TOPIC: LIGHT PART III
General Objective: The Learner should be able to use the principle and laws of refraction to explain dispersion of light and images formation by lenses.

SUB-TOPIC: Refraction of light at a plane surface.
SPECIFIC OBJECTIVES: The learner should be able to;
- State the law of refraction.
- Verify laws of refraction using glass block and a triangular prism.
- Numerical problems involving refractive indeed.
- Explain some effects of refraction.
- Explain the phenomena of real and apparent depth qualitatively.
- Define critical angle.
- Explains total internal reflection.
- Calculate critical angle of a medium.
- Trace a monochromatic ray of light through a prism.
- Describe the use of total internal reflection in prisms.
- Explain how a mirage is formed.
- Describe applications of total internal reflection.

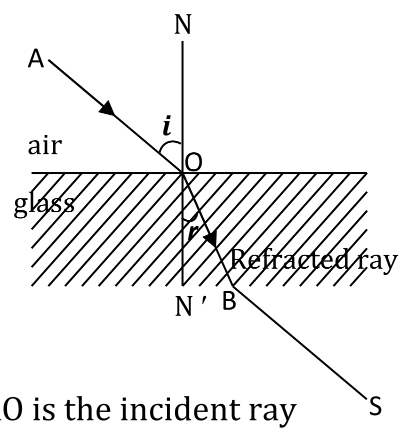
REFRACTION AT PLANE SURFACES

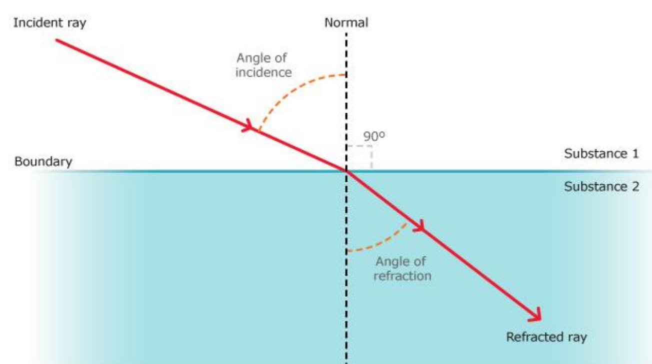
Light is an electromagnetic wave. When it crosses from one medium to another of different optical density, its speed changes. If the incident light meets the boundary obliquely, a change of direction occurs.

Refraction is the bending of light as it crosses from one medium to another of different optical density.

Refraction is caused by the change in speed as light passes from one medium to another of different optical density.

Key Terms



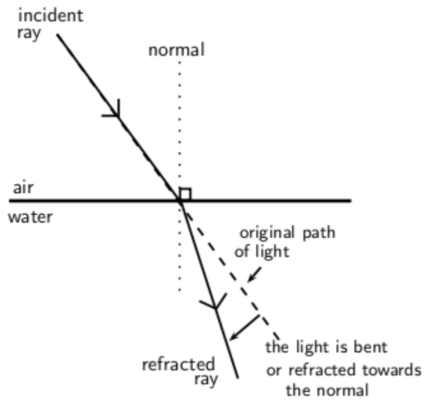


AO is the incident ray
OB is the refracted ray
NN′ is the normal
i is the incident angle
r is the angle of refraction

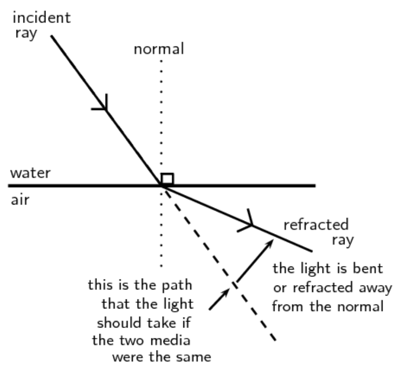
i is the incident angle – This is the angle between the incident ray and the normal at the point of incidence.

r is the angle of refraction – This is the angle between the refracted ray and the normal at the point of incidence.
BS is the emergent ray.
The emergent ray is always parallel to the to the incident ray, as shown by the dotted line QT.

A ray passing from a less dense medium to a denser medium bends towards the normal.

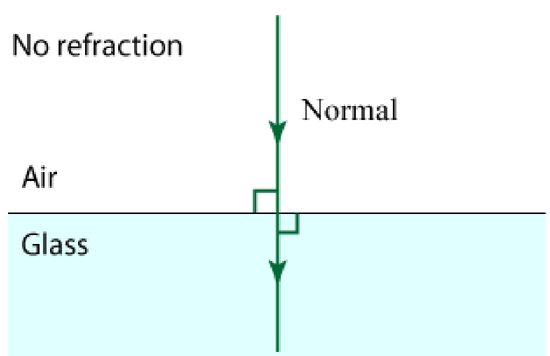


A ray passing from a denser medium to a less dense medium bends away from the normal.



NB: At the boundary or the surface that separates the two media, there is a change in the velocity of light that causes the change in the direction of light.

However, if light travels at right angles to the boundary, there is no change in the direction. Light continues in a straight line but the speed of light is reduced in the denser medium.
This is referred to as **normal refraction**.

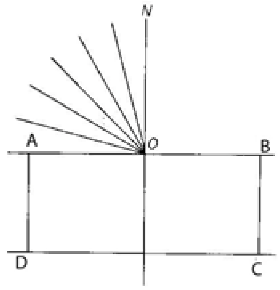


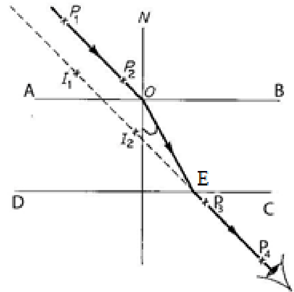
Laws of Refraction

1. The incident and refracted rays are on opposite sides of the normal at the point of incidence and all three are in the same plane.

2. Snell's law: The ratio of the sine of the angle of incidence to the sine of the angle of refraction is a constant for a given pair of media.

Experiment: To Investigate Snell's Law
(An experiment to determine the refractive index of a glass using a glass block)
A white sheet of paper is fixed on a soft cardboard using thumb tacks at its corners.
A glass block is placed on a white sheet of paper and its outline ABCD drawn as shown below.



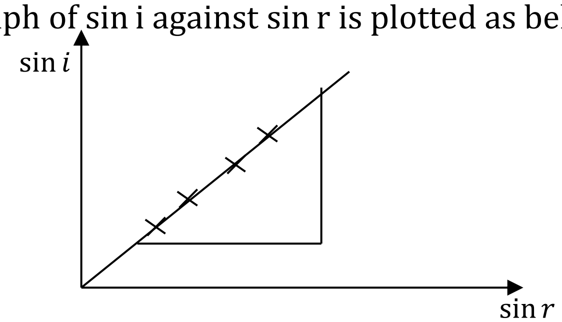


- The glass block is then removed. Using a protractor; the normal is drawn at a point O along AB and an angle of incidence i is measured.
- Pins P_1 and P_2 are fixed on the line making an angle of $i = 10^0$ to the normal and the glass block replaced on its outline ABCD.
- While looking through side CD, two other pins P_3 and P_4 are fixed so as to appear in lines of images P_1 and P_2.
- The glass block, pins P_3 and P_4 are removed and a line drawn through points where P_3 and P_4 were fixed. This line is called the emergent ray. It is drawn to meet CD at E.
- Point O is joined to E. The line is called the refracted ray.
- The angle of refraction r is measured.
- The experiment is repeated using other angles of incident 20, 30, 40, and 50.
- The values of i, r are tabulated as shown.

$i(^{o})$	$r(^{o})$	$\sin i$	$\sin r$	$\frac{\sin i}{\sin r}$
20				
30				
40				
50				
60				

- The values in the column for the ratio of $\sin i$ to $\sin r$ are the same within experimental errors. This is Snell's law.

Alternatively, a graph of sin i against sin r is plotted as below:



A straight line graph of constant slope is obtained. The slope/gradient of the graph is equal to the refractive index of the glass.

Refractive Index

The constant $\frac{\text{Sin i}}{\text{Sin r}}$ for a ray passing from one medium to another is called the refractive index of the second medium with respect to the first.

$$\text{i. e} \qquad \mathbf{n = \frac{Sin\ i}{Sin\ r}}$$

Definitions

1. **Refractive index of a given pair of medium** is the ratio of the sine of the angle of incidence to the sine of the angle of refraction for a ray of light passing from one medium to another.

2. The **absolute** refractive index of any medium is the ratio of the sine of the angle of incidence to the sine of the angle of refraction for light moving from a **vacuum** to the medium.

$$\text{Absolute refractive index of any medium(n)} = \frac{\text{Sin i(in a vacuum)}}{\text{Sin r(in the medium)}}$$

3. Refractive index of a **medium** is the ratio of the sine of the angle of incidence to the sine of the angle of the sine of the angle of refraction for **light moving from air to that medium.**

$$\text{Refractive index of any medium, n} = \frac{\text{Sin i(in air)}}{\text{Sin r(in the medium)}}$$

Note: The difference between the refractive indices of air and vacuum is very small and hence the refractive index of a medium with respect to air is taken as absolute refractive index (unless extreme accuracy is required).

The refractive index can also be expressed in terms of velocity of light in the media.

$$\text{Refractive index of any medium, n} = \frac{\text{velocity of light in the vacuum, c}}{\text{velocity of light in the medium, v}}$$

$$n = \frac{c}{v}$$

Examples

1. Calculate the refractive index of water, given that the velocity of light in air is $3.0 \times 10^8 \text{ms}^{-1}$ and velocity of light in water is $2.25 \times 10^8 \text{ms}^{-1}$ (Ans: 1.33)

2. The velocity of light in glass is $2.0 \times 10^8 \text{ms}^{-1}$. Calculate;
   (a) the refractive index of glass (Ans: 1.50)

(b) the angle of refraction in glass for a ray of light passing from air to glass at an angle of incidence of 40^0 (Ans: 25.4^0)

The table of absolute refractive indices (refractive indices of media) of some materials

Substance(material)	Refractive index
Air	1
Water	1.33
Paraffin	1.44
Alcohol	1.36
Ice	1.31
Glycenne	1.47
Benzene	1.50
Mica	1.56
Glass: crown : flint	1.5 1.65
Diamond	2.42

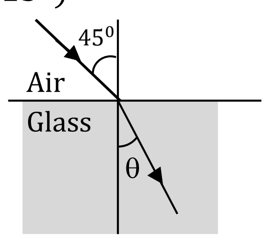
Examples

1. A ray of light is incident on air-water boundary at angle of incidence 42^0. Given that the angle of refraction is 30^0, find the refractive index of water. (1.34)

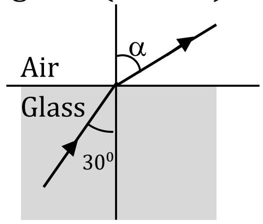
2. Light is incident to an air-glass boundary at an angle of 50^0. If the refractive index of glass is 1.52, calculate the angle of refraction. (30.26^0)

3. A ray of light is incident on a diamond-alcohol boundary at an angle of 22^0. Calculate the angle of refraction in alcohol. (41.80^0)

4. A ray of light enters glass at angle of incidence of 45^0. If the refractive index of glass is 1. 5, determine the angle θ. (28.13^0)



5. A ray of light travelling from glass, of refractive index 1.55, to air emerges as shown in the diagram. Determine the angle α. (50.81^0)



Refraction on plane parallel boundaries.

The refractive index of the medium 2 relative to medium 1 is denoted by $_1\cap_2$ for a ray of light moving from medium 1 to medium 2.

Principal of reversibility of light.

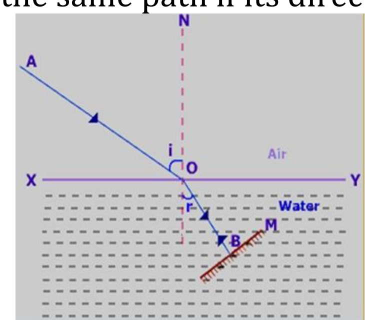
It states that when the direction of ray of light is reversed, it follows exactly the same path as before.

Or

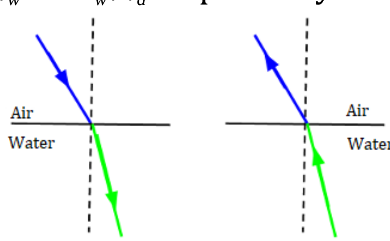
It states that the path of light is reversible.

Or

It states that light will follow exactly the same path if its direction of travel is reversed.



Refractive indices of a ray of light passing from air to water and from water to air may be differentiated by using notations $_a\cap_w$ and $_w\cap_a$ respectively.



$$_a\cap_w = \frac{\sin i}{\sin r} \quad \text{...(i)}$$

$$_w\cap_a = \frac{\sin r}{\sin i} \quad \text{...(ii)}$$

$$\frac{\sin i}{\sin r} = \frac{1}{\frac{\sin r}{\sin i}}$$

$$_a\cap_w = \frac{1}{_w\cap_a}$$

From (i) and (ii)

$$\frac{\sin i}{\sin r} = \frac{1}{\frac{\sin r}{\sin i}}$$

$${}_a\cap_w = \frac{1}{{}_w\cap_a} \quad \text{or} \quad {}_w\cap_a = \frac{1}{{}_a\cap_w}$$

Similarly

$${}_a\cap_g = \frac{\sin i_a}{\sin i_g} \quad \therefore \quad {}_a\cap_g \sin i_g = \sin i_a \text{ ……………….. (i)}$$

$${}_a\cap_w = \frac{\sin i_a}{\sin i_w} \quad \therefore \quad {}_a\cap_w \sin i_w = \sin i_a \text{ ……………….. (ii)}$$

Comparing equations (i) and (ii):

$${}_a\cap_g \mathbf{\sin i_g} = {}_a\cap_w \mathbf{\sin i_w}$$

Generally:

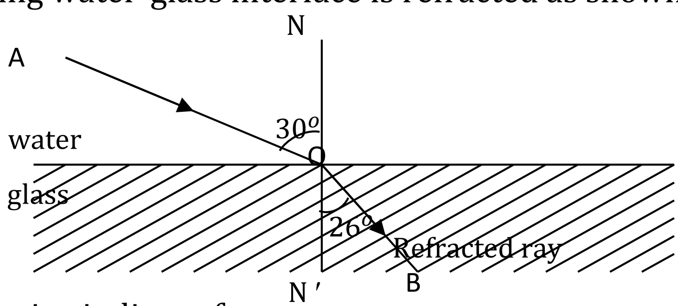
$$\cap_1 \mathbf{\sin i_1} = \cap_2 \mathbf{\sin i_2}$$

$$\frac{\cap_2}{\cap_1} = \frac{\mathbf{\sin i_1}}{\mathbf{\sin i_2}} = {}_1\cap_2$$

Examples

1. Calculate the refractive index of water for a ray of light travelling from water to air given that ${}_a\cap_w = 1.33$. (${}_w\cap_a = 0.75$)

2. A ray of light striking water-glass interface is refracted as shown below.



Calculate the refractive indices of:

(i) glass with respect to water. (${}_w\cap_g = 1.14$)

(ii) water with respect to glass. (${}_g\cap_w = 0.88$)

3.

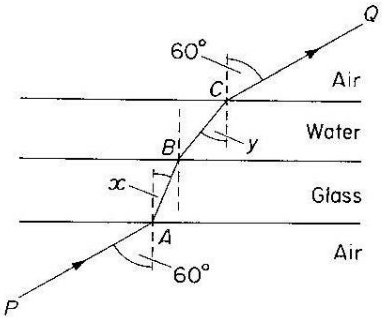


Figure above shows a glass slab of uniform thickness, lying horizontally. Above it is a layer of water. A ray of light PQ is incident upwards on the lower surface of the glass and is refracted successively at A, B and C, the points where it crosses the interfaces. Calculate

(i) angle x, (35.26^0)

(ii) angle y, (40.5^0)

(iii) the refractive index for light passing from the water to glass. (Refractive indices of glass and water are $\frac{3}{2}$ and $\frac{4}{3}$ respectively.) (1.125)

ATTEMPT EXERCISE 10.1 PAGE 147-149 IN LONGHORN BOOK THREE

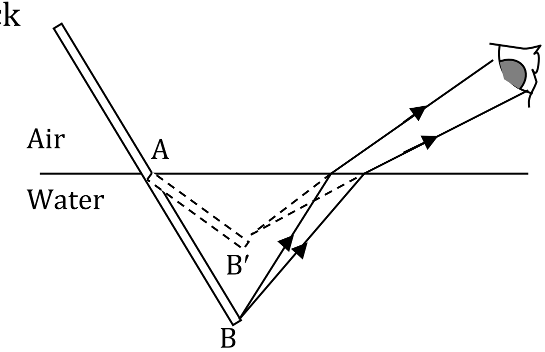
During refraction;

The ray of light bends towards the normal as it moves from a less dense medium to a denser one.
The ray of light bends away from the normal as it moves from a denser medium to a less dense one.

Some effects of Refraction.

- A thin rod dipped obliquely into water appears to bent at the air-water surface.
- A pool of water appears to be shallower than it actually is.
- A colorful rainbow is formed in the atmosphere usually after some rainfall.
- A shimmering pool of water seems to be ahead of a traveler on tarmac road or desert sand on a hot day (formation of a mirage).

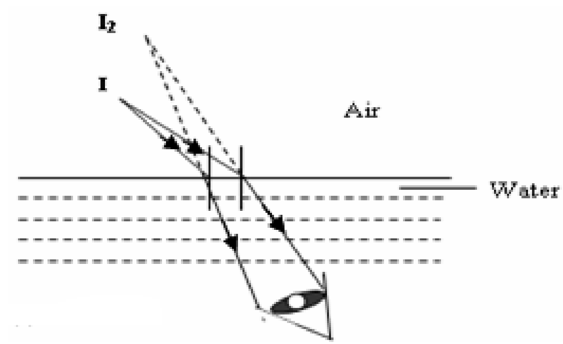
1. Apparent bending of a stick



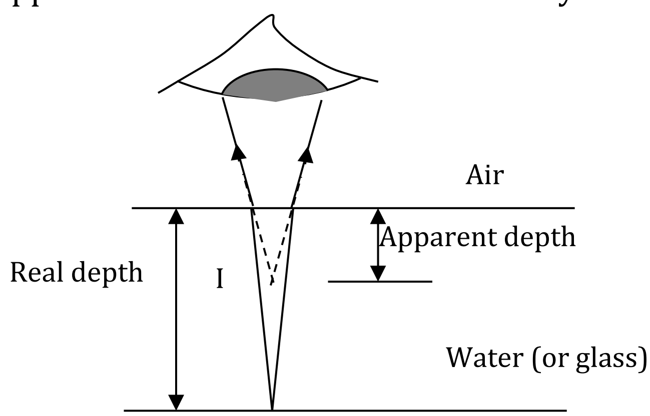
Rays of light from end B bend away from their normals because light is moving from a region denser medium to a rare medium, as shown in the diagram below, and appear to come from B′as they enter the eye. B′ is thus the image of B by refraction.
The same reasoning applies to any point on the immersed part of the stick. So the stick appears bent.

Why is the apparent height of the star is bigger than the real height?
The position of **stars** appears slightly above to their **actual** position because of change in refracting index of the atmosphere. The refractive index is not stationary throughout because of many physical conditions of the atmosphere of earth.

An analogy



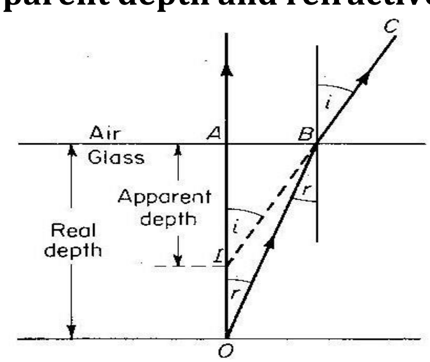
2. Apparent shallowness of a transparent medium.
A pool of water appears to be shallower than it actually is.



Rays of light from a point O at the bottom bend away from their normals as they cross from glass to air and appear to come from I as they enter the eye. So the bottom appears to be at I.

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

Relationship between real apparent depth and refractive index



$$n = \frac{\text{real depth, OA}}{\text{aparent depth, AI}}$$

Examples

1. A swimming pool appears to be only 1.5m deep. If the refractive index of water is $\frac{4}{3}$, calculate the real depth of water in the pool.

   Solution:

   $$n = \frac{\text{real depth}}{\text{apparent depth}}$$

   $$\frac{4}{3} = \frac{r}{1.5} \qquad \therefore \quad r = \frac{4 \times 1.5}{3} = 2.0\text{m}$$

2. A coin is placed at the bottom of the beaker which contains water at a depth of 8cm. By how much does the coin viewed from above appear to be raised (take n to be $\frac{4}{3}$).

   Solution:

   $$n = \frac{\text{realdepth}}{\text{apparentdepth}}$$

   $$\frac{4}{3} = \frac{8}{\text{apparent depth}} \therefore \text{apparent depth} = 8 \times \frac{3}{4} = 6 \text{ cm}$$

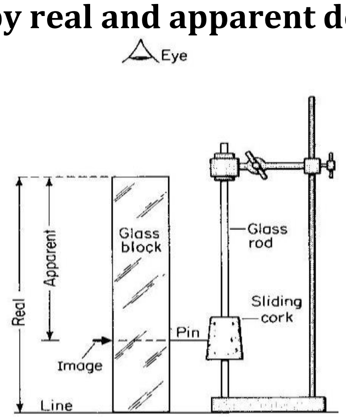
   the coin appear1s to be raised by distance = real depth − apparent depth.
   $= (8 - 6)\text{cm} = 2 \text{ cm}$

Test yourself

1. A pin at the bottom of the beaker containing a transparent liquid at a depth of 24cm is apparently displaced by 6cm. Calculate the refractive index of the liquid.

2. A flask full of water appears to be 8cm deep. If the speed of light in water is $2.25 \times 10^8\text{ms}^{-1}$ and the speed of light is $3.0 \times 10^8\text{ms}^{-1}$. Calculate
   (a) the refractive index of water
   (b) the actual depth of the flask
   (c) the vertical displacement.

Determination of refractive index by real and apparent depth method



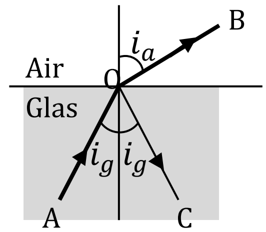
A glass block is placed vertically over a cross (X) drawn on a white sheet of paper as shown above. A pin clamped on a sliding cork adjacent to the block, is moved up and down until there is no parallax between it and the image of the cross (X) seen through the block.
The real depth (length of glass block) and apparent depth are measured and the refractive index is then calculated from.

$$n = \frac{\text{real depth}}{\text{apparent depth}}$$

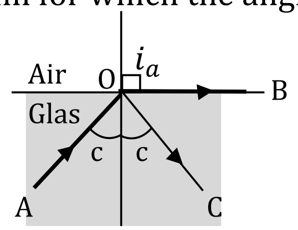
ATTEMPT EXERCISE 10.2 PAGE 155-156 IN LONGHORN BOOK THREE

TOTAL INTERNAL REFLECTION

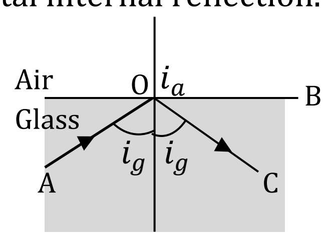
Imagine a ray of light AO travelling from a dense medium to a less dense one e.g from glass to air. While the main ray is refracted along OB, a fraction of it is reflected along OC inside the glass.



As the angle of incidence, i_g increased, i_a also increases until a certain value of $i_g = c$ is reached when the ray fails to emerge but instead moves along the boundary. Under these conditions the angle of incidence, c, in the denser medium for which the angle of refraction is 90^0 is called the critical angle.



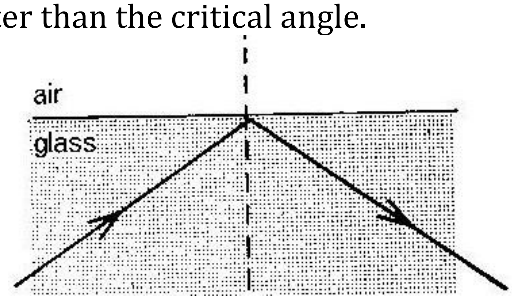
When the angle of incidence i_g is increased beyond c, all the light is reflected into the same medium. This behavior is known as total internal reflection.



DEFINITIONS:

Critical angle(C) is the angle of incidence in the denser medium for which the angle of refraction is 90^0 in the less dense medium.

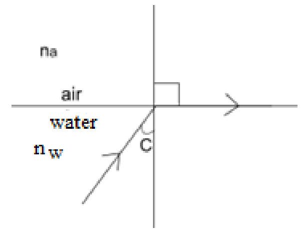
Total internal reflection is the reflection of light within a denser medium when light is incident in the same medium at angle greater than the critical angle.



Conditions necessary for total internal reflection to occur:

1. Light must be traveling from an optically dense medium to a less dense medium.
2. The angle of incidence in the denser medium must be greater than its critical angle.

Relation between Critical Angle and Refractive Index



Using Snell's law

Refractive index, $\quad {}_w\cap_a = \frac{\text{Sin } i_w}{\text{Sin } i_a}$

When $i_g = \text{c and } i_a = 90^0$

${}_w\cap_a = \frac{\text{Sin c}^o}{\text{Sin } 90^0}$

${}_a\cap_w = \frac{\text{Sin } 90^o}{\text{Sin c}^0}$

$\therefore {}_a\cap_w = \frac{\mathbf{1}}{\mathbf{sin\ c}}$ or $\mathbf{sin\ c} = \frac{\mathbf{1}}{{}_a\cap_w}$

Or

$n_1 sinl_1 = n_1 sinl_1$

$n_w sinl_w = n_a sinl_a$

$n_w sinc = 1 \times sin90^0$

$n_w sinc = 1 \times 1$

$n_w sinc = 1$

$sinc = \frac{1}{n_w}$ or $n_w = \frac{1}{sinc}$

Example:

1. Find the critical angle of a medium of refractive index 1.55. (Ans: 40.17°)

2. Find the refractive index of a material whose critical angle is 45°. (Ans: 1.41)

3. Calculate the critical angle for glass-air interface, if the refractive index of glass is 1.50. (Ans: 41.8^0)

4. Calculate the critical angle at the water-air interface, if the refractive index of water is 1.33. (Ans: 48.8^0)

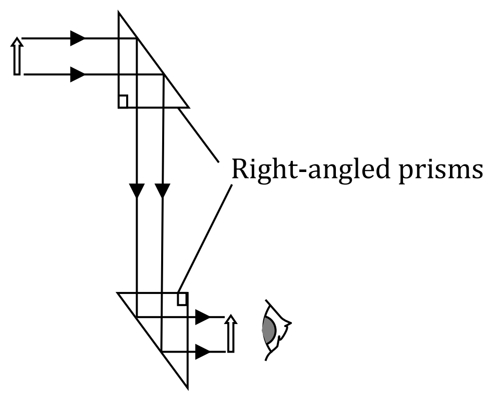
5. Calculate the refractive index of diamond, if the critical angle for diamond is 24^0. (Ans: 2.46)

APPLICATIONS OF TOTAL INTERNAL REFLECTION

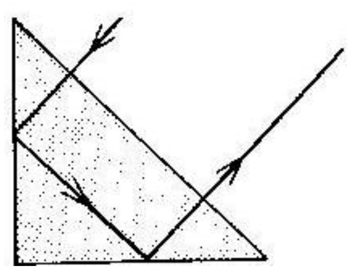
1. In reflecting prisms which are in binoculars, periscopes and cameras e.g
   (i) Turning a ray through 90^0

   The Prism Periscope

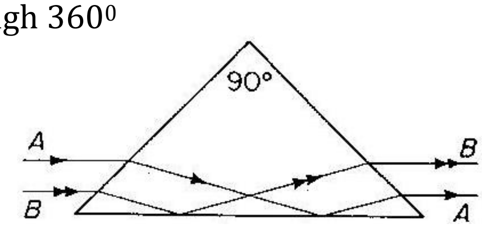
   A periscope is a devise which enables us to see over the top of an obstacle.
   Two right angled prisms are used in the prism periscope.
   A parallel beam of light normally incident on the first prism is totally internally reflected and proceeds to the second prism where it is again totally internally reflected to reach the eyes of the person.
   The final image produced is virtual and upright.
   The periscope of this type is normally used in submarines to sight enemy ships over the surface of the sea.



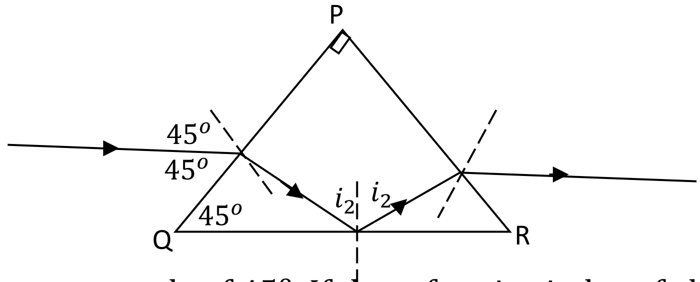
   (ii) Turning a ray through 180^0



   (iii) Turning a ray through 360^0



Explanation for behaviour of light rays in above prism



At face PQ: the ray is incident at an angle of 45°. If the refractive index of glass is about 1.5, the angle of refraction in glass at PQ is obtained as follows:

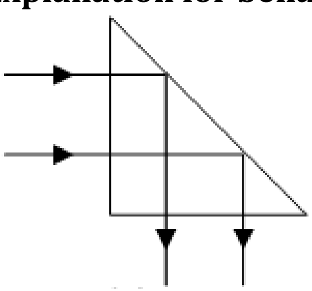
$${}_a\cap_g = \frac{\sin 45^o}{\sin r} \quad \therefore \ \sin r = \frac{\sin 45^o}{{}_a\cap_g} = \frac{\sin 45^o}{1.5} = 0.471$$

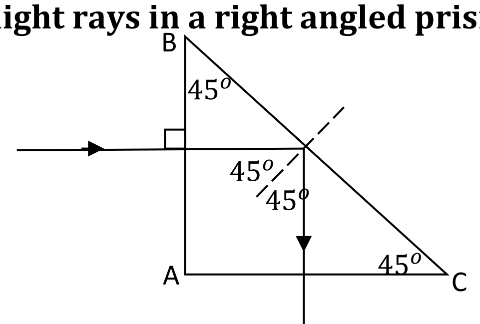
$\therefore$ r $= \sin^{-1} 0.471 = 28.1^o$

$g = 180^o - (45 + 90 + 28.1)^o = 16.9^o$
on face QR: the angle of incidence, $i_2 = 90^o - 16.9^o = 73.1^o$
Since i_2 is greater than the critical angle of the glass ($c = \sin^{-1}\left(\frac{1}{1.5}\right) = 41.8^o$), total internal reflection occurs at face QR.

At face PR, the angle of incidence in the glass material is $r = 28.1^o$, therefore the ray emerges into air at an angle of refraction of 45^o.

Explanation for behaviour of light rays in a right angled prism

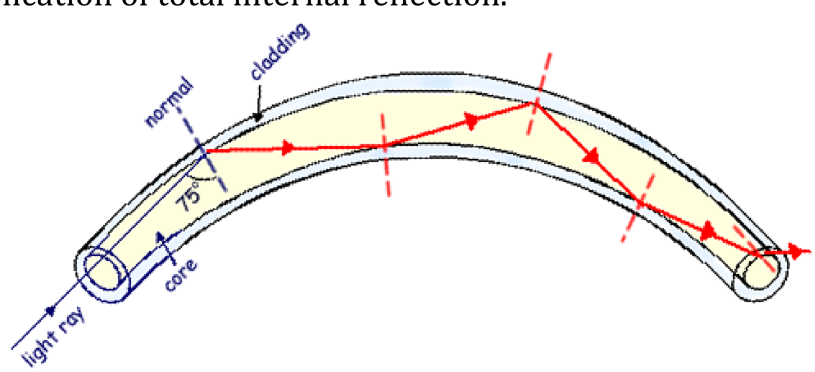




At face AB: the ray is incident along the normal, therefore it enters the glass prism undeviated.
At face BC: the ray is incident at an angle of 45^o which is greater than its critical angle ($c = 41.8^o \approx 42^o$), therefore the ray experiences total internal reflection.
At face AC: the ray is incident along the normal and emerges out of the glass prism undeviated.
The resultant effect of such a prism is to deviate (change the direction) of the incident ray through 90^o.

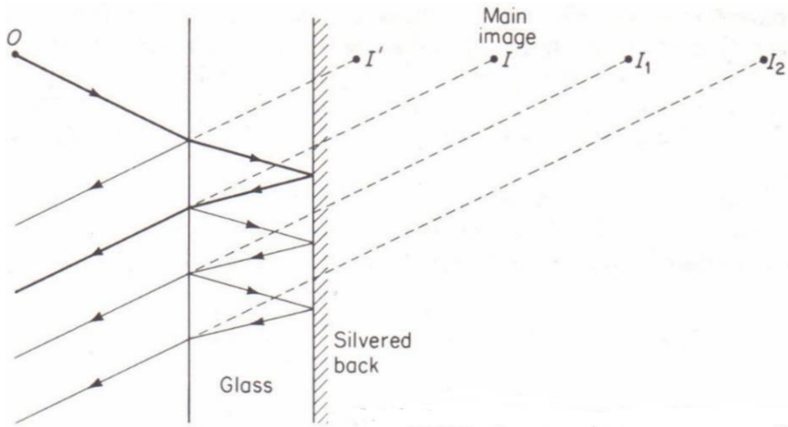
2. Optical fibre

This is also an application of total internal reflection.



It is a very fine glass rod of diameter of about 125µm with a central glass core surrounded by a coating of smaller refractive index.
A beam of light entering one end of the core is totally internally reflected several times until it comes out at the other end.
Optical fibre is used in transmission of signals and data. In medicine, optical fibres are used to examine the inside of a tract.
Optical fibres can be used by doctors and engineers to light up some awkward spot for inspection. Modern telephone cables are optical fibres using laser light.

3. Multiple Images in Thick Mirrors



When an incident ray from O meets the front surface of the mirror, a small fraction of it is reflected there giving rise to a faint image $I^{/}$.
The main ray is refracted and then reflected on the back surface and as it emerges it is refracted to give rise to the main image I.
At each emergence a small fraction of the ray is internally reflected and this results in a series of faint multiple images in a line.

Disadvantages of thick mirrors

1. Formation of multiple images leading to loss in clarity of the final image. (i.e. the image does not have fine edges but appears blurred)
2. Loss of intensity due to multiple reflections and refractions resulting in not so sharp and well-focused image.

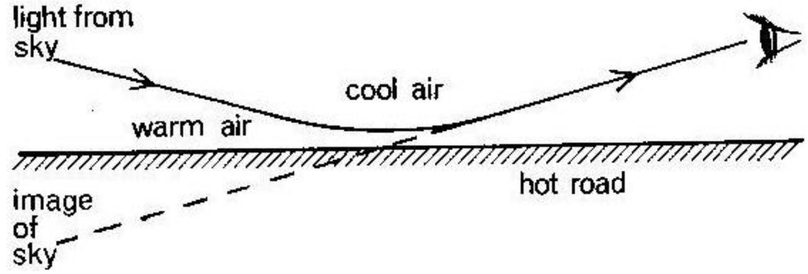
The above limitations are overcome as follows;

1. Using total internal reflecting prisms.
2. The front surface of curved mirrors is aluminized highly. Care is taken not to scratch the front surface of such mirrors.

EFFECTS OF TOTAL INTERNAL REFLECTION

1. **The mirage**

This is an optical illusion that takes place in a hot desert or on a hot road due to total internal reflection.
The traveler sees in a distance a shimmering pool of water in which the surrounding objects, like a tree, appear inverted.
This can happen when the air nearer the surface of the ground is less dense than the above. Cool air is dense than warm air.



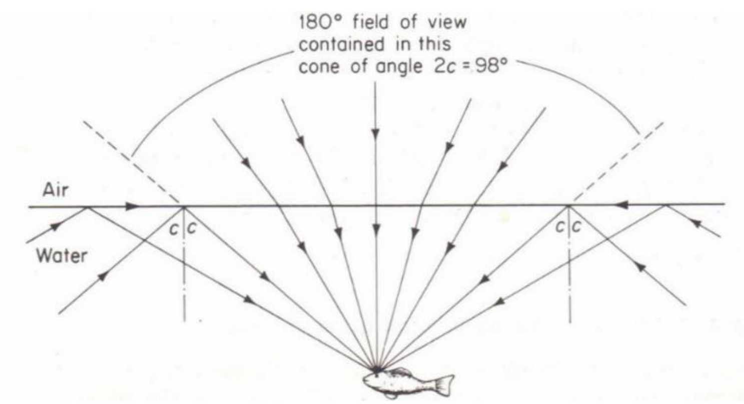
Light from the sky is gradually refracted away from the normal as it passes from denser layer of air to less dense layers

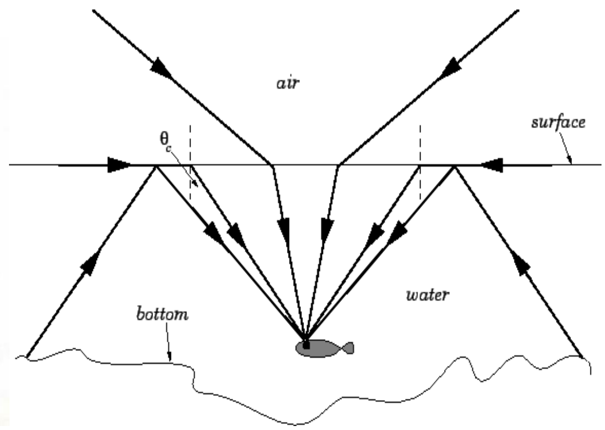
When light meets a layer at angles of incidence greater than the critical angle, it suffers total internal reflection. After this it proceeds to bend progressively upwards and on entering the eye it appears to come from the ground.

The reflection of the sky forms an image which appears as a pool of water on the road.

So the ground appears like water reflecting the sky.

2. **The fish's Eye view**





A fish in water can have a wide field of view as it can see any object above and below the water surface.

If angle i is less than the critical angle, it can see any object above the water surface by refraction. It can also see an object at the bank of lake if the angle of incidence is equal to the critical angle. And if i is greater than the critical angle, an object below the water surface can be seen by total internal reflection.

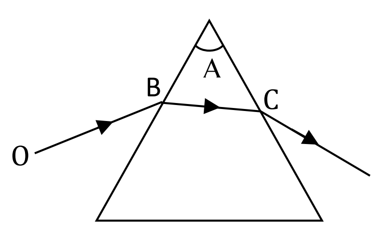
Therefore:

As long as the water surface is calm a fish has a full view of everything above and below the water.

- **ATTEMPT EXERCISE 10.3 PAGE 163-164 IN LONGHORN BOOK THREE**
- **ATTEMPT REVISION EXERCISE 10 PAGE 165-169 IN LONGHORN BOOK THREE**

REFRACTION OF LIGHT THROUGH A GLASS PRISM

PRISMS



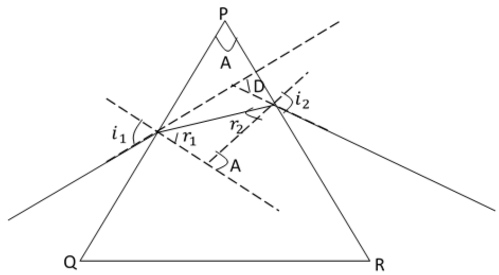
A prism is a solid with plane faces and of uniform cross-section.

The diagram shows a cross-section of a prism.

An incident ray OB is refracted at B and then at C as it emerges. The net result is that the ray bends towards the base of the prism as it passes through it.

A ray of light entering the prism at one face emerges from the prism in a different direction. The ray is deviated and the angle of deviation D can be calculated.

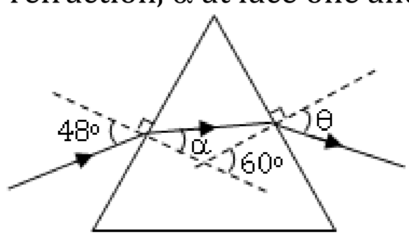
Consider a monochromatic ray of light incident at face 1 of a triangular glass prism.
Note: A monochromatic ray of light is light of one colour.



Angle A is called the refracting angle or the prism angle.
Angles i_1 and r_1 are the angles of incidence and refraction at face PQ
Angles $i_2$and r_2 are the angles of incidence and refraction at face PR when light is reversed
Angle of deviation, D: This is the angle between the ray of incidence and the emergent ray.
Now:
$r_1 + r_2 = A$ (sum of two interior angle = exterior angle) …………… (i)
Also, the angle of deviation, D is determined as follows:
$D = (i_1 - r_1) + (i_2 - r_2)$
$\therefore \mathbf{D = (i_1 + i_2) - (r_1 + r_2)}$ …………………………………………………………(ii)
$\mathbf{D = (i_1 + i_2) - A}$ ……………………………………………………………………………(iii)

Examples

1. A ray of light enters a prism, whose material is of refractive index 1.53, at an angle incidence of 48°. Calculate the angles of refraction, α at face one and angle of emergency, θ.



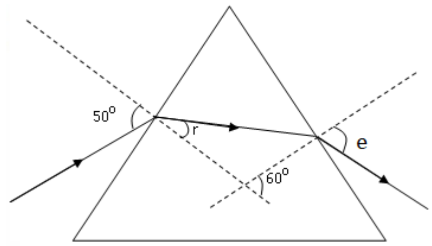
2. A prism of refractive 1.5 and refractive angle 60^0 has an angle of refraction of 28^0 on the 1st face. Determine
   (a) angle of incidence i (44.7)

   (b) angle of refraction on 2nd face r_2 (32)

(c) angle of emergency e (52.64)

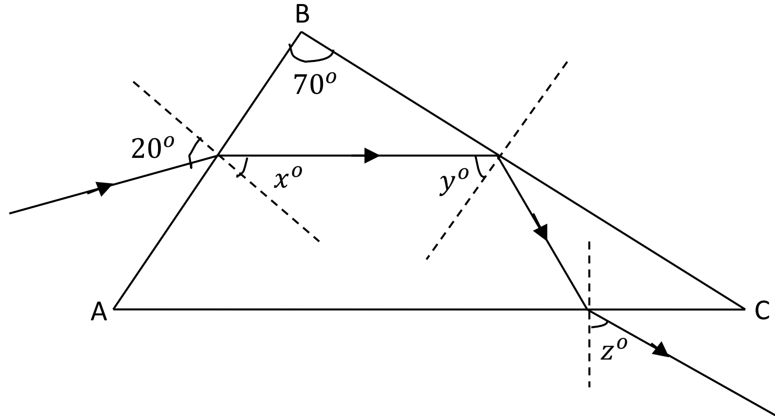
(d) angle of deviation d (37.34)

3. The diagram below shows a ray of yellow light incident at an angle of 50^o on one side of an equilateral triangular glass prism of refractive index 1.52.



Calculate the angles marked r and e.

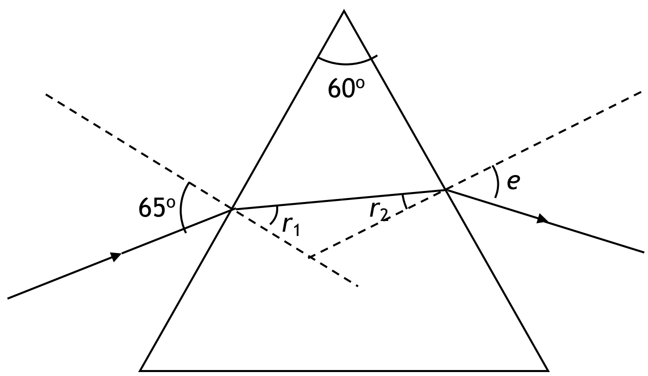
4. LEAVE 5 LINES FOR THIS DIAGRAM



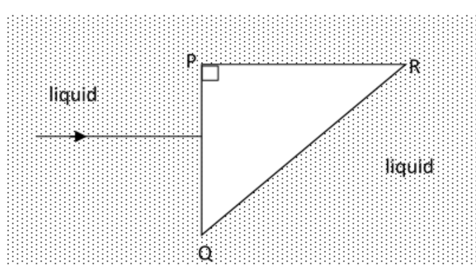
The diagram above represents a ray of light travelling from air as it enters and emerges from the prism ABC of refractive index, 1.6 .
Find the angle y^o .

State the conditions necessary for the ray of light to behave as shown in the diagram when it is incident on the face BC of the prism.

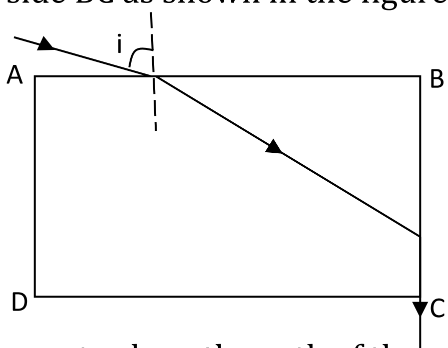
5. The diagram below shows a ray of yellow light incident at an angle of 65^o on one side of an equilateral triangle prism of refractive index 1.52. Find the angle, e at which the ray emerges from the opposite side of the prism.



6. The figure below shows a ray of light incident normally on face PQ of a right-angled isosceles prism whose refractive index is $\frac{8}{5}$. The prism is surrounded by a liquid of refractive index $\frac{7}{5}$.



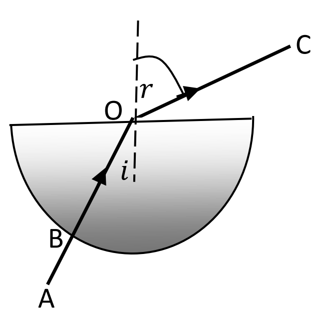
7. A ray of light incident on the edge AB of a rectangular glass block ABCD of refractive index 1.40 just emerges from the side BC as shown in the figure. Calculate the angle of incidence, i.



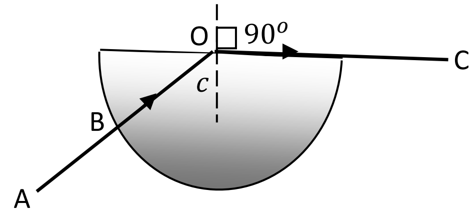
Copy and complete the diagram to show the path of the ray after striking face QR.
Find the
(a) angle of incidence of the light on face QR.

(b) angle of refraction of the light on face QR.

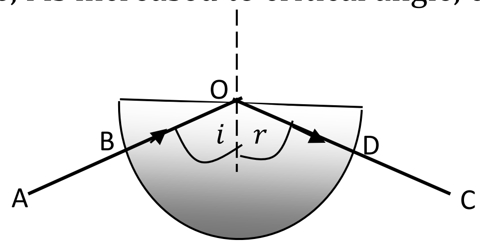
Semi-circular glass prism.



Any ray like AO incident on the circumference of the semi-circular prism at a point like B enters the glass prism unit deviated because it is incident along the normal to the circumference.
If the angle of incidence, i is less than the critical angle of the glass, the ray will emerge into the air being refracted away from the normal.

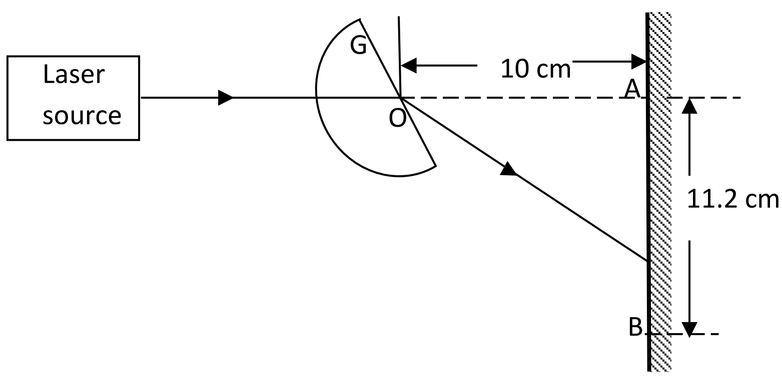


As the angle of incidence, i is increased to critical angle, c the angle of refraction increases to 90^0.



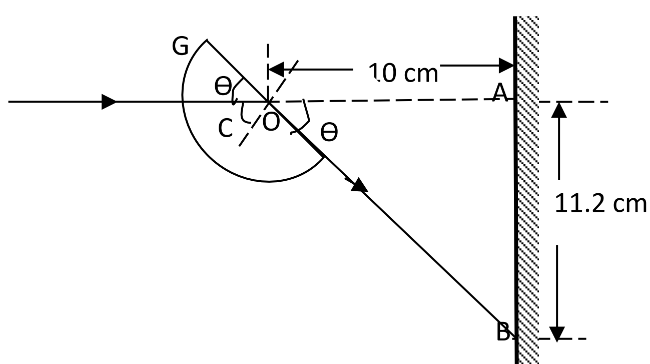
When the angle of incidence is increased beyond the critical angle, total internal reflection occurs. The reflected ray emerges undeviated at point D.

Examples:
The figure below shows a narrow beam of monochromatic light from a laser directed towards point A on a vertical wall.
A semi-circular glass prism G is placed symmetrically across the path of light with its straight edge vertical. As the block is rotated in a vertical plane about its centre O, the bright spot where the beam strikes the wall moves downwards from point A, and disappears at point B.



(a) Explain why the spot of light disappears at point B.
(b) Find the refractive index of the material of the glass block.
(c) Explain whether the distance AB will be longer or shorter if a glass block of lower refractive index is used.

Solution:

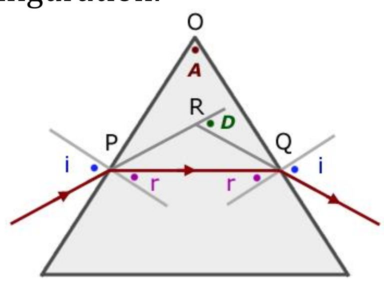


From $\measuredangle OAB$: $\tan\theta = \frac{11.2}{10} = 1.12$
$\theta = \tan^{-1} 1.12 = 48.2^0$
Critical angle of the glass block , $c = 90^o - \theta = 90^o - 48.2^o = 41.8^o$
The spot of light disappears after point B because the light undergoes total internal reflection when the angle of incidence at O becomes greater than the critical angle C.
Refractive index of the glass: $\cap_g = \frac{1}{\sin C} = \frac{1}{\sin 41.8^o} = 1.5$

$\cap_g = \frac{1}{\sin C}$ therefore decreasing the refractive index of the glass will increase the critical angle C (i.e $C > 41.8^o$.
Then $\theta < (90^o - C) = (90^o - 41.8^o) < 48.2^o$
If $\theta = 47^o$ then,
$AB = 10\tan\theta = 10\tan 47^o = 10.7$ cm
Therefore, lowering the refractive index of the glass will make AB shorter.

Minimum Deviation by a Prism

Ray tracing through a prism is nothing conceptually new -- it is just an application of the rules of refraction.
The minimum deviation *D* in a prism occurs when the entering angle and the exiting angle are the same, a particularly symmetrical configuration.

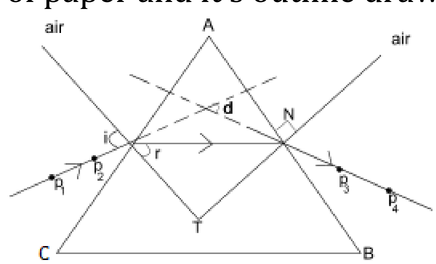


The angle of minimum deviation is responsible for some meteorological phemomena, like **halos** and **sundogs**, produced by deviation of sunlight in the hexagonal prisms of ice crystals in the air.

ADVANTAGES OF GLASS PRISMS OVER PLANE MIRRORS
- No energy is lost to refraction and reflection.
- They form clear images
- Prisms may last longer than mirrors since mirror coatings such as silver fade with time.

An experiment to determination of refractive index using a triangular prism

A prism is placed on a white sheet of paper and it's outline drawn as shown below.



Two object pins P_1 and P_2 are fixed upright on side AC and while looking through the prism for side AB, two other pins p_3 and p_4 are fixed such that they appear to be in line with images of P_1 and P_2, the prism is removed, a line drawn through P_1 and P_2 another drawn through P_3 and P_4.

Points M and N are joined by a straight line and normal ST drawn at a point M as shown.
Angle i and r are measured
The procedure is replaced to obtain different values of i and r and the results tabulated as shown.

$i(^0)$	$r(^0)$	Sin i	Sin r
	-	-	-
	-	-	-
	-	-	-

A graph of Sin i against Sin r is plotted. The slope of the graph is the refractive index of the prism.

SUB-TOPIC: Dispersion of white light through a prism and appearance of objects in Coloured light.
SPECIFIC OBJECTIVES: The learner should be able to;

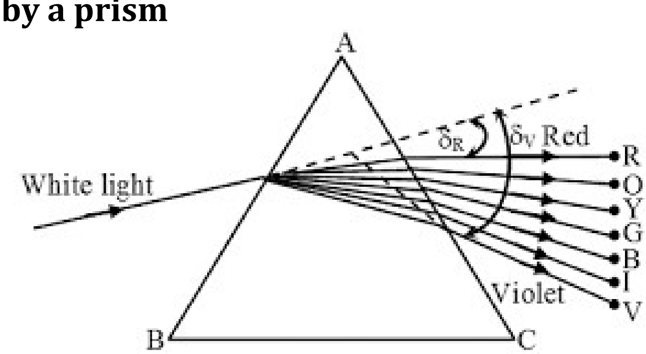
- Perform an experiment to demonstrate passage of white light through a prism.
- Draw rays of light to show passage of light through a prism and label the spectrum.
- Perform an experiment to produce a pure spectrum.
- Investigates the appearance of objects in Coloured light.
- Investigate the effect of light filters and mixing Coloured lights.
- Draw the complete electromagnetic spectrum in order of wavelength or frequency.
- Mention the properties and uses of the components of the electromagnetic spectrum.

DISPERSION OF LIGHT

White light consists of seven colours, each having its own wavelength (and therefore frequency). So when white light crosses a boundary between two media of different optical densities, each colour is refracted to a different angle. Therefore, the beam that proceeds consists of a series of coloured lights arranged in order from one side to the other. The phenomenon is known as dispersion.
i.e. **dispersion is the splitting up of (white) light into its constituent colours.**

The band that displays these colours in their order is known as the spectrum of the incident light.

Dispersion of white light by a prism



The colour (Red), with the shortest wavelength is deviated most while that with the longest wavelength (violet), is least deviated.

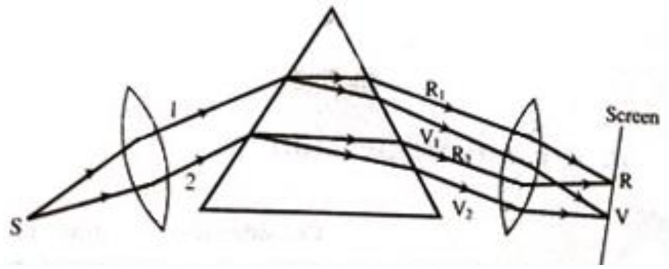
Exercise

Arrange the colours in the spectrum of white light beginning with one of shortest wavelength.

In most cases, the colours of a spectrum tend to overlap resulting into an impure spectrum.

Production of Pure Spectrum

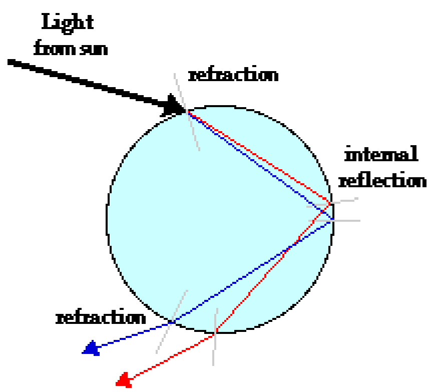
A pure spectrum is one in which the colours of the spectrum DO NOT overlap. This may be obtained using a spectrometer.



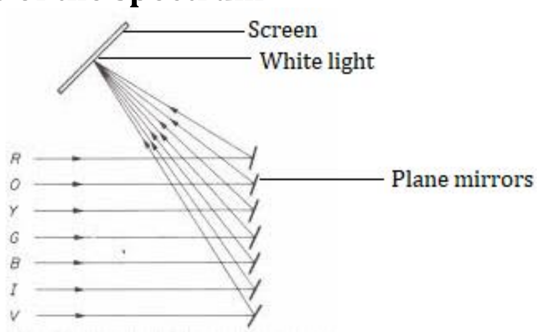
The arrangement of the slit with the lens C is called a collimator. The slit is at the principal focus of the collimator lens C. So the light emerging from C is a parallel beam, and this is the purpose of the collimator.
The prism disperses the light into its constituent colours, the lens T focuses each colour to a different position, thus producing a pure spectrum.

RAINBOW

White light from the sun undergoes dispersion as it enters into the rain drops of water in the sky. Total internal reflection takes place at the opposite side of the raindrop and different colours emerge from the raindrop after refraction.



Recombination of the colours of the spectrum



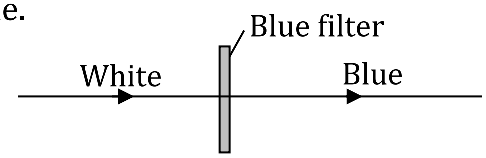
If all the colours in the spectrum of white light are reflected to the same place on a white screen, in a dark room, a white patch is formed.
This explains why when a disc with sectors coloured with colours of the spectrum of white light appears white when rotated at high speed. In this case, due to persistence of vision, the brain perceives all the colours as though they are arriving at the same time.

Colour of objects in white light

An object appears coloured in white light because it absorbs all other colours and appears the colour it reflects. E.g. if white light falls on a body which looks red, the object is reflecting red and absorbing all the other colours. The energy of the absorbed light is converted into heat. A black body absorbs all the colours of white light and reflects none.

Light filters

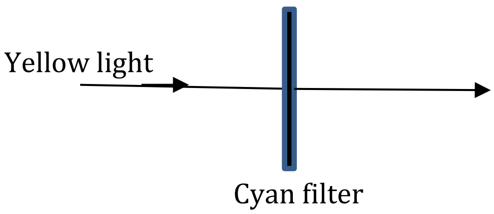
A light filter is a material that transmits only a particular colour of light and absorbs the rest e.g a blue filter will transmit only blue.

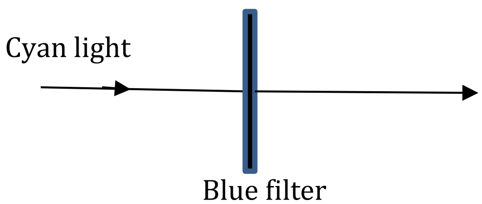


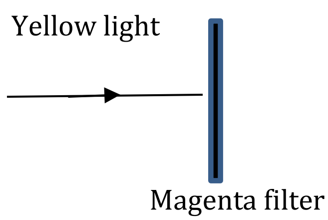
This means that if the incident light lacks blue, no light will be transmitted through the filter.

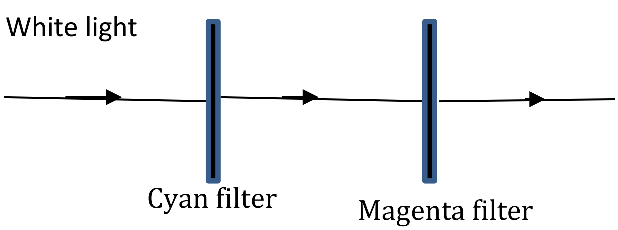
Questions:

Name the colour that is permitted to pass through each of the colour filters named below.

1. 

2. 

3. 

4. 

PRIMARY AND SECONDARY COLOURS

A primary colour of light is one that cannot be obtained by mixing any two or more colours. Examples are: red, blue and green.

Secondary colours are those obtained by mixing two primary colours e.g.

Cyan = Blue + green

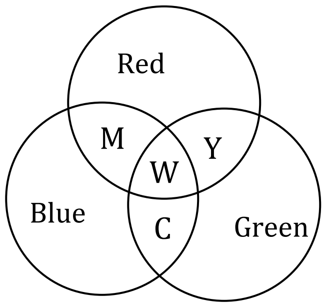
Yellow = Red + green

Magenta = Red + blue

This is colour mixing by **addition.**

When the three primary light colours: red, blue and green are mixed, white light is obtained.
Therefore, the following combinations result in white light as shown.
Red + cyan = white
Blue + yellow = white
Green + magenta = white

Any two colours that are mixed to give white light are known as complementary colours.
The following diagram summarises the situation.



M = magenta
C = cyan
Y = yellow
W = white

Colour of yellow petals

Yellow petals reflect, yellow, red and green at the same time and the whole combination still looks yellow. This is known as compound yellow. This is why in green light the yellow petals look green because they reflect green and in red light they look red.

Appearance of objects in coloured light

An object will appear the colour that it reflects and absorbs all the other colours.
A black object absorbs all the colours of white light.

Exercise

1. A red object looks red in white light but it looks black in green light. Explain why?

2. Fill the following table.

Incident light	Colour of object	Appearance of object
White		Blue
Yellow	Green	
Magenta	Green	
Cyan	Magenta	
Yellow	Cyan	

Mixing coloured pigments (paints)

When yellow paint is mixed with blue paint the resulting paint looks green. This is because yellow paint reflects pure yellow, red and green and absorbs blue. The blue paint also is not pure but reflects blue, green and absorbs red and yellow. The only colour they both reflect is green. So the mixture looks green.
Red, yellow and blue have been removed from the reflected light. Hence, this is known as colour mixing by **subtraction.**

Questions:
1. A house is painted green and blue. What colour will it appear when viewed through a magenta filter? (Ans: the green appears black, the blue appears blue).

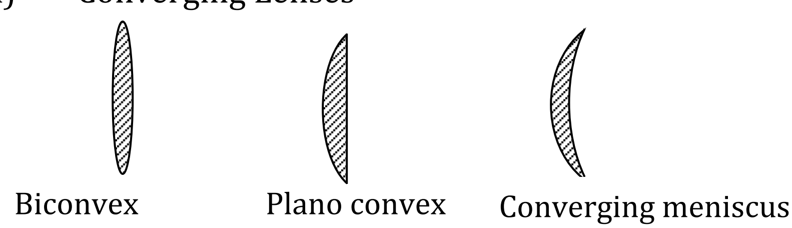
2. A yellow dress with blue dots is placed in a room lit with red light. What colours will it appear? (Ans. The yellow will appear red while the blue dots will appear black).

SUB-TOPIC: Lenses and optical instruments.
SPECIFIC OBJECTIVES: The Learner should be able to;
- Define optical lenses.
- Define power of a lens (in dioptres).
- Graphically construct images (on scale) formed by lenses using the standard rays.
- Describe images formed by lenses.
- Determine magnification of images formed by lenses.
- Determine the local length of thin converging lenses.
- Draw the projector and describe how it works.
- Draw the human eye and the lens camera (only optically essential parts) and explain how they form images.
- Explain the use of lenses in correction of eye defects.

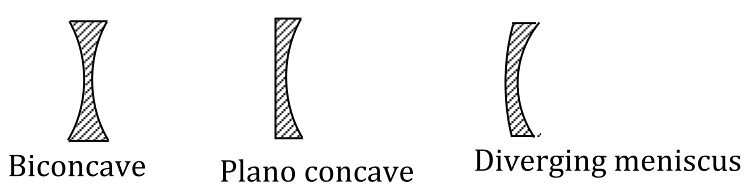
LENSES

A lens is a transparent medium bound between two surfaces of definite geometrical shape.
There are mainly two types of lenses, namely;
(a) Convex (converging) lens
(b) Concave (diverging) lens

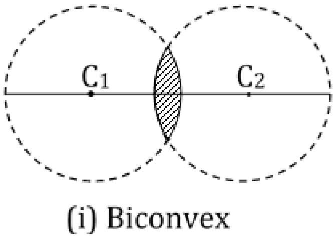
(a) Converging Lenses

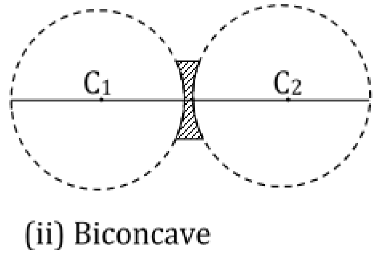


(b) Diverging Lenses



A lens has two surfaces, each surface being part of a sphere with its own centre. The centre of each surface is called the centre of curvature.



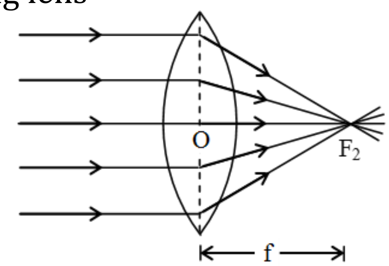


The centre of curvature is the centre of a sphere of which the concerned surface of the lens is part.

TERMS USED

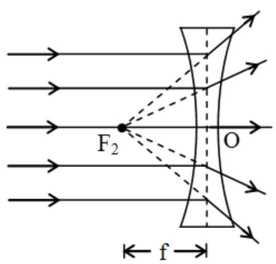
1. Principal axis
   This is a line passing through the centres of curvature.

2. Principal focus of a converging lens



   This is a point to which all rays originally parallel and close to the principal axis converge for a converging lens after passing through the lens.

3. Principal focus of a diverging lens



   This is a point to which all rays originally parallel and close to the principal axis from which they appear to emerge for a diverging lens after passing through the lens.

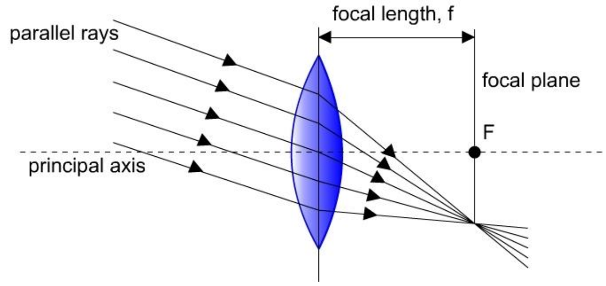
   A lens has two principal foci, one on either side.

4. Focal length
   This is the distance between the optical centre and the principal focus.

5. Aperture the portion of the lens which is subjected to light.

6. Optical centre.
   This is the point which lies exactly in the middle of the lens.

7. Focal plane



This is a plane that passes through the principle focus and is perpendicular to the principal axis.

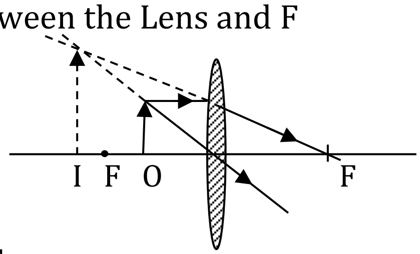
Ray Diagrams

The following rules can be applied when constructing ray diagrams for lenses:

- Rays parallel to the principal axis pass through the principal focus after refraction.
- Rays through the principal focus emerge parallel to the principal axis after refraction.
- Rays through the optical centre are not deviated.

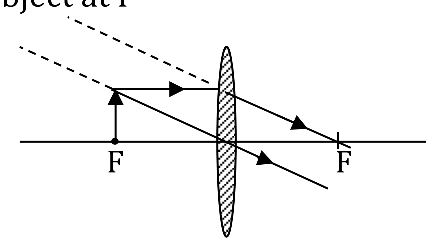
IMAGES BY A CONVERGING LENS

1. Object between the Lens and F



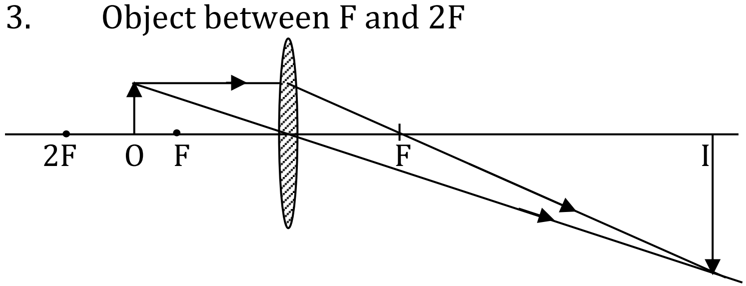
The image is:
(i) virtual
(ii) erect
(iii) magnified
(iv) on same side as object

2. Object at F



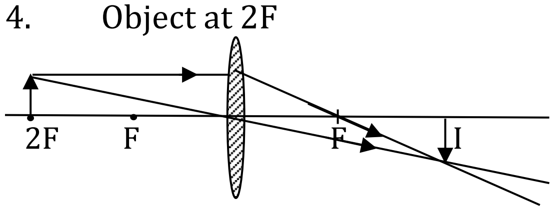
The image is at infinity

3. Object between F and 2F



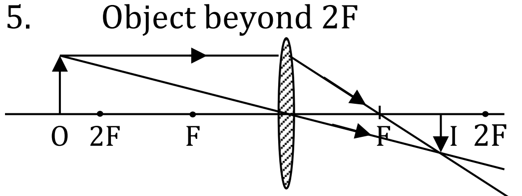
The image is
(i) Beyond 2F
(ii) Real
(iii) Inverted
(iv) Magnified

4. Object at 2F



The image is:
(i) at 2F
(ii) real
(iii) inverted
(iv) same size as object

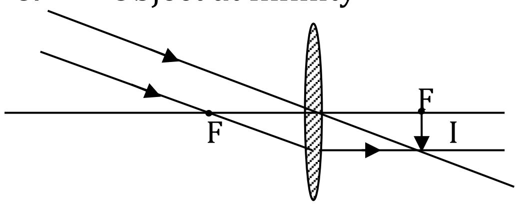
5. Object beyond 2F



The image is:
(i) between F and 2F
(ii) real

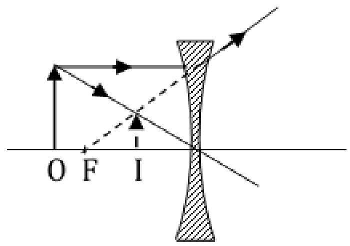
(iii) inverted
(iv) diminished

6. Object at Infinity



The image is:
(i) real
(ii) at F
(iii) inverted
(iv) diminished

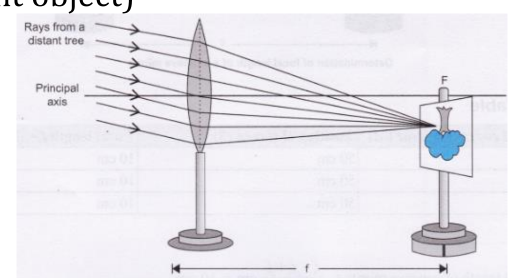
IMAGES FORMED BY DIVERGING LENSES



The image is:
(i) virtual
(ii) erect
(iii) diminished
(iv) on same side of lens as the object

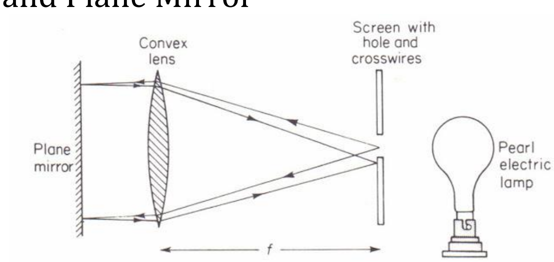
DETERMINATION OF FOCAL LENGTH OF A CONVERGING LENS

1. Simple Method (using a distant object)



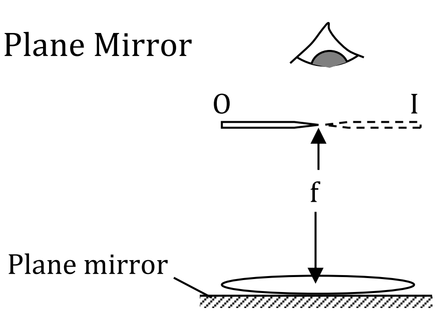
A white screen is placed behind the lens that is facing an open window
The distance between the lens and the screen is adjusted until a sharp image of a distant object is formed on the screen.
The distance between the two is measured and it is equal to the focal length.

2. Using an Illuminated Object and Plane Mirror



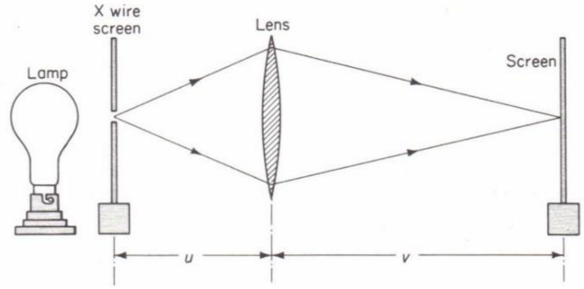
The plane mirror is placed facing the lens, which is supported in a holder.
On the opposite side of the lens is placed a white screen having a hole with wire gauze in it.
The wire gauze is illuminated from behind and the position of the screen is adjusted until a sharp image of the gauze is formed on the screen.
The distance between the screen and the lens gives the focal length of the lens.

3. Using a Pin and Plane Mirror



A plane mirror is placed on a bench facing up and the lens is placed on top of it.
A horizontal optical pin, O, is held above the lens on a stand.
The height of the pin is adjusted while looking from above it, until the object pin and its image, I, are in the same position (this is so when there is no parallax between the two)
The distance between the pin and the lens gives the focal length of the lens.

4. By Measurement of Object and Image Distances



Illuminated wire gauze, mounted in a hole in a screen, is placed on one side of the lens at some distance, u.
A white screen is placed on the opposite side of the lens.
The distance of the white screen is adjusted until a sharp image of the wire gauze is formed on it.
The distance, v, between the screen and the lens is measured.
The procedure is repeated using various distances, u, and a table, as shown below is filled.

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

A graph of $^1/_V$ against $^1/_u$ is plotted. Its intercept gives $^1/_f$, where f is the focal length of the lens. So f can be calculated.

POWER OF A LENS

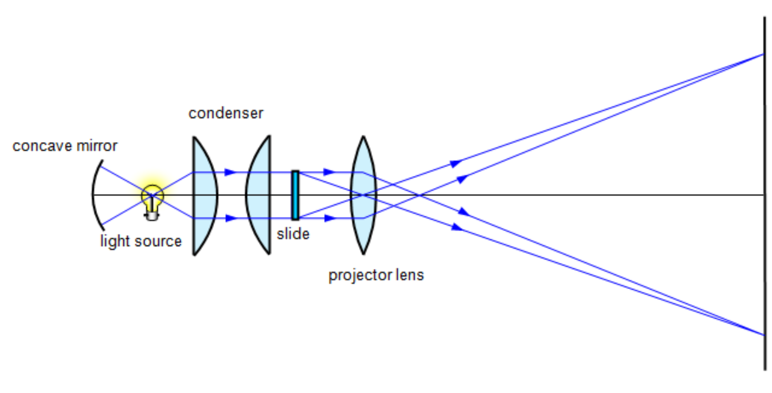
This is defined as the reciprocal of its focal length in metres.

The unit of power of a lens is the dioptre (D) e.g for a lens of focal length 25cm, the power is

$$\frac{1}{0.25} = 4\text{ D}$$

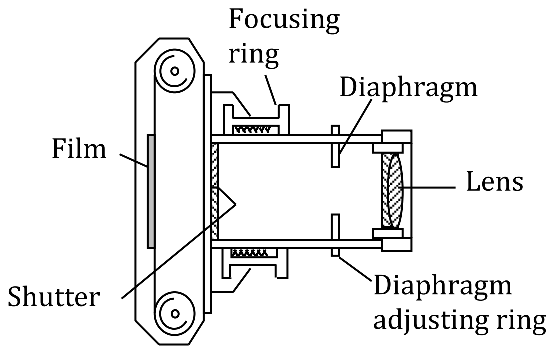
APPLICATIONS OF LENSES

1. The Projector



The light source is a small but very bright (it may be a carbon electric arc or a quartz iodine lamp) situated at the centre of curvature of a concave mirror. This mirror reflects back light would otherwise be wasted.
The condenser concentrates the light onto the slide. The light goes through the slide to the projection lens which forms an inverted magnified image of the slide.
To form a sharp image on the screen, the projection lens is mounted on a sliding tube so that it may be moved to and fro for this purpose.
The size of the image depends on the distance between the slide and the projection lens i.e. for a larger image, the lens should be moved towards the slide while the screen is moved further away.

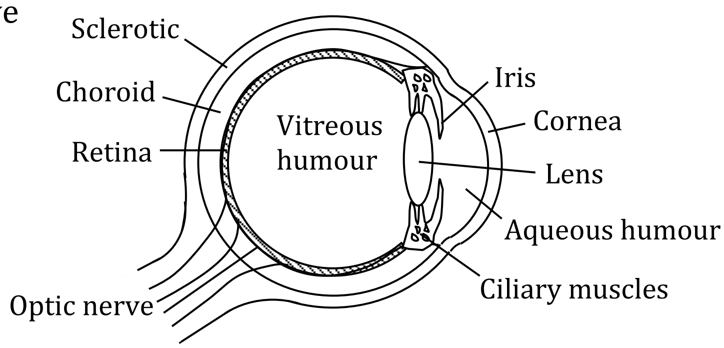
2. The Lens Camera



The main parts of the camera ad their functions can be summarised in the following table.

PART	FUNCTION
Diaphragm	Regulates the amount of light reaching the film
Focusing ring	Adjusts the distance between the lens and the film for focusing
Shutter	Opens for light through the lens to reach the film and determines for to how long it does so.
Lens	Forms a real image of an object on the film.
Film	Keeps records of the image that was formed.

3. The eye



The major parts of the eye and their function are tabulated as below:

PART	FUNCTION
Pupil	is the opening that admits light into the eye. Its size is adjusted by the iris and this way it controls the amount of light reaching the lens.
The Iris	This controls the size of the pupil. It controls the amount of light entering the eye.
The lens	This focuses the light, hence forming an image of the object onto the retina.

The ciliary muscles	This varies the focal length of the lens by either compressing it or stretching it so as to focus the images on the retina for different object distances. The alteration of the focal length by the ciliary muscles is known as accommodation.
The retina	This is where the images are formed. It sends the signals through the optic nerve to the brain for interpretation.

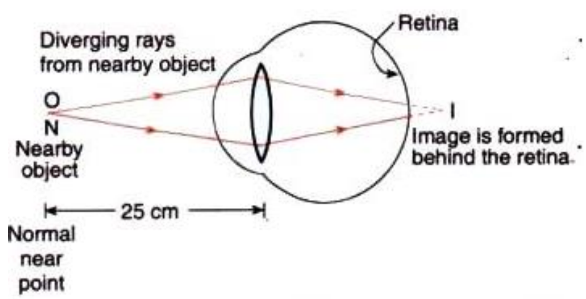
Question: Identify similarities between the lens camera and the eye:

DEFECTS OF VISION AND THEIR CORRECTION

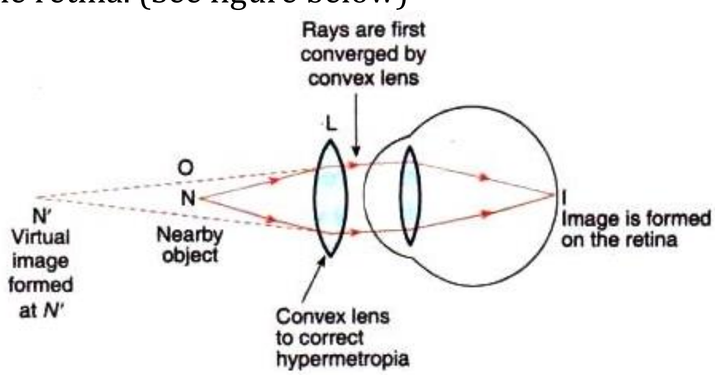
A normal eye is capable of accommodating for clear vision of objects at infinity down up to about 25cm.

1. Long Sightedness (Hypermetropia)

   The eye ball is too short, i.e the distance between the lens and the retina is too short. The eye can accommodate for far objects but not for near ones. Rays from the near point would meet after the retina.
   (See figure below)

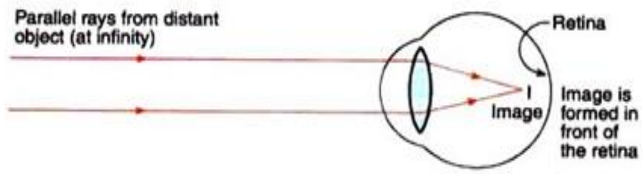


   Correction: – It is corrected by use of a converging lens so that now the rays from a near point converge at the retina. (See figure below)

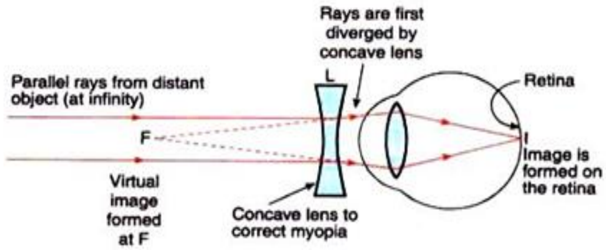


2. Short sightedness (Myopia)

The eye ball is too long, i.e the distance between the lens and the retina is too long. The eye can accommodate for near objects but not for very distant ones. Rays from a very distant object meet before the retina. See the figure below.



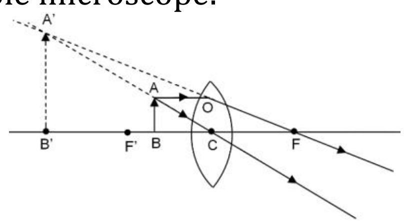
Correction:- A diverging lens is used to correct this defect as shown in figure below



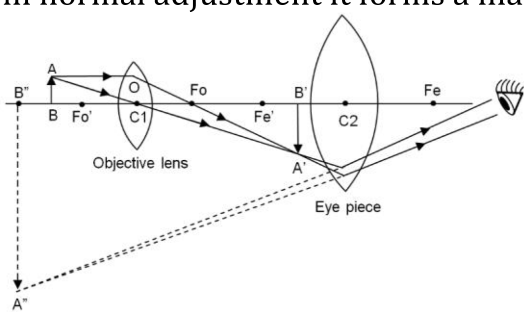
Microscope

A microscope is an instrument for viewing near objects.

1. Simple Microscope (The magnifying glass)
 When the object is placed between a converging lens and its principal focus, the arrangement becomes a simple microscope.



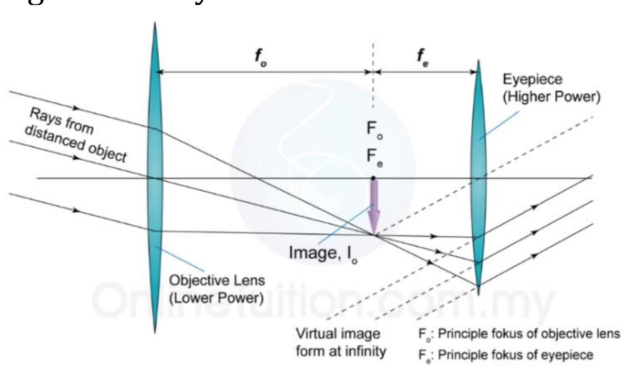
2. The compound microscope
 This uses two lenses and in normal adjustment it forms a magnified image at near point.



The small object O is placed between F_o and $2F_o$ of the objective. The objective forms the intermediate image I_1 of O. Then I_1 acts as the object for the eyepiece, which forms the final magnified image I_2.

Telescope

A telescope is used for viewing distant objects. It also uses two lenses and in normal adjustment it forms the final magnified image at infinity.



THE END.