its own image on the screen which will eventually overlap.

Magnification is the number of times the image is made bigger or smaller than the object.

$Magnification = \frac{v}{u} = \frac{h_I}{h_O}$ where $h_o$ is the height of object and $h_I$ is the height of image

***Example***

1. An object was placed 10cm from the pinhole and an image was produced on the screen at a distance of 15cm from the hole. Find the magnification of the image. $m = \frac{15cm}{10cm} = 1.5$
2. An object 5cm tall was used in a pinhole camera and the image 25cm tall was produced on the screen. Find the magnification of the image. $m = \frac{25cm}{5cm} = 5$

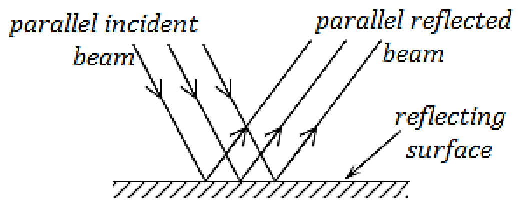
3. Calculate the height of a building 300maway from the pinhole camera which produces an image 2.5cm high if the distance between the pinhole and the screen is 5cm. $\frac{5}{30000} = \frac{2.5}{h_o} \Rightarrow h_o = 15000cm$

**(B) REFLECTION OF LIGHT**
**(1) Reflection of light on plane surfaces**

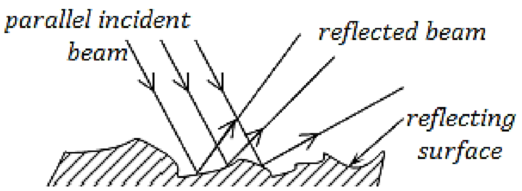
Reflection of light is the bouncing of light rays from body's surface.
Plane mirrors and highly polished surfaces are good reflectors of light.

***Types of reflection***

(a)

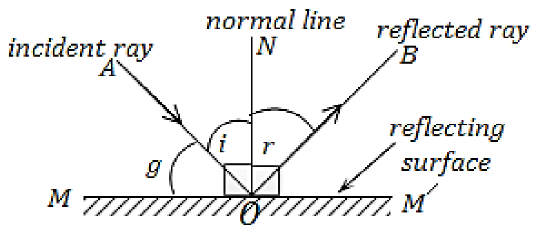



(b)




(a) ***Regular reflection***: This occurs when a parallel beam of light falls on a highly polished surface and is reflected in a parallel direction (*fig a*)
(b) ***Irregular/diffuse reflection***: This occurs when a parallel beam of light falls on a rough surface and is reflected in different directions. (*fig b*)

***Terms used***




1. Incident ray (AO): this is a ray falling onto the reflecting surface
2. Point of incidence, O: this is a point where an incident ray falls on the reflecting surface.
3. Reflected ray (OB ): this is a ray leaving the reflecting surface
4. Normal line (NO): this is a line drawn at the point of incidence. This line makes an angle of $90^0$ to the reflecting surface
5. Angle of incidence $(i)$: this is the angle between the incident ray and the normal line.
6. Angle of reflection $(r)$: this is the angle between the reflected ray and the normal line.
7. Glancing angle $(g)$: this is the angle between the reflecting surface and the incident/reflected ray

***Laws of reflection of light***
1. The angle of incidence is equal to the angle of reflection
2. The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane

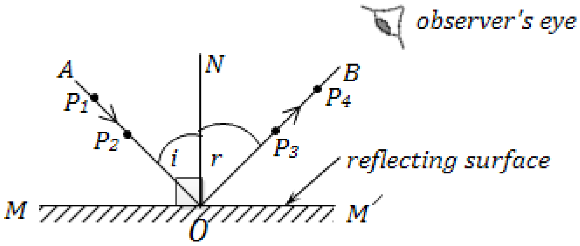
***Experiment to verify laws of reflection (practical)***

*Apparatus: plane mirror, plasticine, white plane paper, 4optical pins, 4 drawing pins, mathematical ruler.*

*(a)* Fix a white sheet of paper on the cardboard using drawing pins.

*(b)* Draw a mirror line $MM' = 5.0cm$ at the centre of the paper

*(c)* Draw a normal line $\overline{NO}$ mid – way $MM'$.




*(d)* Draw a line $\overline{AO}$ at angle $i = 20^0$ to the normal.

*(e)* Fix pins $P_1$ and $P_2$ standing vertically on the line $\overline{AO}$.

*(f)* Place a plane mirror vertically along line $MM'$ using plasticine

*(g)* Viewing from a reflecting surface, fix pins $P_3$ and $P_4$ such that they are in a straight line with image pins of $P_1$ and $P_2$.

*(h)* Remove the plane mirror and the pins $P_3$ and $P_4$ .

*(i)* Draw a line through pin marks of $P_3$ and $P_4$ to meet mirror line at O.

*(j)* Measure and record angle of reflection $r$

*(k)* Enter your results in the table below

| $i(^0)$ | $r(^0)$ |
|---|---|
| 20 | |

Questions:

*What can you conclude from values of angle $i$ and $r$?*

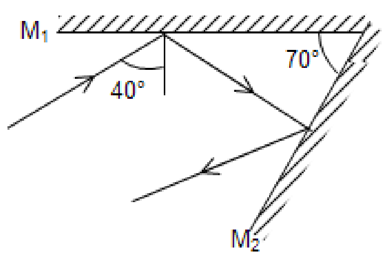
*What can be seen from your tracing paper?*

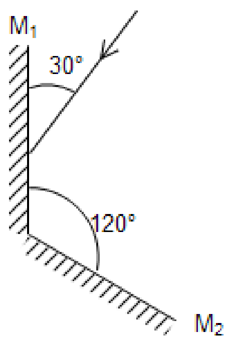
Expected answers

It will be observed that:

- The angle of incidence is equal to angle of reflection
- The incident ray, the normal line and the reflected ay at same point of incidence all lie in the same plane.

*Example:* use rules of reflection in the figures below to find the angle of reflection at mirror $M_2$

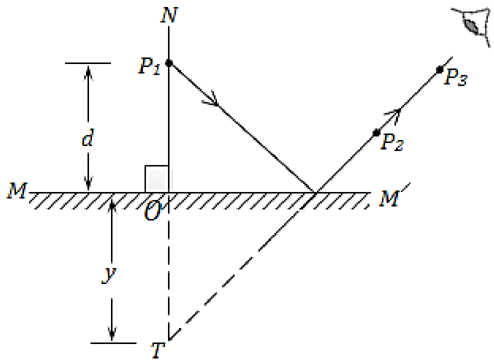


***Images formed in a plane mirror***

*Apparatus: plane mirror, plasticine, white plane paper, 4optical pins, 4 drawing pins, mathematical ruler.*

(a) Fix a white sheet of paper on the cardboard using drawing pins.
(b) Draw a mirror line $MM' = 10.0cm$ at the centre of the paper
(c) Draw a normal line $\overline{NO}$ mid – way $MM'$.




(d) Fix pin $P_1$ vertically on line $\overline{NO}$ at a distance $d = 5.0cm$ from $MM'$.
(e) Place a plane mirror vertically along line $MM'$ using plasticine
(f) Viewing from aside as seen on the figure above, fix pins $P_2$ and $P_3$ such that they are in a straight line with image pin of $P_1$.
(g) Remove the plane mirror and the pins $P_2$ and $P_3$ .
(h) Draw a line through pin marks of $P_2$ and $P_3$ to meet line $\overline{NO}$ at T.
(i) Measure and record distance $y$.

Questions:

*What can you conclude from values of angle d and $y$?*
*What can be seen from your tracing paper?*

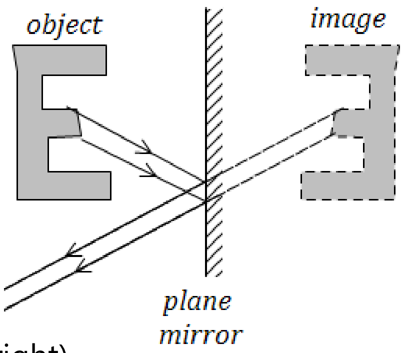
Expected answers

It will be observed that:

- $d = y$
- The image pin is in opposite side as object pin $P_1$

*Conclusion*: images formed in a plane mirror are:

- at the same distance behind the mirror as the object is in front
- of the same size as the object
- laterally inverted (left of the image appears to be the right of the object)




- erect (upright)
- virtual (can not be formed on the screen). A virtual is formed by apparent intersection of rays.

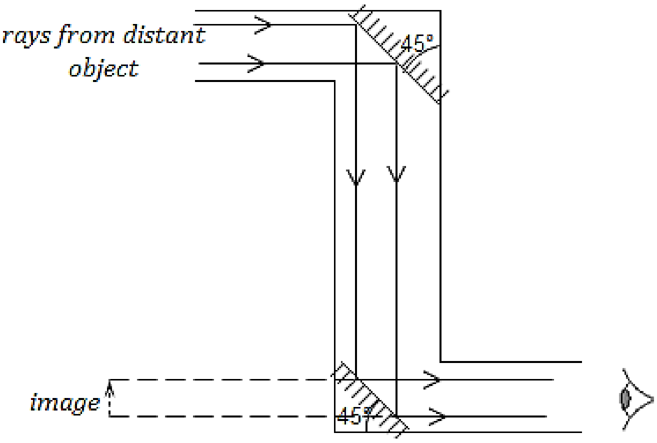
***Application of reflection***

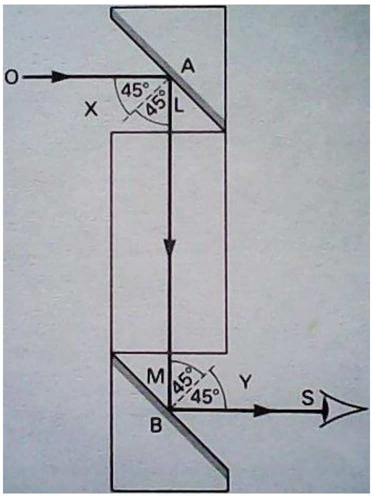
Reflection of light is applied in periscopes, prism binoculars, car driving mirrors,

***Periscope***

A periscope is an optical instrument for conducting observations from a concealed or protected position such as viewing devices in military aircraft, in nuclear physics laboratories to observe radioactive reactions.

A simple periscope consists of reflecting mirrors at opposite ends of a tube with the reflecting surfaces parallel to each other, and at a 45° angle to the axis of the tube.

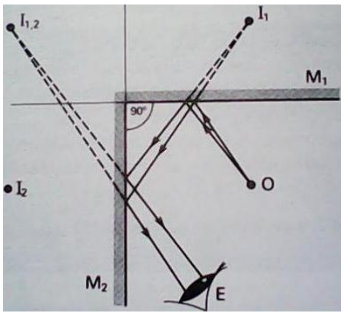



Images formed in a periscope are erect

***Images formed in inclined plane mirrors***

Due several reflections from inclined mirrors, a number of images formed $n = \frac{360}{\theta} - 1$ where $\theta$ is the angle between the mirrors.



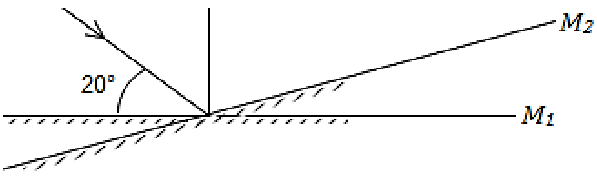

e.g.

| $\theta(^0)$ | $n$ |
|---|---|
| 90 | 3 |
| 60 | 5 |
| 45 | 7 |
| 30 | 11 |

Note: when $\theta = 0^0$, the mirrors are parallel and infinite images are seen. This knowledge is applied in saloons.

***Rotation of a reflected ray***

An incident ray makes an angle of $20^0$ with the plane mirror in position $M_1$ as shown in the figure below




i. What will be the angle of reflection if the mirror is rotated through $6^0$ to position $M_2$ while direction of the incident ray remains the same?
ii. Find the angle of rotation of the reflected ray.

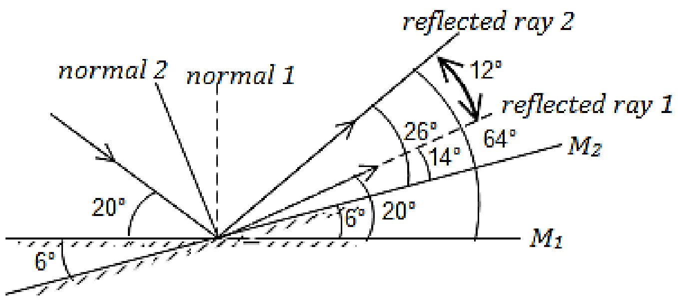
*Solution*

(i) $Total\ glancing\ angle\ \ g = 20^0 + 6^0 = 26^0$

$\Rightarrow 26^0 + r = 90^0 \ \Rightarrow r = 64^0$

*Angle of reflection*$= 64^0$

(ii)




*In position* $M_1$*, glancing angle* $= 20^0$

*Angle between reflected ray1 and mirror*$M_2$

$= 20^0 - 6^0 = 14^0$

*In position* $M_2$*, glancing angle* $= 26^0$

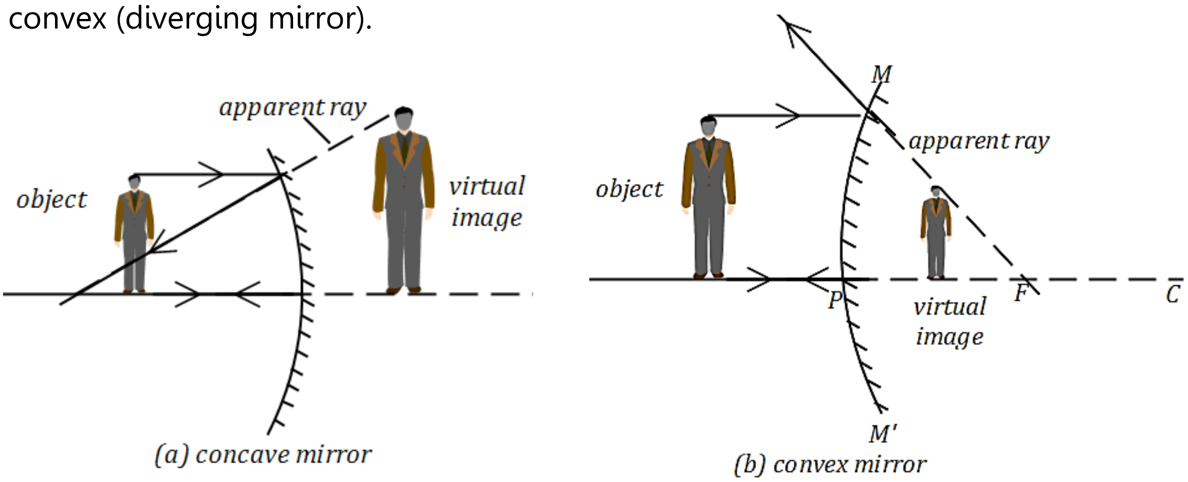
*Angle between reflected ray1 and reflected ray2* $= 26^0 - 14^0 = 12^0$

*Angle of rotation of the reflected ray is* $12^0$

*<u>Generally:</u> angle of rotation of the reflected ray is twice the angle of rotation of the mirror.*

**(2) <u>Reflection on curved surfaces</u>**

Laws of reflection apply to curved reflecting surfaces at any point of incidence. The normal at any point on the curved mirror is the line from the centre of the circle of which the reflector is a part. This point is called *centre of curvature*, C. There are two types of curved mirrors – the concave (converging) mirror and the convex (diverging mirror).




The centre of the mirror is called *pole*, P.

The line joining the centre of curvature and the pole is called the *principal axis*.

The width of the mirror $MM'$ is its *aperture*.

The point on the principal axis where parallel rays close to the principal axis converge at or diverge from after reflection from the concave or convex mirror is called *focal point* F.

<u>Note:</u>

A concave mirror has a real focus because rays of light do really reach it and cross over there after reflection.

A convex mirror has a virtual focus because rays of light only *appear* to come from it after reflection.

The distance between the focal point and the pole of the mirror is called *focal length*.

The distance between the centre of curvature and the pole of the mirror is called *radius of curvature*, $r$. Where $r = 2f$

## ***Ray diagrams***

These are used to locate the position and nature of the images formed after reflection of light from the mirror. However, position and the nature of the image depend entirely on the position of the object from the mirror.
In constructing ray diagrams,

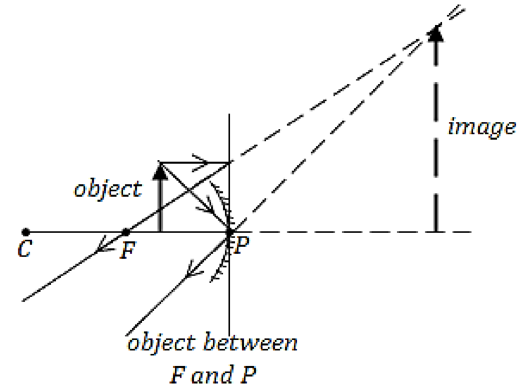
- rays originate from the head of the object,
- images are formed where rays intersect after reflection from the mirror,
- both the images and objects are perpendicular to the principal axis

*Key rays to consider*

- A ray parallel to principal axis is reflected through the focal point, F
- A ray through centre of curvature C is reflected along original path (incident along the radius where angle of incidence is $90^0$)
- A ray incident at the pole is reflected such that angle of incidence is equal to angle of reflection.

Any two rays should be used to locate the image or sometimes the object.

*Images formed in a concave mirror*




*Nature of image formed*

- *magnified( bigger than object)*
- *erect*
- *virtual*
- *behind the mirror as the object is in front*

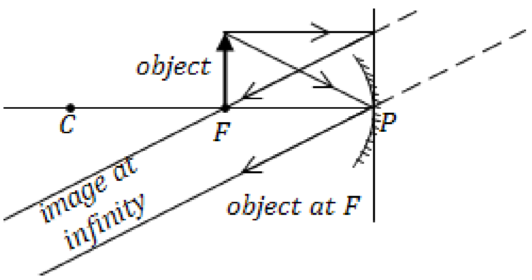
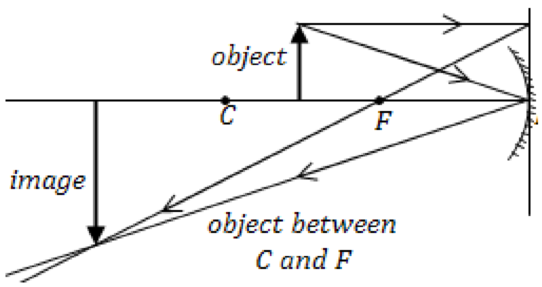
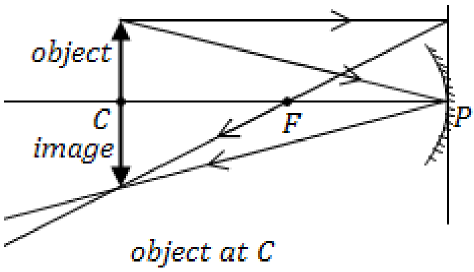



*image is formed at infinity*

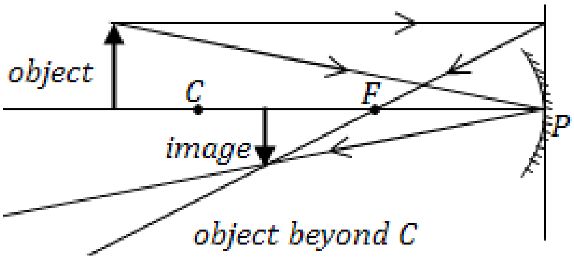



*Nature*

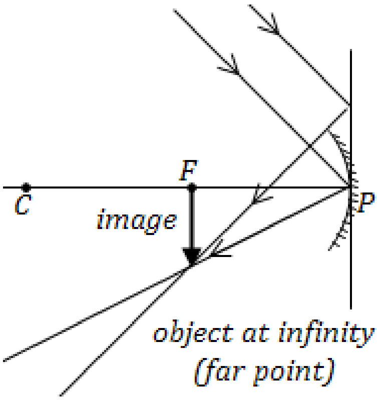
- *magnified*
- *inverted (upside down)*
- *real*




*Nature*
- *real*
- *inverted*
- *same size as the object*

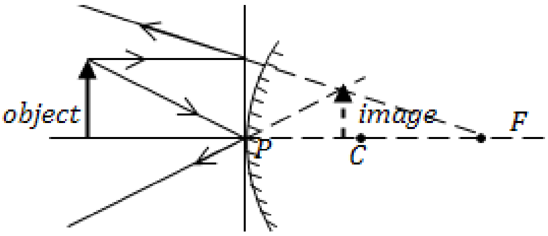



*Nature*
- *real*
- *inverted*
- *diminished ( smaller than object)*




*Nature*
- *image is real and*
- *inverted*

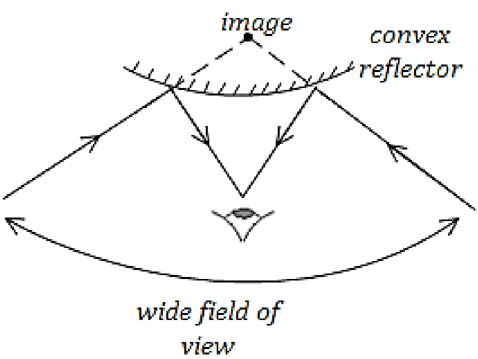
*Images formed in a convex mirror*




*Regardless of position f the object, images formed by convex mirrors are always*
- *virtual*
- *erect*
- *diminishes*
- *formed between P and F*

## Uses of curved mirrors

1. Concave mirrors are usually used for shaving and by dentists for examining teeth. These mirrors form magnified, erect and virtual images when objects are placed between F and P.
2. Concave mirrors are used as reflectors when the source of light is placed at its focal point F.
3. Concave mirrors are used as solar concentrators
4. Convex mirrors are use as car driving mirrors since they give a wide field of view than plane mirrors. Because of this, convex reflectors are used in supermarkets.



**Note;** when a wide parallel beam is incident onto a mirror of large aperture, paraxial rays (*rays very close and parallel to the principal axis*) and the marginal rays (*rays far from and parallel to the principal axis*) come from different focal points. *(See fig 1 below)*
A caustic curve (*a brightly illuminated area*) is formed as a result.
The reflected rays are tangential to the curve. *(See fig 2 below)*
A caustic curve is often seen in tea cups owing to reflection from the inner surface of the cup.

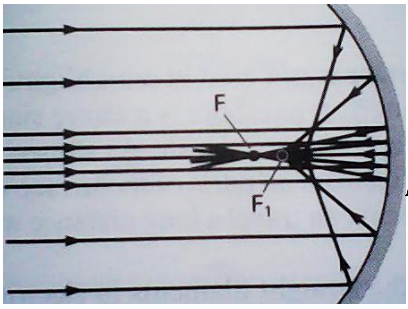
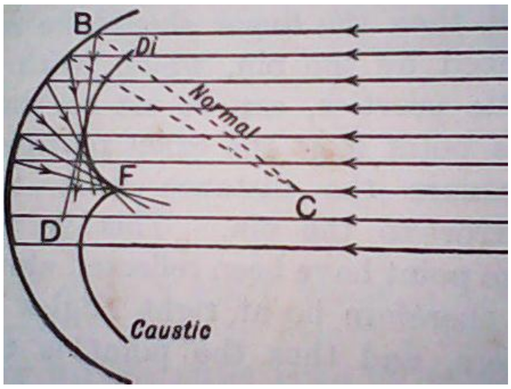
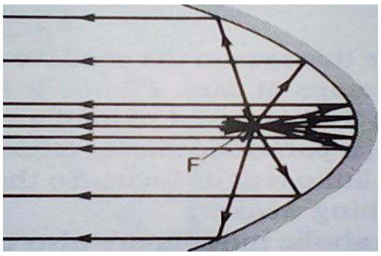



*Fig.*1

*Fig.*2




The above defect is reduced by using parabolic mirrors to obtain a large parallel beam of light.
Parabolic mirrors (reflectors that have the shape of a parabola) *reflect wide beam of light rays from a light source placed at the mirror's focus as a perfectly parallel beam without reducing its intensity as the distance from the mirror increases.*




Such reflectors are used in *automobile headlights, reflectors in torches and in searchlights*. Parabolic mirrors also bring parallel rays of light to a focus. This type of reflector is therefore valuable in astronomical telescopes.
Parabolic reflectors are also used as antennas in radio astronomy and radar to concentrate signals sent out by radio-transmitters.

***Mirror formula***

If $u$ is the object distance from the mirror of focal length, $f$ and $v$ is the image distance from the mirror,

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

This is the mirror formula.
*Sign convention*: "real" is "positive" and "virtual" is "negative"
In calculations, $f$ is "positive" for a concave mirror and "negative" for a convex mirror.

***Examples***

***Method I** (use of $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$)*

1. An object is placed 10cm from a concave mirror of focal length 6cm. determine the position ,magnification of the image formed. State the nature of the image formed.

   *Solution:* $u = 10cm, f = 6cm, v = ?$ $\frac{1}{6} = \frac{1}{10} + \frac{1}{v}$ $\Rightarrow v = 15cm$

   *Image is* $15cm$ *from the mirror in front of the mirror.*

   *Magnification* $m = \frac{15}{10} = 1.5$

   *Nature: image is*
   - *magnified (since* $m > 1$ *)*
   - *real (since* $v$ *is positive )*
   - *inverted (since* $v$ *is positive or* $u > f$*)*

2. An object 8cm high is placed perpendicularly on the principal axis 12cm away from a convex mirror. Find the focal length of the mirror if the height of the image formed is 2cm.

   *Solution:* $h_0 = 8cm, u = 12cm, f = ?,\ h_I = 2cm$

   $$m = \frac{h_I}{h_0} = \frac{v}{u} \Rightarrow \frac{2}{8} = \frac{v}{12} \Rightarrow v = 3cm \text{ behind the mirror (for a convex mirror)}$$

   $i.e\ \ u = 12cm, v = -3cm,\ f = ?,\ \Rightarrow \frac{1}{f} = \frac{1}{12} + \frac{1}{-3} \Rightarrow f = -4cm$

   *Focal length of the mirror is 4cm.*

3. An object is placed 4cm from a convex mirror of focal length 8cm.calculate the position of the image formed state the nature of the image.

   *Solution:* $u = 4cm, f = 8cm,\ v = ?$ $\frac{1}{8} = \frac{1}{4} + \frac{1}{v}$ $\Rightarrow v = -8cm$

   *Image is* $8cm$ *from the mirror behind the mirror.*

   *Magnification* $m = \frac{8}{4} = 2$

   *Nature: image is*
   - *magnified (since* $m > 1$ *)*
   - *virtual (since* $v$ *is negative )*
   - *erect (since* $u < f$*)*

4. An object 10cm high is placed at a distance of 60cm from a concave mirror of focal length 20cm. Find how high is the image.

   *Solution* $h_0 = 10cm, u = 60cm, f = 20cm,\ h_I = ?$

   $\frac{1}{20} = \frac{1}{60} + \frac{1}{v} \Rightarrow v = 30cm.\ \ m = \frac{h_I}{h_0} = \frac{v}{u} \Rightarrow \frac{h_I}{10} = \frac{30}{12} \Rightarrow h_I = 25cm$

   *Image is* $25cm$ *high.*

5. When an object is placed 20cm from a concave mirror, a real image magnified three times is formed.

   Find

   (i) the focal length of the mirror.

   (ii) where the object must be placed to give a virtual image three times the height of the object.

   *Solution:* $u = 20cm, f = ?,\ m = 3$ ,

   *(i)* $m = \frac{v}{u} \Rightarrow 3 = \frac{v}{20} \Rightarrow v = 60cm$ $\frac{1}{f} = \frac{1}{20} + \frac{1}{60} \Rightarrow f = 15cm$

   *(ii)* $u = ?, f = 15cm,\ m = 3 \Rightarrow h_I = 3h_0$ *and* $v = -3u$

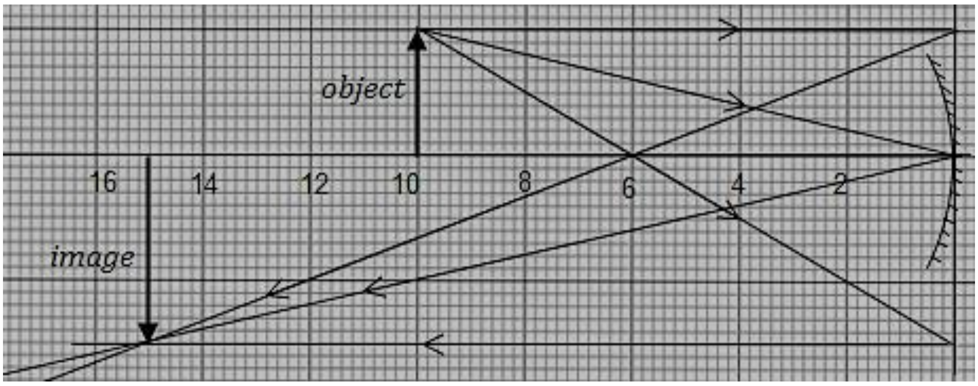
$\frac{1}{15} = \frac{1}{u} + \frac{1}{-3u} = \frac{2}{3u} \Rightarrow u = 10cm$

*Object has to be place is* $10cm$ *in front of the mirror.*

***Method II: Graphical***

- *A scale has to be chosen to ensure that the given information fits on the graph.*
- *Construction rays are used to locate the position of the object or the image.*

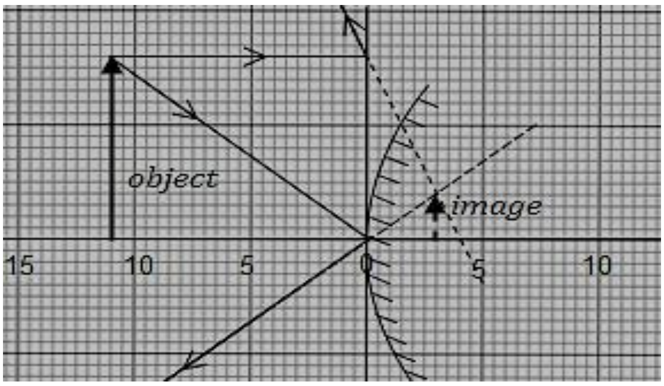
*Example: for question 1 above* $u = 10cm, f = 6cm, v = ?$




*From the graph, image is* $15cm$ *in front of the mirror.*

*For question 2 ,* $h_0 = 8cm, u = 12cm, f = ?, \quad h_I = 2cm$

$m = \frac{h_I}{h_0} = \frac{v}{u} \quad \Rightarrow \frac{2}{8} = \frac{v}{12} \quad \Rightarrow v = 3cm$



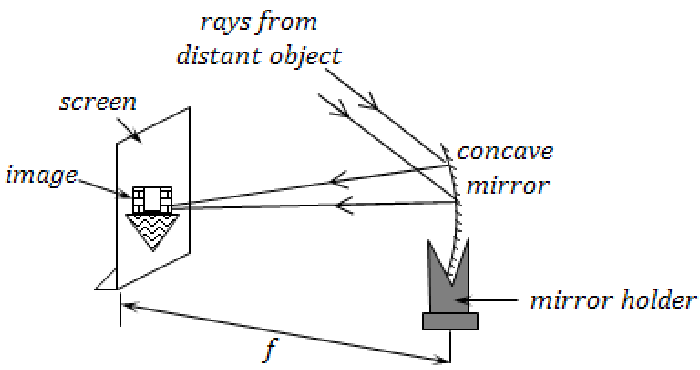

*From the graph, focal length of the mirror is* $4cm$.

***Methods of measuring focal length of a concave mirror***

(a) *Focusing a distant object*

*Apparatus: concave mirror, metre rule and screen.*

- A mirror and the screen are arranged as in the figure below.

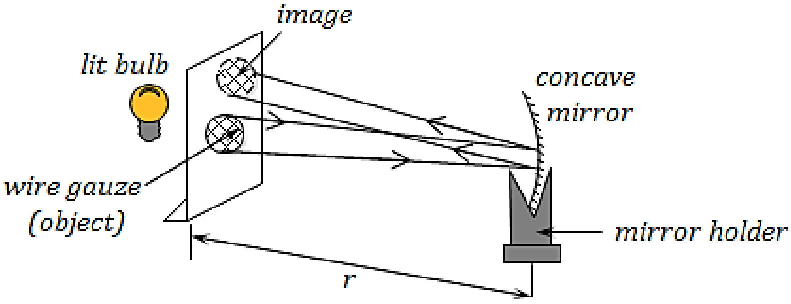


- A mirror is moved to and fro until sharp image of a distant object is formed on the screen
- Distance $f$ from the mirror to the screen is measured and recorded.
- This distance is the estimated focal length of the mirror.

*(b) <u>Focusing a lit/illuminated object</u>*

*<u>Apparatus:</u> concave mirror, screen with wire gauze mounted, metre rule, lit torch bulb*

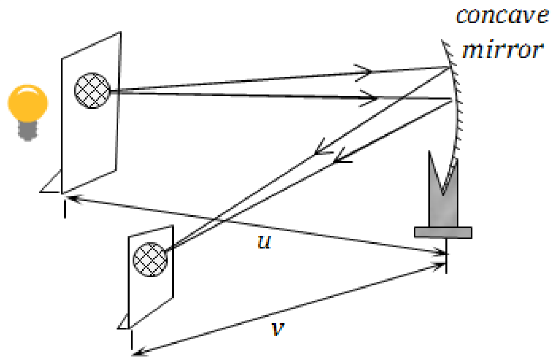
- The apparatus is arranged as in the figure below.




- A lit bulb is placed near the wire gauze and the mirror move to and fro until a sharp image is formed alongside the object.
- Distance $r$ between the screen and the mirror is measured.
- Focal length $f$ of the mirror is obtained from $f = \frac{r}{2}$

*(c) <u>Measurement of image and object distances</u>*

*<u>Apparatus:</u> concave mirror, 2 screens one with wire gauze mounted, metre rule, and lit torch bulb.*




- The apparatus is arranged as in the figure above.
- A mirror is placed at a known distance $u$ from the wire gauze.
- The screen is moved to and fro until a clearly focused image is observed.
- The distance $v$ between the mirror and the screen is measured and recorded.
- Focal length $f$ is obtained from $f = \frac{uv}{u+v}$
- Experiment is repeated for different values of $u$ and the mean value of $f$ gives the focal length of the mirror.

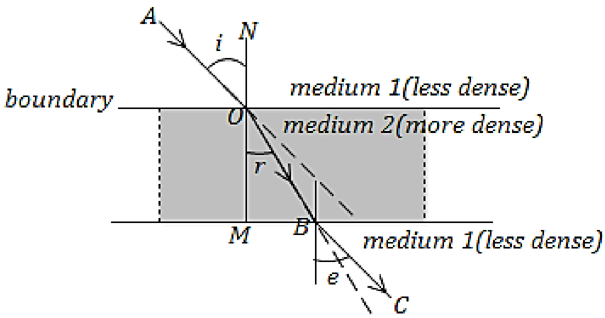
## (C) REFRACTION OF LIGHT

This is the bending of light rays at the boundary as they travel from one transparent medium to another of different densities.

Refraction is caused by differences in speeds of light as it travels through various media.

e.g $3.0 \times 10^8 ms^{-1}$ in vacuum, $2.24 \times 10^5 ms^{-1}$ in water and $1.98 \times 10^5 ms^{-1}$ in glass.

When a ray of light travels from a **L**ess optically dense medium to a **M**ore optically dense medium it bends **T**owards the normal (**LMT**) and it bends **A**way from the normal as it travels from a **M**ore optically dense to a **L**ess optically dense medium(**LMA**)

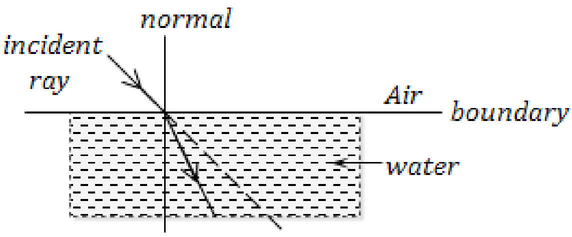


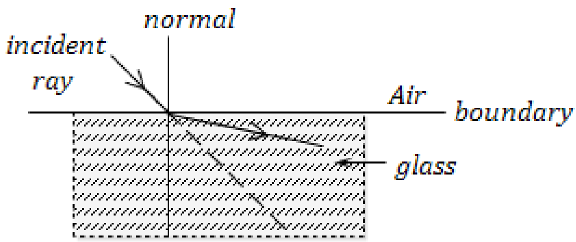

$\overrightarrow{AO}$ is the incident ray, $\overline{NO}$ is the normal at O, $\overrightarrow{OB}$ is the refracted ray and $\overrightarrow{BC}$ is the emergent ray

$i$ is the angle of incidence and $r$ is the angle of refraction and $e$ is the angle of emergence.

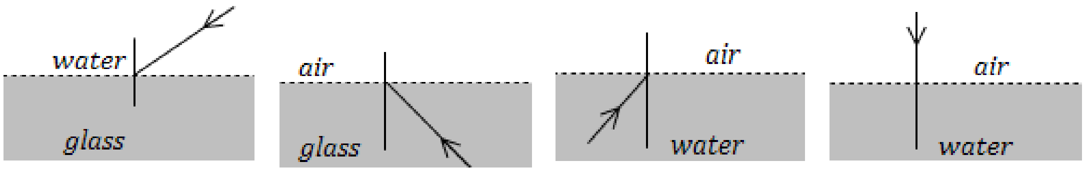
The incident ray is parallel to the emergent ray.

Experiments show that glass is more optically dense than water and denser than air.




*Question*: *In the diagrams below, show the refracted ray and the emergent ray*




### *Laws of refraction of light*

1. The incident ray, the normal and the refracted ray at the point of incidence all lie in the same plane.
2. The ratio of the angle sine of angle of incidence to the sine of angle of refraction is a constant. i.e. $\frac{\sin i}{\sin r} = constant$. This is referred to as Snell's law

   The constant is called *refractive index*, $n$ of the second material with respect to the first material.

If a ray of light travels from medium 1 to medium 2, $\boxed{n_1 \sin i_1 = n_2 \sin r_2}$

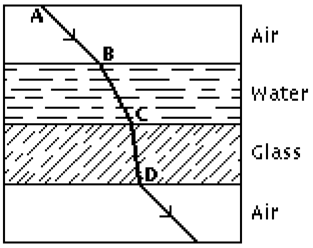
Where $n_1$ and $n_2$ are absolute refractive indices of medium 1 and 2 respectively.

E.g. For glass $n = 1.52$ water $n = \frac{4}{3} \approx 1.33$ and air $n = 1$

*Generally,*

- The refractive index of a denser transparent substance is higher than that of a less dense material; that is, the velocity of light is lower in the denser substance.
- Rays of light incident along the normal are reflected and refracted along the normal.

The figure below shows a ray of light travelling from layers of different media




***Worked examples***

1. A ray of light is incident on glass – water boundary at an angle of incidence $50^0$. Calculate the angle of refraction (refractive index of water $n = \frac{4}{3}$ and that of glass $n = 1.5$ )
   $n_1 \sin i_1 = n_2 \sin r_2$ *where* $n_1 = 1.5$ $i_1 = 50^0$ *and* $n_2 = \frac{4}{3}$
   $\Rightarrow 1.5 \sin 50^0 = \frac{4}{3} \sin r_2 \quad \Rightarrow r_2 = 59.5^0$
   *Angle of refraction is* $59.5^0$
2. A ray of light is incident on a water – air boundary such that the angle of refraction is $70^0$. What is the angle of incidence? (Refractive index of water $= 1.33$)
   $n_1 \sin i_1 = n_2 \sin r_2$ *where* $n_1 = 1.33$ $i_1 = ?$ $r_2 = 70^0$ *and* $n_2 = 1$
   $\Rightarrow 1.33 \sin i = \sin 70^0 \quad \Rightarrow i_1 = 44.95^0 \approx 45^0$
   *Angle of incidence is* $45^0$

***Questions***

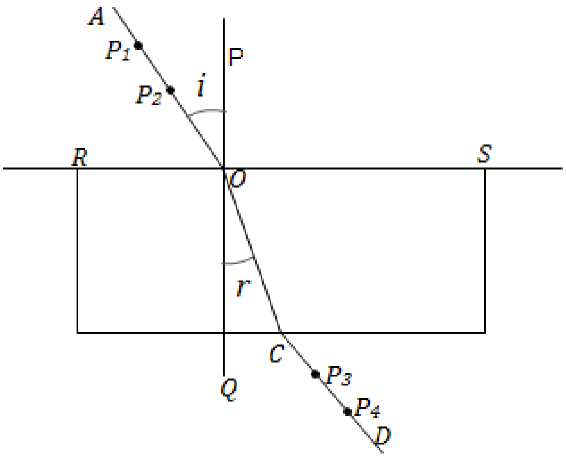
1. A ray of light travelling from air to glass makes an angle of incidence $40^0$. Find the angle of refraction.
2. A ray of light to a glass – water boundary makes an angle of incidence $30^0$. Find the angle of refraction (refractive index of water $n = 1.33$ and that of glass $n = 1.52$ )

***Experiment to determine refractive index of material of glass***

*Apparatus: glass block, cardboard, 4 optical pins, 4drawing pins, white plane sheet of paper, complete mathematical set.*

(a) Fix the white sheet of paper provided on a soft board using the drawing pins provided.

(b) Draw two lines $\overline{PQ}$ and $\overline{RS}$ intersecting at right angles at O as shown in the figure below.




(c) Draw a line $\overline{AO}$ making an angle $i = 20^0$ with PQ. Stick two pins $P_1$ and $P_2$ vertically along $\overline{AO}$.

(d) Place the glass block with the longest edge along RS and trace its outline.

(e) Looking through the glass block from the opposite face, stick two other pins $P_3$ and $P_4$ such that they appear to be in line with image pins of $P_1$ and $P_2$.

(f) Remove the glass block and the pins. Draw lines $\overline{DC}$ and $\overline{CO}$.

(g) Measure and record angle $r$

(h) Repeat procedures (e) to (f) for values of $i = 20^0, 30^0, 40^0$ *and* $50^0$.

(i) Enter your results in the table below

| $i(^0)$ | $r(^0)$ | $\sin i$ | $\sin r$ | $\frac{\sin i}{\sin r}$ |
|---|---|---|---|---|
| 20 | | | | |
| 30 | | | | |
| 40 | | | | |
| 50 | | | | |

(j) What is the average value of $\frac{\sin i}{\sin r}$?

*The average value of* $\frac{\sin i}{\sin r}$ *gives refractive index of the material of glass used.*

***Effects of refraction of light***

Refraction of light rays at plane surfaces causes

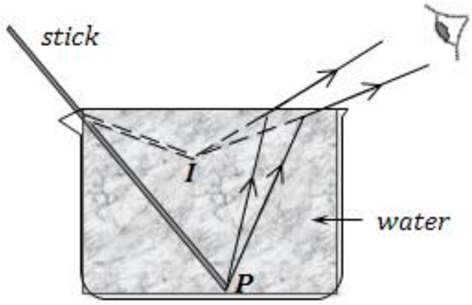
(a) A partially immersed stick dipped at an angle into water to appear bent at the boundary between air and water.

(b) A stick placed upright in water to appear shorter

(c) A water pool to appear shallower

(d) An object placed underneath a glass block appears nearer to the top.

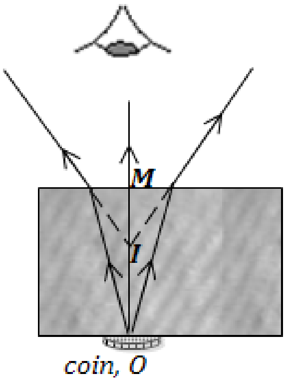
These observations can be explained using the figure below




The rays from a point P on the object in water to air are refracted away from the normal and to an observer; rays appear to come from point I. Thus a stick appears bent.

***Real and apparent depth***

A coin placed underneath a glass block is considered.




$\mathbf{I}$ is the virtual image of the object thus distance $\overline{\mathbf{I}M}$ to the surface is called *apparent depth*, distance $\overline{O\mathbf{I}}$ is the *displacement* and the distance from the object O to the surface is called the *real depth.*

Refractive index of the material of glass $n = \frac{real\ depth}{apparent\ depth}$ and from the figure $\overline{\mathbf{O}M} = \overline{O\mathbf{I}} + \overline{\mathbf{I}M}$

***Example***

1. A swimming bath contains water at a depth of 2.4m. What is the apparent depth of the bath?

$$real\ depth = 2.4m, n = \frac{4}{3}\ apparent = ?\ \ n = \frac{real\ depth}{apparent\ depth} \Rightarrow \frac{4}{3} = \frac{2.4}{app}$$

$$\Rightarrow apparent\ depth = 1.8m$$

2. A glass block 9cm thick of refractive index 1.5 is placed over a mark on a paper. What will be the displacement of the mark in glass when vied from above?

$$real\ depth = 9cm, n = 1.5\ \ apparent = ?\ \ 1.5 = \frac{9}{app} \Rightarrow apparent\ depth = 6cm$$

$$displacement = 9 - 6 = 3cm$$

## ***TOTAL INTERNAL REFLECTION***

A ray of light travelling from glass to air is considered. On incident with glass – air boundary, part of light is strongly refracted and the other weakly reflected (*Fig. a*).

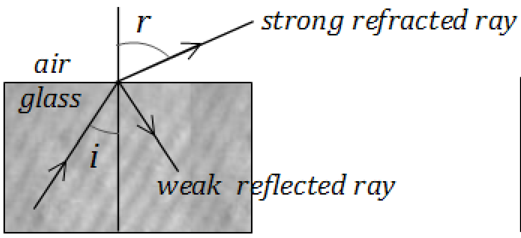



*Fig. a*

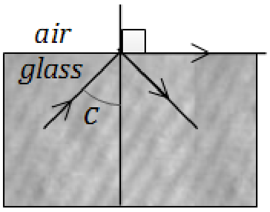



*Fig. b*

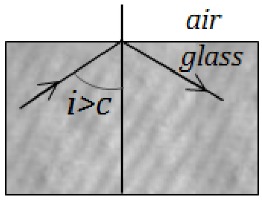



*Fig. c*

As the angle of incidence increases the angle of refraction also increases. An angle of incidence called *critical angle* is eventually reached which produces an angle of refraction equal to $90^0$(*Fig. b*).

*Thus critical angle is the angle of incidence in optically dense medium when angle of refraction in optically less dense medium is* $90^0$.

If the angle of incidence is greater than the critical angle, the reflected ray becomes bright. At this point all the light is totally internally reflected. (*Fig. c*)

Thus total internal reflection occurs when

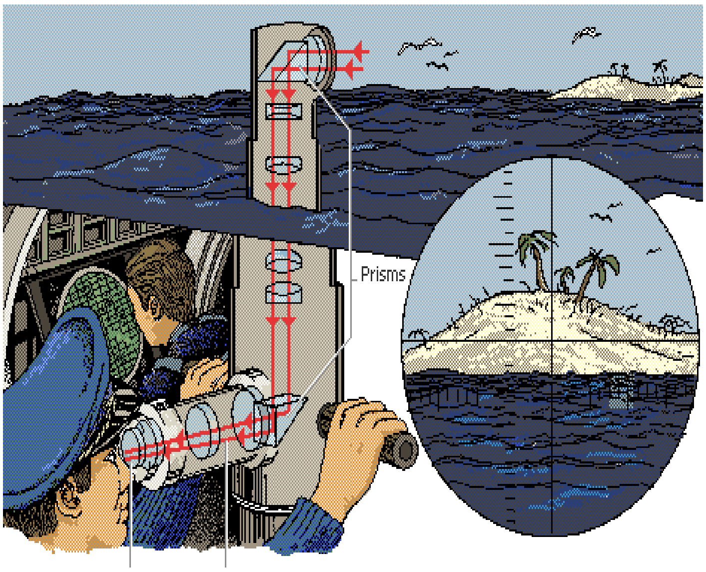
- When light travels from an optically dense medium to optically less dense medium.
- When angle of incidence in optically dense medium is greater than its critical angle.

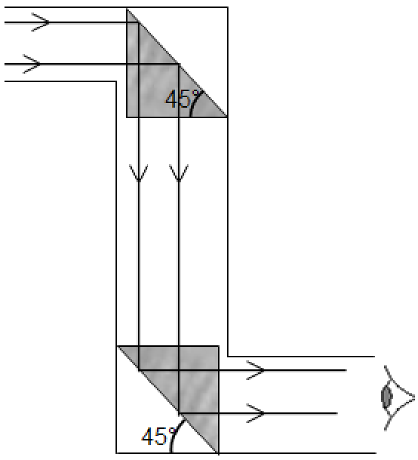
Critical angle, $c$ of a medium of index, $n$ is obtained from $\sin c = \frac{1}{n}$

e.g. for glass of $n = 1.5$ , $\sin c = \frac{1}{1.5}$ $\Rightarrow c = 41.8^0$

## ***Application of total internal reflection***

1. *reflection by prisms in periscopes*




This simple periscope consists of triangular glass prisms at opposite ends of a tube with the longest surfaces parallel to each other, and at an angle of 45° to the axis of the tube. The angle of incidence on the longest side is 45° which is greater than critical angle of glass. Thus light is totally internally reflected at the longest side.

In periscopes prisms are preferred to plane mirrors because

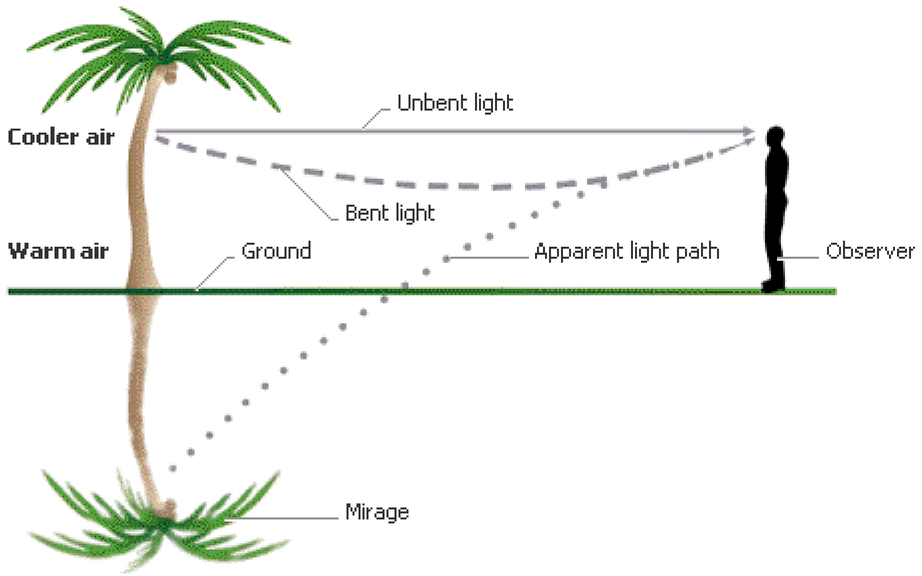
- prisms do not tarnish and deteriorate the quality of image formed as plane mirrors which absorb light and produce fainter images.
- prisms produce clear images since they totally internally reflect light where as mirrors produce blurred images due to several reflections on glass surface and silvered surface.

2. *Mirages*: mirages are created when light is refracted, as it travels through layers of air with differing densities. Changes in air density are usually caused by changes in air temperature.

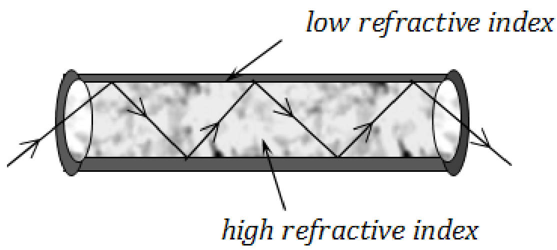
During a hot day, air near earth surface is heated and becomes optically less dense than air above. Light from the sky gradually refracts as it passes from warmer to cold air layers. At a point when critical angle of denser air layers is exceeded, all the light is reflected upwards into denser layers.

To the observer, the ray seems to point into the ground and a pool of water is seen in the road away from him.

In hot deserts, people may see an inverted image of a tree in a pool of water below the actual tree




3. Fibre optics: optical fibres consist of many long fine strands of high – quality glass coated with glass of lower refractive index.

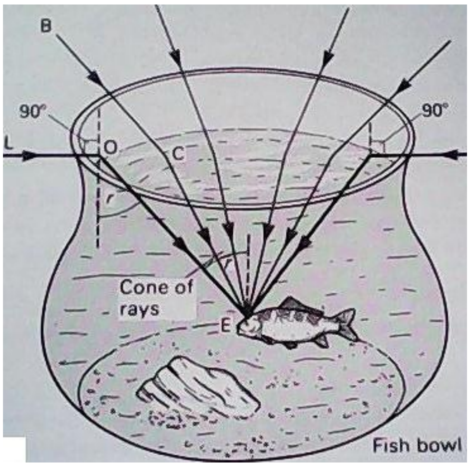



If light enters a solid glass obliquely, it is totally reflected at the boundary of the tube and, after a number of successive total reflections, emerges from the other end.

Glass fibers are used to transmit images especially in examining the inside of the throat.

Fiber-optic cables carry more information, suffer less interference, and require fewer signal repeaters over long distances than wires.

4. Fish-eye view




Rays incident on air-water boundary are refracted as in the figure. At a point when the angle of incidence is $90^0$ angle of refraction $r$ is $49^0$.

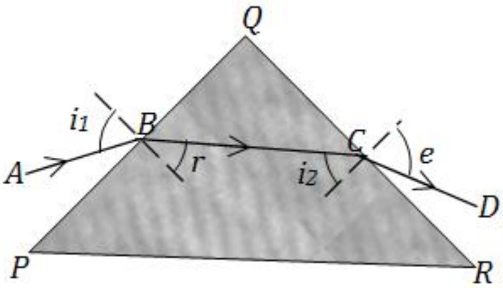
$n_1\, sin\, i_1 = n_2\, sin\, r_2$ *where* $n_1 = 1$ $i_1 = 90^0$
$n_2 = 1.33$ *and* $r_2 = r$ ?
$\Rightarrow sin\, 90^0 = 1.33\, sin\, r \Rightarrow r = 48.75^0 \approx 49^0$

*Angle of refraction is* $49^0$*(this is critical angle of water)*

Thus rays in the cone of angle $98^0$ fall into the fish's eye.

***<u>Refraction by triangular prisms</u>***

If light falls on one surface, PQ of a prism, it is refracted along BC and the emergent ray CD is no longer parallel to the incident ray AB.

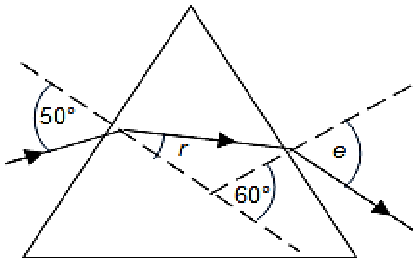



$i_1$ is the angle of incidence on face PQ,
$i_2$ is the angle of incidence on face QR,
$r$ and $e$ are angle of refraction at faces PQ and QR respectively.
$e$ is also called angle of emergence.

At each point of incidence, $\boxed{n_1 \sin i_1 = n_2 \sin r_2}$

***<u>Example</u>***

1. The diagram in the figure below shows a ray of yellow light incident at an angle of $50^0$ on one side of an equilateral triangular glass prism of refractive index 1.52.

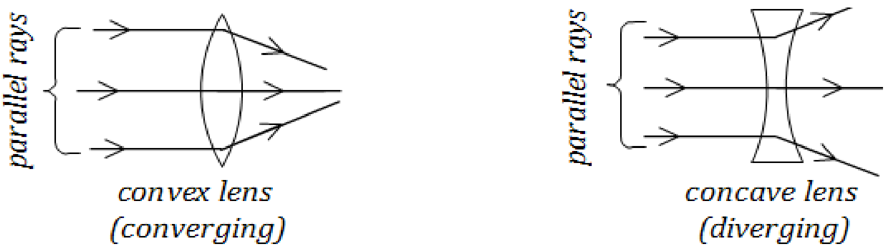



Calculate the angles marked $r$ and $e$

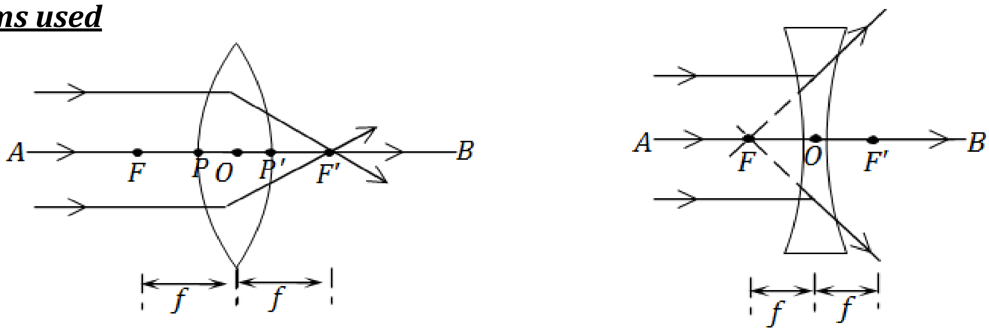
*Solution: for air – glass;* $n_1 = 1, i_1 = 50^0, r =?$
*Using* $n_1\, sin\, i_1 = n_2\, sin\, r_2$
$1\, sin\, 50^0 = 1.52\, sin\, r \quad r = 30.3^0$
*Let angle of incidence on second face be* $i_2$
$r + i_2 = 60^0$ *(sum of two interior angles)*
$30.3^0 + i_2 = 60^0 \Rightarrow i_2 = 29.7^0$
*For glass – air,* $n_1 = 1.52, i_2 = 29.7^0, r = e = ?, n_2 = 1$
*Using* $n_1\, sin\, i_1 = n_2\, sin\, r_2 \Rightarrow 1.52\, sin\, 29.7^0 = \sin e \Rightarrow e = 48.9^0$

## (D)LENSES AND OPTICAL INSTRUMENTS

A lens is a transparent substance usually made of glass, with two refracting surfaces.
Lenses are used in spectacles, cameras microscopes, telescopes, eyes.
A lens is regarded as a combination of many triangular prisms each refracting light toward its base. Rays incident at the centre of the lens pass through un deviated since prisms at the centre have no refracting angles.
There are two types of lenses – convex (converging) and concave (diverging) lens




***Terms used***




1. *Optical centre*, O is the centre of the lens between the poles of the curved surfaces.
2. The *principal axis* (AB) is a line through the optical centre joining the centres of the curved surfaces of the lenses.
3. *Principal focus* F is a point on the principal axis to which rays parallel to the axis converge at or diverge from after refraction through convex lens and concave lens respectively.
4. *Focal length* $f$ is the distance between the focal point and the optical centre of a lens.

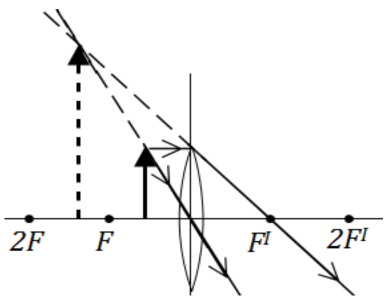
***Construction of ray diagrams***

***(a) For a converging (convex) lens***

*Key rays:*

1. Rays parallel and close to the principal axis converge at focal point, F. (vice versa)
2. Rays through optical centre are not deviated

*(i) Object placed between optical centre and focal point*



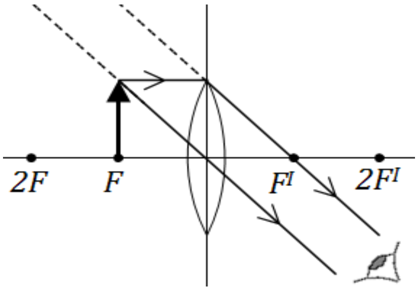

*Nature: image formed is*

- *Magnified*
- *Erect*
- *Virtual*
- *On same side as the object*

A convex lens in this way acts as a magnifying glass

A magnifying glass is a large convex lens commonly used to examine small objects. The lens bends incoming light so that an enlarged, virtual image of the object appears beyond it. The image is called virtual because it is only perceived by the viewer's brain, and cannot be produced on a screen.

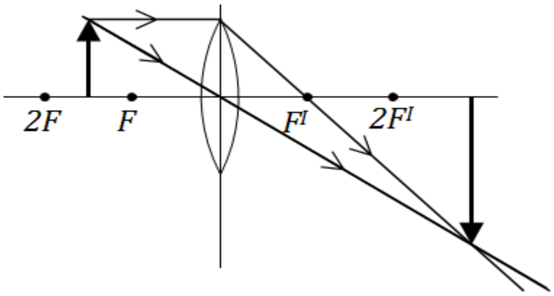
*(ii) Object placed at focal point*




*Nature: image formed is*

- *Magnified*
- *Erect*
- *Virtual*

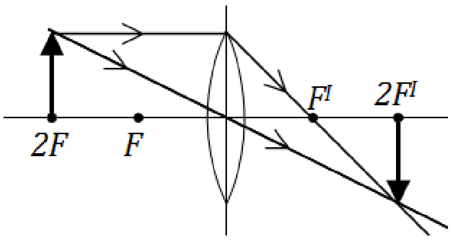
*(iii) Object placed between 2F and focal point, F*




*Nature: image formed is*

- *Magnified*
- *inverted*
- *real*
- *beyond $2F^I$*

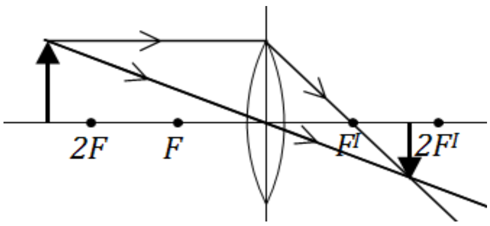
*(iv) Object placed at 2F*




*Nature: image formed is*

- *of same size as the object*
- *inverted*
- *real*
- *at $2F^I$*

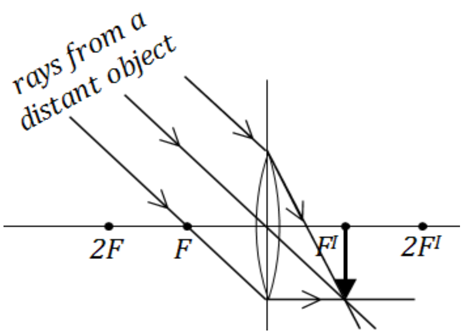
*(v) Object placed beyond 2F*




*Nature: image formed is*

- *diminished*
- *inverted*
- *real*
- *between $F^I$ and $2F^I$*

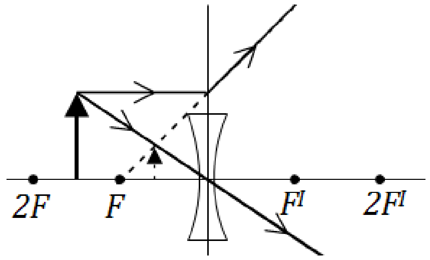
*(vi) Object at infinity*




*Nature: image formed is*

- *diminished*
- *inverted*
- *real*
- *at $F^I$*

### *(b) For a diverging (concave) lens*




Nature: *image formed is*

- *diminished*
- *erect*
- *virtual*
- *between F and optical centre*

Generally, images formed by a diverging lens are always *virtual, erect, diminished* and *formed between optical centre and the focal point*, for all positions of the object.

*Magnification* of the image by a lens $m = \frac{v}{u} = \frac{h_I}{h_O}$
$u$ is the object distance of height/size $h_o$
$v$ is the image distance of height $h_I$
Note: $u$ and $v$ are measured from the optical centre of a lens

***Power of a lens***: is the reciprocal of its focal length $P = \frac{1}{f}$ . $f$ is the focal length of a lens.
S.I units of $f$ are metres $m$ thus S.I units of power of a lens are *diopters* (D).
$f$ is "positive" for a convex lens and "negative" for concave lens.

***Lens formula***
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ Where $u$ and $v$ is the object and image distance from the lens respectively.

***Examples***
***Method 1 (use of*** $\boldsymbol{\frac{1}{f} = \frac{1}{u} + \frac{1}{v}}$***)***

1. A convex lens forms a real image twice the size of an object, 15cm from the lens. The focal length of the lens is 10cm. find the position of the image from the lens.
   *Solution; magnification* $m = 2$ , $u = 15cm$ $v = ?$
   $\Rightarrow m = 2 = \frac{v}{15}, \Rightarrow v = 30cm$
   *The image is* $30cm$ *from the lens.*
   *Or Using* $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{10} = \frac{1}{15} + \frac{1}{v} \Rightarrow v = 30cm$

2. An object is 40mm high and 120cm from the centre of the convex lens of focal length 80mm.
   Find the
   (i) image distance and its height.
   (ii) power of the lens.
   *Solution;* $u = 120mm$ $h_o = 40mm$ $f = 80mm,$ $v = ?$
   *(i) Using* $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{80} = \frac{1}{120} + \frac{1}{v} \Rightarrow v = 240mm$
   $m = \frac{v}{u} = \frac{h_I}{h_o} \Rightarrow \frac{240}{120} = \frac{h_I}{40} \Rightarrow h_I = 80mm$

   *(ii)* $f = 80mm = \frac{80}{1000} = 0.08m$ *Thus power* $P = \frac{1}{f} = \frac{1}{0.08} = 12.5D$

3. A lens 20cm from an object produces a virtual image $\frac{2}{3}$ the size of the object. Find the position of the image, the kind of the lens used and its focal length

   *Solution; magnification* $m = \frac{2}{3}, u = 20cm \ v = ?$

   *Since the image is virtual,* $\Rightarrow m = \frac{2}{3} = \frac{-v}{20}, \Rightarrow v = -\frac{40}{3}cm$

   *The image is about* $13.3cm$ *from the lens*

   *Using* $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{20} + \frac{-3}{40} \Rightarrow f = -40cm$

   *Since f is a negative, the lens used was a concave.*

4. A screen is placed 80cm from the object. A lens is used to produce an image with magnification 3 on the screen.
   What is the
   (i) distance between the object and the lens,
   (ii) focal length of the lens?

   *Solution;*

   *(i) Magnification* $m = 3, u + v = 80cm \ v = ?$

   $m = 3 = \frac{v}{u} \Rightarrow, \Rightarrow \ v = 3u$

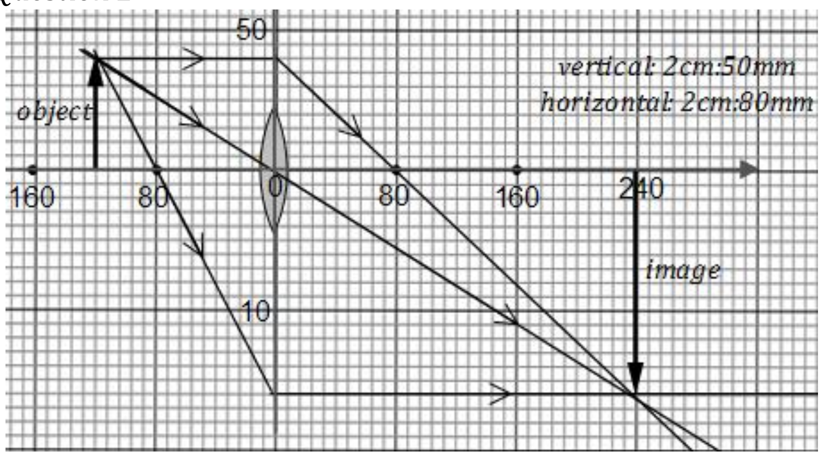
   *Thus* $u + 3u = 80cm \Rightarrow 4u = 80cm \Rightarrow u = 20cm.$ *The object is* $20cm$ *from the lens.*

   *(ii)* $v = 3 \times 20 = 60cm$

   *Using* $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{20} + \frac{1}{60} \Rightarrow f = 15cm$ *Focal length of the lens is* $15cm$

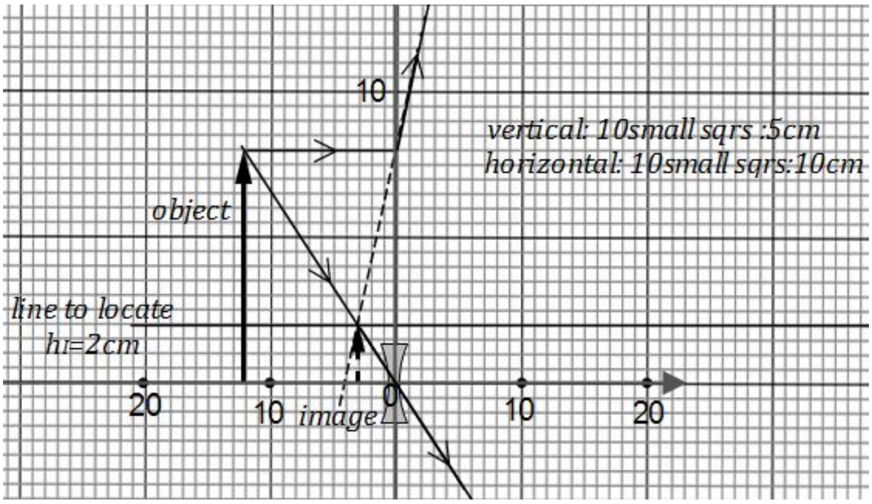
***<u>Method II</u> (use of graph)***

*Question 2*




*From the graph;*
*Image distance is* $240mm$ *and*
*Height of image* $= 16 \times 5 = 80mm$

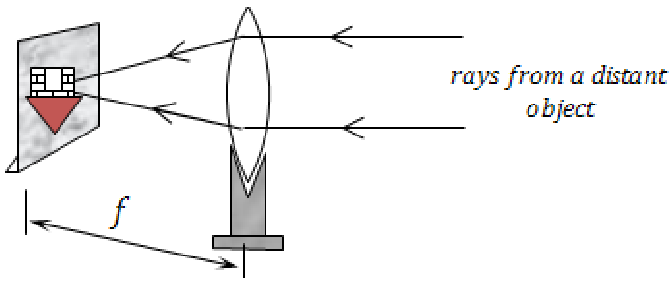
2. An object 8cm high is placed perpendicularly on the principal axis 12cm away from a diverging lens. If the height of the image formed is 2 cm, with the aid of a ray diagram, find the
   (i) image distance and
   (ii) focal length of the lens.




*<u>Location of image:</u>*
*Draw a horizontal line at* $h_I = 2$cm
*Draw a ray through the optical centre.*
*Where these intersect, is the where the head of the image is supposed to be.*
*The other ray parallel to the axis passes through this point after refraction. This ray meets the axis at the focal point of the lens. Thus image distance* 3cm *and the focal length is* 4cm

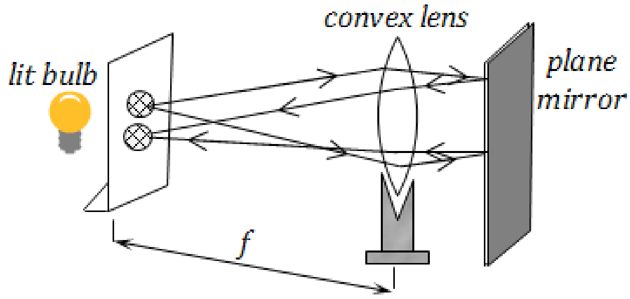
## DETERMINATION OF FOCAL LENGTH OF A CONVERGING LENS

1. *<u>Focusing a distant object</u>*
   *Apparatus: screen, convex lens, metre rule*




The apparatus is arranged as in the figure above.
A lens is moved to and fro until a clearly focused image is obtained.
The distance $f$ between the screen and the lens is measured and recorded.
This distance give estimated focal length of the lens.

2. *<u>Plane mirror method</u>*
   *Apparatus: plane mirror, convex lens, screen with hole covered with wire gauze, metre rule, lit bulb*

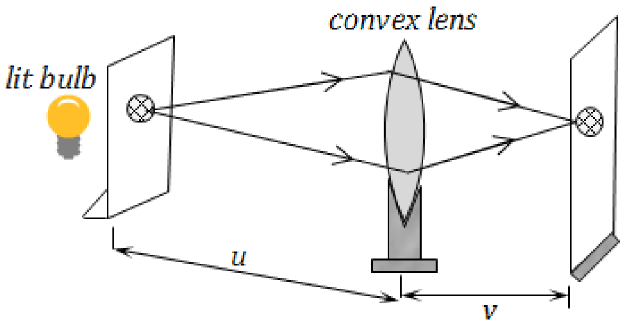



A plane mirror is placed behind a lens and an illuminated object in front of the lens.
The lens is moved to and fro until a sharp image is formed alongside the object.
The distance $f$ between the screen and the lens is measured and recorded.

At different positions of the lens, various values of $f$ are obtained and the average value gives focal length of the lens.

3. *Measurement of u and v*

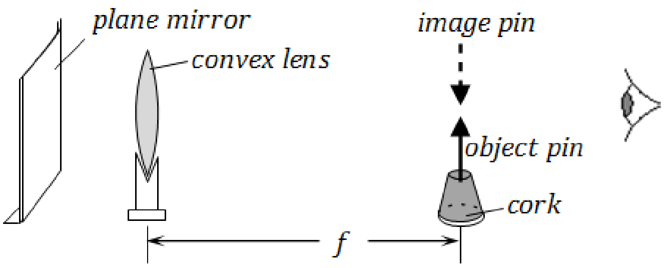
*Apparatus: convex lens, 2 screens one with hole covered with wire gauze, metre rule and lit bulb*




The apparatus is arranged as in the figure above.
A lens is placed at a known distance $u$ from the wire gauze.
The screen is moved to and fro until a clearly focused image is observed.
The distance $v$ between the lens and the screen is measured and recorded.
Focal length $f$ is obtained from $f = \frac{uv}{u+v}$
Experiment is repeated for different values of $u$ and the mean value of $f$ gives the focal length of the lens.

4. *No parallax method*

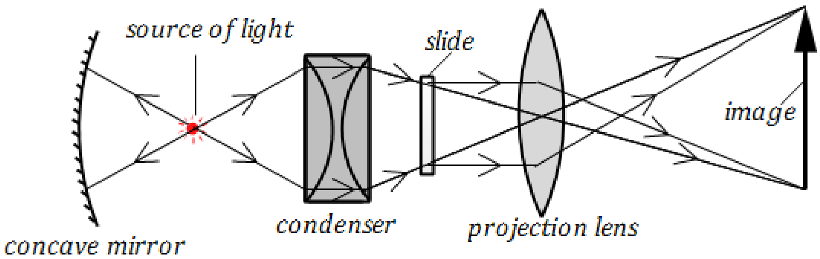
*Apparatus: convex lens in a holder, plane mirror fixed on a piece of wood, optical pin stuck in a cork and metre rule.*




- The apparatus is arranged as in the figure above with the tip of the pin in line with the centre of the lens
- The pin is moved to and fro until it coincides with its image as seen through the lens.
- The distance, $f$ between the pin and the lens is measured and recorded
- More than two values of $f$ are obtained and the average value gives focal length of the lens.

## ***Application of lenses***

*(a) Slide projector*




The slide is illuminated by a powerful source of light which is placed at the centre of curvature of the concave mirror.
The mirror reflects back the light which would be wasted.
The condenser (combination of Plano – convex lenses) collects and concentrates light onto the slide
A heater filter inside the condenser (*not shown*) helps to absorb any heat from the source which would melt the slide
A projection lens moved to and fro forms a sharp, real, erect and magnified image on the screen.

Note: distance from the slide to the lens should be greater than the focal length of the lens so as to form a real image.

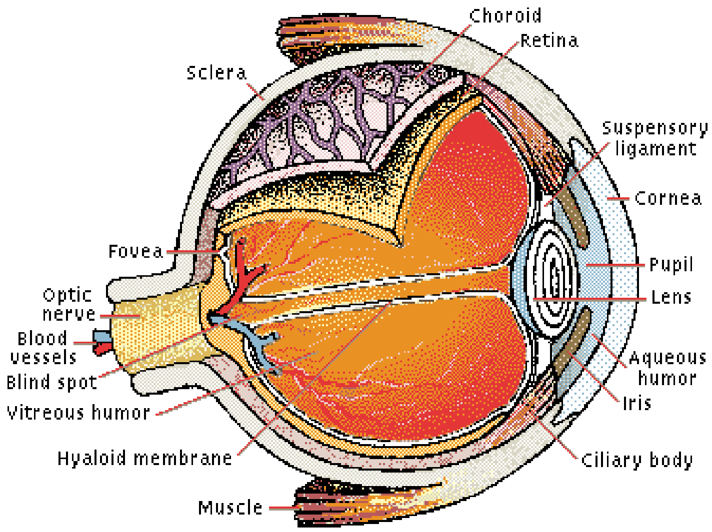
### ***Examples***

1. A projection lens is used to produce a sharp image of an object when the object and the screen are 160cm apart. If the linear magnification is 7, calculate the focal length of the lens used.

   *Magnification* $m = 7\,, u + v = 160cm \;\; v = ?$
   *Thus* $u + 7u = 160cm \;\; \Rightarrow 8u = 160cm \;\; \Rightarrow u = 20cm$. *The object is* $20cm$ *from the lens.*
   $v = 7 \times 20 = 140cm$
   *Using* $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{20} + \frac{1}{140} \Rightarrow f = 17.5cm$ *focal length of the lens is* $17.5cm$

2. A slide projector using slide 5cm by 5cm produces a picture of 3cm by 3cm on the screen at a distance of 24cm from the projection lens.
   (i) How far from the lens must the slide be?
   (ii) Make an approximate focal length of the projection lens.
   *Solution;* $u = ? \;\; h_o = 5cm \; h_I = 3cm, \; f = ?, \; v = 24cm$
   *(i)* $m = \frac{3}{5} = \frac{24}{u} \Rightarrow u = 40cm$ *The slide must be* $40cm$ *from the lens.*
   *(ii) Using* $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} \Rightarrow \frac{1}{f} = \frac{1}{14} + \frac{1}{40} \Rightarrow f = 15cm$
   *Focal length of the projection lens is* $15cm$.

(b) <u>The eye</u>



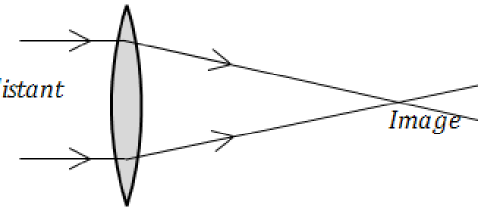

The eye lens is elastic and focuses light entering the eye forming a real, inverted and diminished image on the retina.

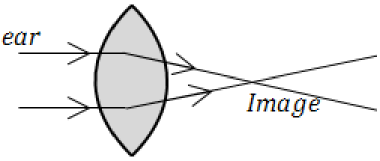
Iris controls size of the pupil by making it narrow in bright light and wide in dim light, by reflex action.

The pupil allows light to pass through.

*Accommodation* is the ability of the lens for a normal eye to focus the images of objects at different distances on the retina.

A normal eye in focusing a distant object makes its lens thinner with a longer focal length. Lens is made thicker with a short focal length to focus nearby objects.



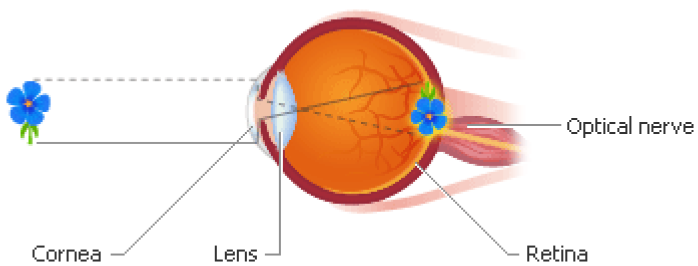

An image is formed on the retina and impulses are sent to the brain for interpretation. The image lasts on the retina for about a $\frac{1}{10}^{th}$ of a second after the object has disappeared. This means that the brain retains an impression of the image on the retina for a bout a $\frac{1}{10}^{th}$ of a second. This is termed as *persistence vision.*

***<u>Defects of the eye</u>***

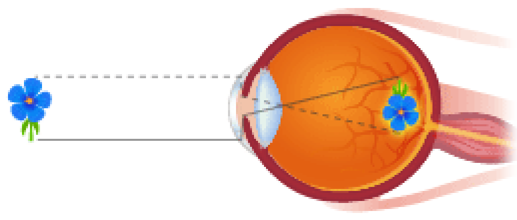
A normal eye forms an inverted, real and diminished image on the retina.

The defects of the eye are *short sightedness (myopia)* and *long sightedness (hyperopia)*

**Normal vision**

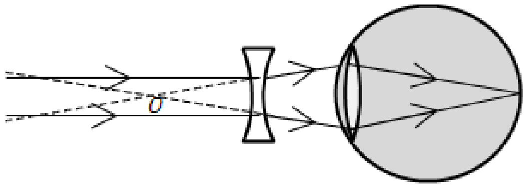



1. ***<u>Short sightedness:</u>*** a person with this defect sees near objects clearly and distant objects appear blurred.
   Rays from distant objects come to focus before reaching the retina. This is caused by eyeball being too long hence shorter focal length of the lens.



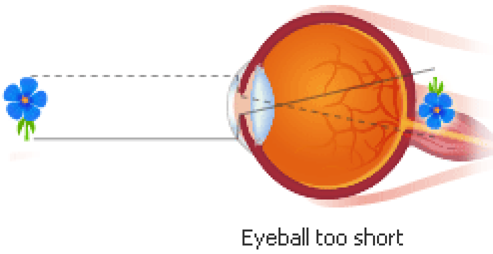
Eyeball too long

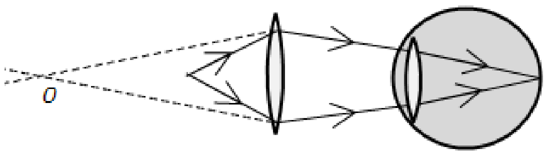
It is corrected by wearing spectacles containing a diverging lens.




*Diverging lens causes rays to diverge as though coming from O*

2. ***Long sightedness:*** a person with this defect sees distant objects clearly but not near ones.
   Rays from near objects are focused behind the retina. This is caused by eyeball being too short hence long focal length.
   This is corrected by wearing spectacles containing converging lens

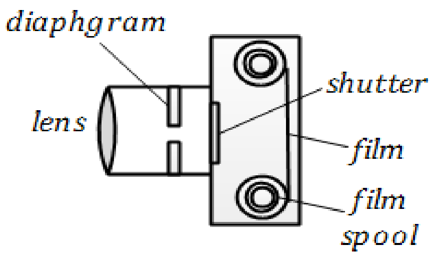



*Converging lens reduces divergence of rays so that they appear to come from O*

*(c) The lens camera*

This is a light – tight box in which a convex lens at the front forms a real, inverted image on the photo – sensitive (film) at the back.
Its inside is painted black in order to absorb any stray light that would blur the image.


The diaphragm regulates the size of the aperture thus controlling the amount of light from the lens.
The shutter controls amount of light entering the camera by the length of time it is opened.

**Comparisons of the eye and the lens camera**

*(a) Similarities*

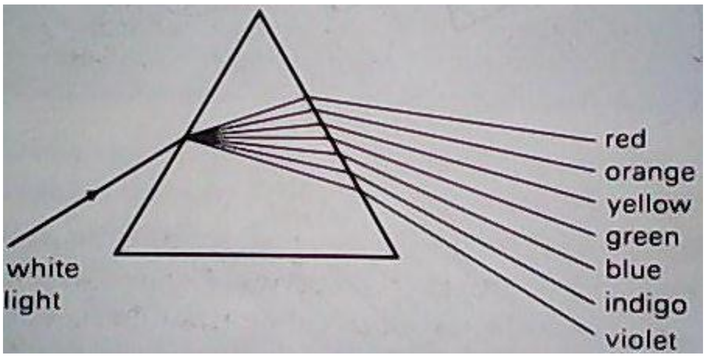
1. The camera is painted black inside and the eye is impregnated with a black pigment called choroid.
2. Both have systems regulating the amount of light entering them – diaphragm for a camera and iris for the eye.
3. Both have light sensitive parts – film for a camera and retina for the eye.
4. Both have lenses for focusing light from external objects.

*(b) Differences*

1. Image distance in an eye is fixed whereas it is variable in a camera.
2. Eye lens has a variable focal length whereas for a camera it is variable
3. Lens in a camera is artificial whereas in an eye is a biological organ
4. Aperture is changed mechanically in a camera whereas in an eye it is altered involuntarily by reflex action.
5. Only a lens refracts light in a camera whereas vitreous humor, aqueous humor and the lens do refract light.

## (E) THE SPECTRUM

When white light is passed through a glass prism a band of coloured patches showing colors of rainbow is formed on the screen. This band is called *spectrum.* Its constituent colors are *red, orange, yellow, green, blue, indigo and violet (ROYGBIV)*

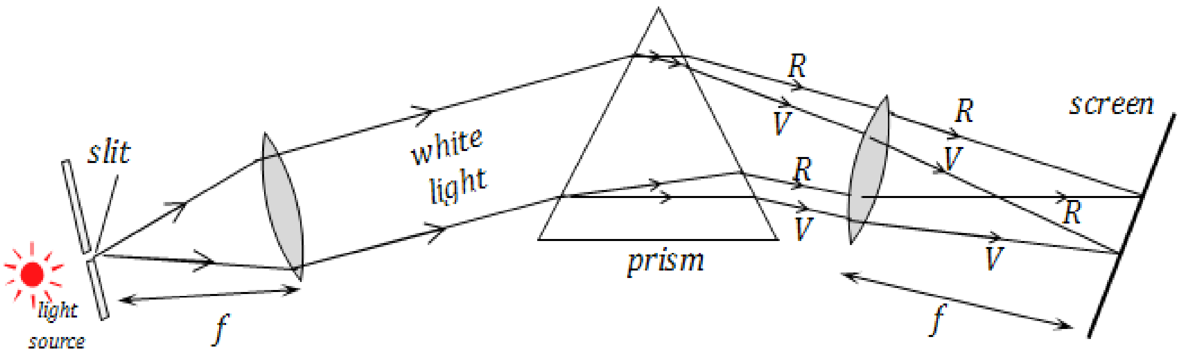



The separation of white light by glass prism into its constituent colors is called *dispersion.*
Dispersion occurs because glass has different refractive indices for each colour. Red colour which has least refractive index than violet is least deviated.

The spectrum formed is impure since different colours overlap on the screen.

## Production of a pure spectrum

A pure spectrum is the one in which colours do not overlap on the screen. This can be obtained by by using a narrow beam of white light through a slit placed at the focal point of the first lens so that a parallel beam of white-light is incident to the prism.
Separate parallel beams of different colours are brought in focus in the plane of second lens.



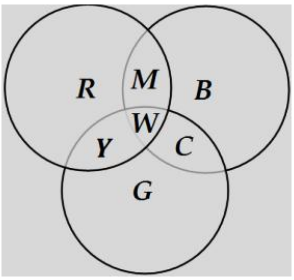
## ***MIXING OF COLOURS***

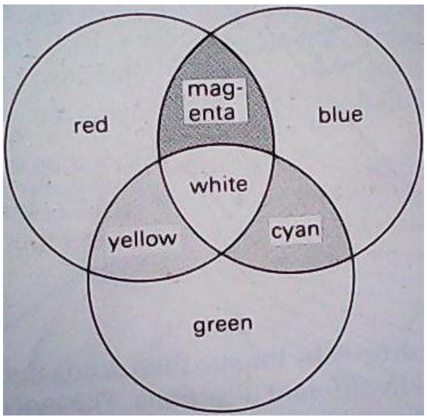
### *(a) by addition*

(i) *Primary colours*: these are colours of light which can not be made by mixing any other colours of light.
Examples primary colours are *red, blue* and *green*(RBG)

(ii) *secondary colours*: These are colours of light which are made by adding two primary colours. These are *yellow, magenta* (reddish purple) and *cyan* (greenish purple).
i.e. $red + green = yellow\ (RGY)$, $red + blue = magenta(RBM)$ and $blue + green = cyan(BGC)$

(iii) *complementary colours*: these are pairs of colours which when mixed together form a white light. A combination of one primary cplour and one secondary colourgives a complementary colour.
$Red + cyan = white(RCW)$, $Green + magenta = white(GMW)$
$Blue + yellow = white(BYW)$

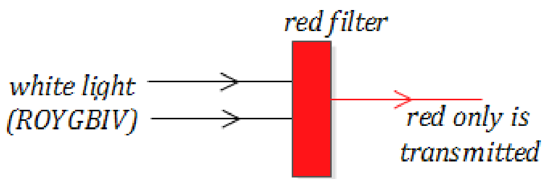


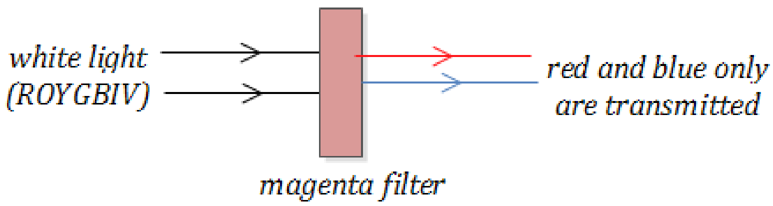

### *(b) by subtraction (absorption)*

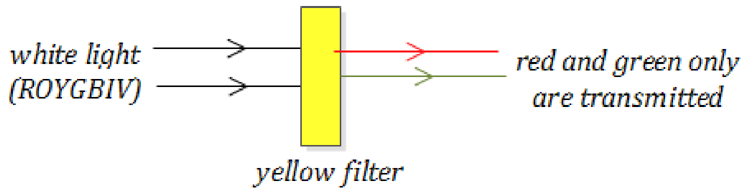
When light falls on any object, it is either reflected, absorbed or transmitted. The colour of an object is determined by the colours of light which it reflects i.e. it absorbs all other colours which fall on it and transmits only its own colour. Such a behavior is shown by a colour filter.

*Case 1*: when white light falls on a primary colour filter all the other colours are absorbed and only the colour of the filter is transmitted.

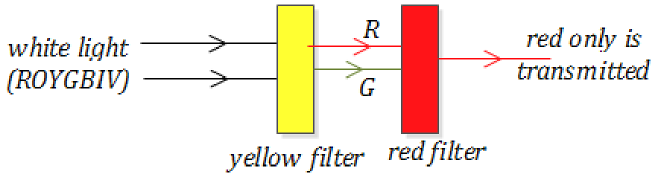


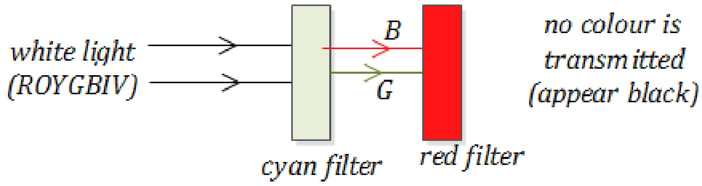

*Case 2*: when white light falls on a secondary colour filter only the colours forming the filter are transmitted and the other colours are absorbed.






*Case 3*: a primary colour filter placed after a secondary colour filter




***The colour of an object in white light***

An object appears red because it absorbs all other colours of light and reflects red. A black object absorbs all other colours and reflects none.

The colour of an object depends on the

- colour of incident light
- colour it reflects

| *Colour of object* | *Colour of incident light* | *Colours absorbed* | *Colours reflected ( appearance of object)* |
|---|---|---|---|
| Blue | White | ROYGBIV | Blue |
| Blue | Blue | None | Blue |
| Blue | Red | Red | None (black) |
| Red | Blue and green | Blue and green | None (black) |
| Red | Red | None | Red |

## Questions

### (A) REFLECTION ON PLANE SURFACES

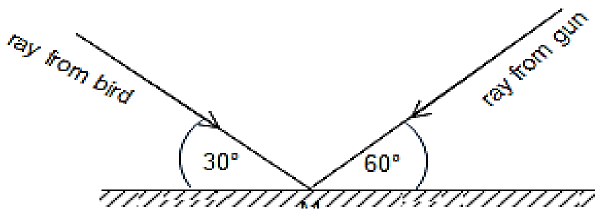
1. (a) Describe an experiment to show that light travels in straight line.
   (b) An object of height 4cm is placed 5 cm away from a pinhole camera. The screen is 7 cm from the pinhole.
   (i) Draw to scale, a ray diagram to show the formation of the image by the pinhole camera.
   (ii) What is the nature of the image?
   (iii) Find the magnification
   (iv) Explain what happens to the image if the pinhole is made larger.
   (c) Draw a diagram to show the formation of a solar eclipse.
   (d) An object 6 cm high is placed 24 cm from a tiny hole in a pinhole camera. If the distance from the hole to the screen is 8 cm, find the size of the image on the screen.

2. (a) Describe an experiment to demonstrate the laws of reflection of light.
   (b) With the aid of a diagram, illustrate how the shadows are formed when an opaque object is placed between an extended source of light and a screen.
   (c) An object 10 cm high is placed at a distance of 25cm from a convex mirror of focal length10 cm.
   (i) Draw a ray diagram to locate the position of the image.
   (ii) Calculate the magnification
   (e) Give reasons for use of convex mirrors in vehicles.

3. (a) State the laws of reflection of light
   (b) With the help of ray diagrams,
      (i) Explain the action of a pinhole camera
      (ii) Distinguish between partial and total eclipses of the moon

2. (a) An object is placed 30 cm in front of a plane mirror. If the mirror is moved a distance of 6 cm towards the object, find the distance between the object and its image.
   (b) Explain with the aid of diagram, the formation of umbra and penumbra.

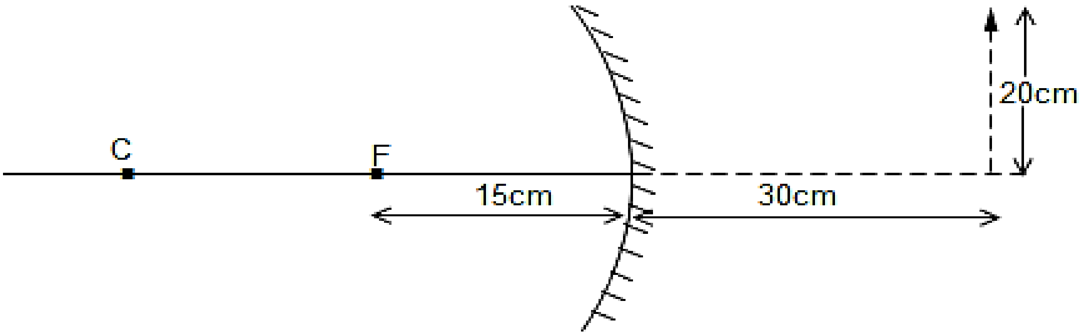
   (c)




A ray of light from a bird makes an angle of $30^0$ with a plane reflector and a ray from the barrel of a gun makes an angle of $60^0$ to the same reflector at the same point, M as shown in the figure a above. Find the angle through which the reflector must be rotated about M such that the ray from the gun falls on the bird. 5mks

**(B) REFLECTION ON CURVED SURFACES**

1.




(a) An object is placed in front of a concave mirror of focal lenght15cm and its image is formed30cm behind the mirror as shown in the diagram above. On the diagram, draw rays to find the

(i) object distance (ii) object height

(b) (i) describe a simple a simple experiment to determine focal length of a concave mirror

(ii) State and explain one application of a convex mirror

2. a) Explain the term virtual image as applied to optics

b) with the aid of a ray diagram, explain why a convex mirror is used as a driving mirror

c) An object is placed 15 cm in front of a concave mirror. An n upright image of magnification four is produced. By graphical, determine the:

(i) nature of the image (ii) focal length of the mirror

(iii) Distance of the image from the mirror

d. Name two applications of a concave mirror.

3. (a) Draw a ray diagram to show the formation of an image of the object O placed in front of a convex mirror shown in figure below. F is the principal focus of the mirror.

(b) With the aid of a diagram explain why a parabolic mirror is most suitable for use in car headlights.

(c) List three uses of a concave mirror

(d) With the aid of diagrams, distinguish between diffuse and regular reflection.

**(C) REFRACTION AND OPTICAL INSTRUMENTS**

1. (a) explain the causes of refraction of light

(b) Describe an experiment you would use to measure refractive index of glass using a glass block

(c) (i) state the conditions for total internal reflection to occur.

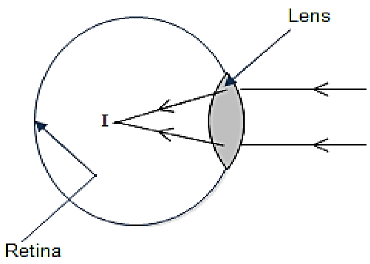
(ii) State one application of total internal reflection

(iii) Calculate the critical angle for an air – glass interface if the refractive index of glass is 1.5.

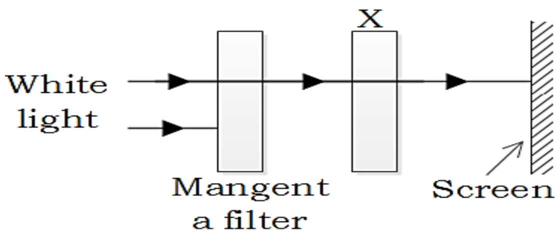
(d) With the aid of a labeled diagram, describe how a lens camera works

2 (a) Use array diagram to show how a virtual image may be formed in a converging lens.
(b) A converging lens of focal length 20cm forms a real image 4cm high of an object which is 5cm high. If the image is 36 cm away from the lens, determine by graphical method the position of the object.
(c) State two differences between a pinhole camera and a lens camera.
(d) With the aid of a diagram, explain why a pond appears shallower than it actually is.
(e) Using a labeled diagram show how two right- angled isosceles prisms may be used to produce an erect image of a distant object.

3.

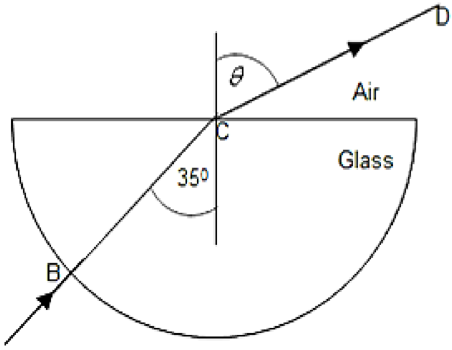



The figure above shows refraction of light rays from a distant object by a human eye.
(a) Explain whether the eye is able to see the object clearly.
(b) (i) What is meant by *accommodation*?
(ii)Give three parts of the eye that help in accommodation.
(c) Using well labeled diagrams, show how lenses are applied in the following:
(i) A slide projector. (ii) The eye (iii) The lens camera.
(d) Give similarities and differences between a lens camera and an eye.
(e) (i) Explain the experiment to determine the focal length of a converging lens.
(ii) An object of height 7.5cm is placed a distance of 15cm from a convex lens of focal length 20cm. By scale drawing determine the height, image distance and linear magnification.
(f) The figure below shows white light incident on a magenta colour filter. What colour filter should X be so that red is seen on the screen?



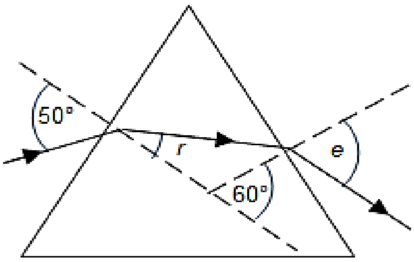

4. (a) what is meant by the following terms: critical angle and total internal reflection
(b) State two applications of converging lenses

3. The figure below shows a ray of light incident on a semi-circular glass block of centre C



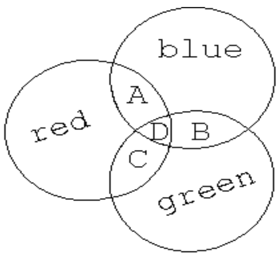

(a) Why is the ray not deviated?
(b) Calculate the value of $\theta$ if the refractive index of glass is 1.52
(c) Light traveling in water is incident at a water – air surface at $30^0$. What is the angle of refraction if the refractive index from air to water is 1.33?

4. (a) The diagram in the figure below shows a ray of yellow light incident at an angle of $50^0$ on one side of an equilateral triangular glass prism of refractive index 1.52.




(i) Calculate the angles marked *r* and *e*
(ii) State and explain what would be observed if a ray above were of white light.
(b) Explain with the aid of a diagram, why the writing on a paper placed under a glass block appears raised when observed from above.

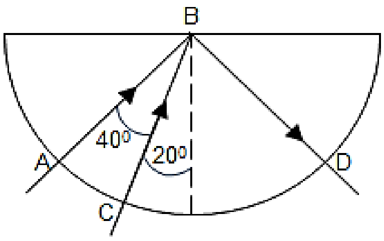
7. (a) Explain dispersion as applied to light
(b) (i) what is a pure spectrum?
(ii) With the aid of a labeled diagram, describe briefly how a pure spectrum is produced.
(c) (i) distinguish between a primary and a secondary colour




(ii) The figure aside shows colours mixed by addition. Name the colours represented by the parts labeled A, B, C and D.
(d) State the colour of yellow dress in green light

8. (a) Explain the phenomenon of *dispersion* as applied to white light.
(b) Draw a ray diagram to show the dispersion of white light by a glass prism.
(c) Name the colour that would be obtained when the following coloured lights are mixed: (i) green and red (ii) cyan and red
(d) Explain why an object illuminated by white light appears: (i) coloured (ii) black.

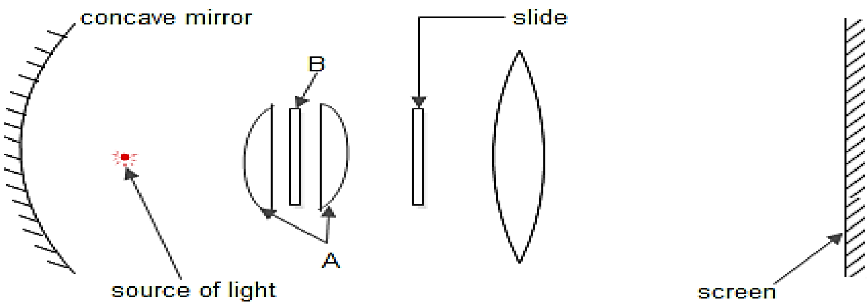
9. Draw a ray diagram to show the action of a converging lens as a magnifying glass.
   (a) What is meant by refractive index?
   (b) Define focal length and the power of a converging lens
10. 




The diagram in the figure above shows rays of light in a semi circular glass block
(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 (refractive index of glass = 1.5)

11. (a) Define principal focus of a converging lens and a virtual image
   (b) With the aid of a labeled diagram, describe a simple experiment to determine the focal length of a converging lens
   (c) An object 4 cm high is placed perpendicularly on the principal axis at a distance of 45cm from a converging lens of focal length 15cm. By graphical method, determine the
   (i) position of the image (ii) magnification
   (c) Give one application of converging lenses.

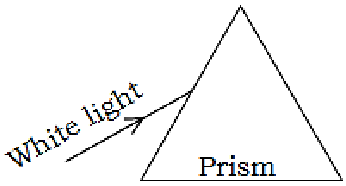
12.(a) A magnifying glass of focal length 5 cm forms an erect image, 25 cm from the lens. By graphical method, find the distance between the object and the image.
   Find the magnification of the image formed.
   (b) The figure below shows the arrangement of a slide projector




   (i) Name the parts labeled A and B
   (ii) On the diagram, draw rays to show the final position of the image on the screen
   (iii) What is the role of B?

12. (a) Define dispersion of light.

(i) What is a pure spectrum? (ii) Using a diagram show how a pure spectrum can be produced.




(b) A ray of light is incident on a glass prism as shown in the figure above. Complete the diagram to show the effect of the prism on the light.

(c) Find the critical angle for glass in air if the refractive index of glass is 1.5.

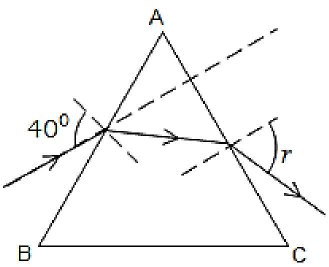
13. (a) What is: (i) total internal reflection. (ii) Refraction of light. (iii) Critical angle.

(b) (i) Describe two applications of total internal reflection.

(ii) State the conditions for total internal reflection.

(iii) A glass block 9cm thick with refractive index 1.5 is placed over a mark on a paper. What is the displacement of the mark when viewed from above?

(c) A ray of light is incident on a glass prism of refractive index1.5 at an angle of 40° as shown below.




(i) Find angle of refraction at face AC.

(ii) Total deviation angle d when the emergent angle is 58.4°