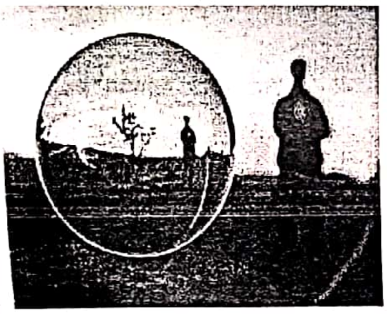
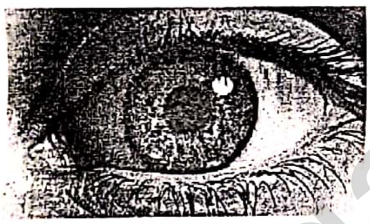
CHAPTER 14:

LIGHT





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O / AS & A Level Physics

Syllabus Content

14.1 Reflection of light
14.2 Refraction of light
14.3 Thin converging and diverging lenses

Learning outcomes

Candidates should be able to:

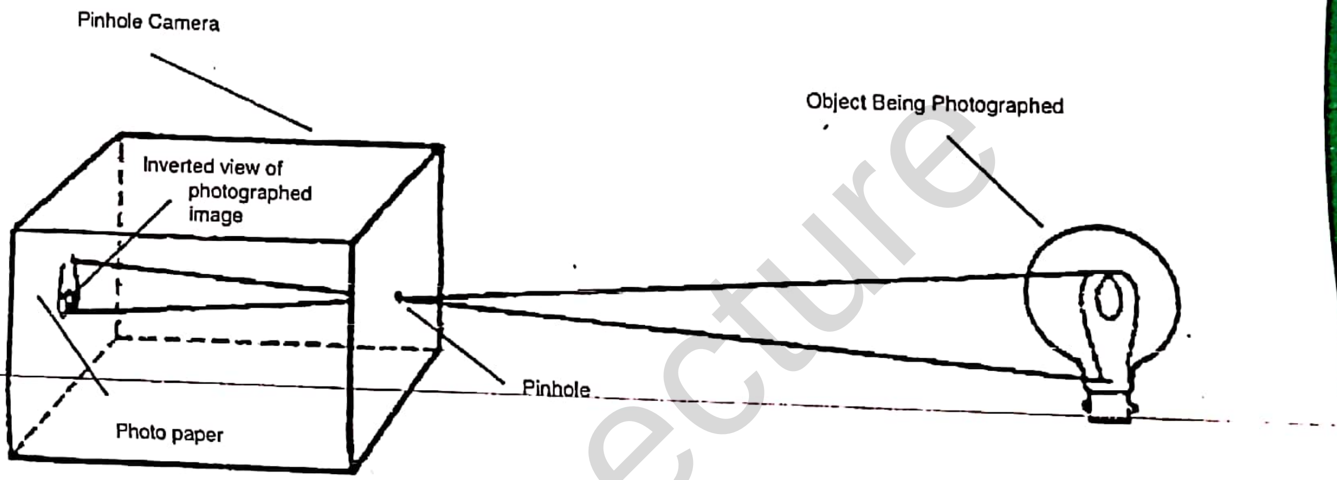
(a) Define the terms used in reflection including *normal*, *angle of incidence* and *angle of reflection*.
(b) Describe an experiment to illustrate the law of reflection.
(c) Describe an experiment to find the position and characteristics of an optical image formed by a plane mirror.
(d) State that for reflection, the angle of incidence is equal to the angle of reflection and use this in constructions, measurements and calculations.
(e) Define the terms used in refraction including *angle of incidence*, *angle of refraction* and *refractive index*.
(f) Describe experiments to show refraction of light through glass blocks.
(g) Recall and use the equation $\sin i / \sin r = n$.
(h) Define the terms *critical angle* and *total internal reflection* and recall and use the formula $\sin c = 1/n$.
(i) Describe experiments to show total internal reflection.
(j) Describe the use of optical fibres in telecommunications and state the advantages of their use.
(k) Describe the action of thin lenses (both converging and diverging) on a beam of light.
(l) Define the term *focal length*.
(m) *draw ray diagrams to illustrate the formation of real and virtual images of an object by a converging lens, and the formation of a virtual image by a diverging lens.
(n) Define the term *linear magnification* and *draw scale diagrams to determine the focal length needed for particular values of magnification (converging lens only).
(o) Describe the use of a single lens as a magnifying glass and in a camera, projector and photographic enlarger and draw ray diagrams to show how each forms an image.
(p) Draw ray diagrams to show the formation of images in the normal eye, a short-sighted eye and a long-sighted eye.
(q) Describe the correction of short-sight and long-sight.

The Light waves are transverse electromagnetic waves. Light travels in vacuum with the greatest speed in the universe (3×10^8 m/s). Wavelengths of light are very short (about 5×10^{-7}m), but the frequencies of light are very high.

Speed of light = $f \times \lambda$

Since speed in vacuum is constant, the frequency is inversely proportional to the wavelength for the different colours of light. Light travels in straight lines, therefore, it can produce shadows and inverted images.

Pin-hole Camera:



The image formed on the screen is real and inverted. The size of the image depends on the distance of the object from the pin-hole, as the distance increases the size of the image decreases and becomes brighter. If we use a wider hole, the image becomes blurred and less in sharpness.

The Ray Method to prove reflection laws:

Shine a narrow ray of light along a certain angle onto the mirror. Mark the position of the reflected ray, remove the mirror and measure the angle of reflection.

Show that: angle of incidence = angle of reflection

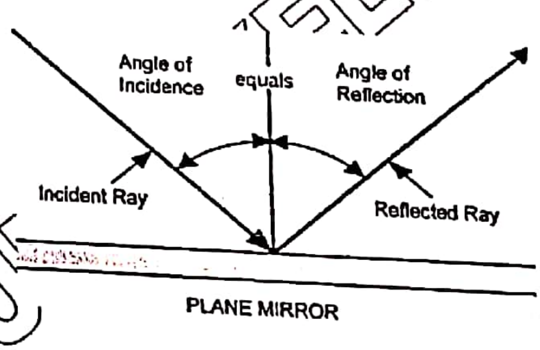
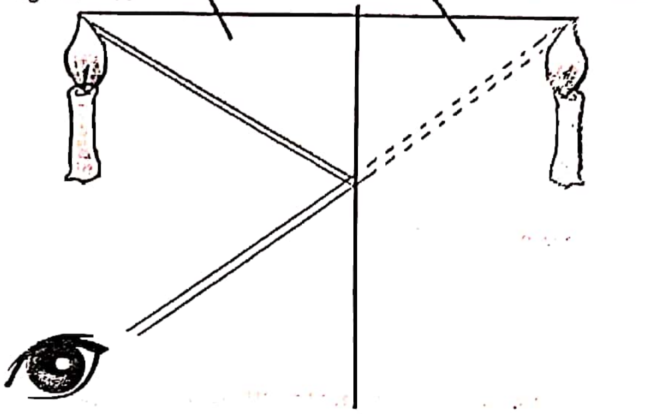
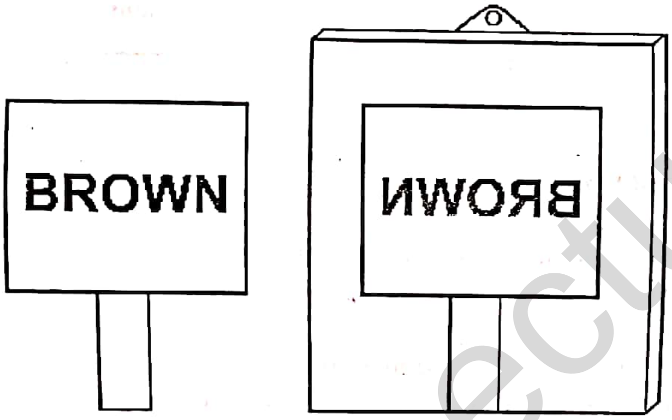


Image in a Plane Mirror:

The properties of the image formed by a plane mirror are:

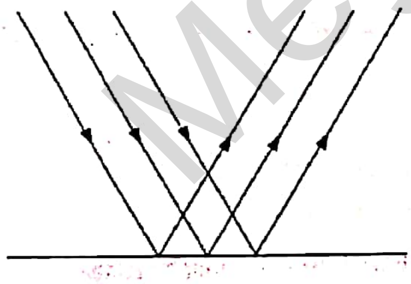
1. It is virtual image (which cannot be formed on a screen).
2. Upright or erect
3. Same size as the object.
4. As far behind the mirror as the object is in front.
5. It is laterally inverted (right-left inversion).

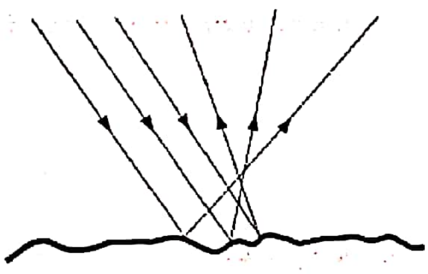




Regular reflection:

Regular reflection occurs on the surface of a plane mirror. Irregular reflection or diffuse reflection occurs on rough surfaces. Most objects are seen by diffuse reflection.





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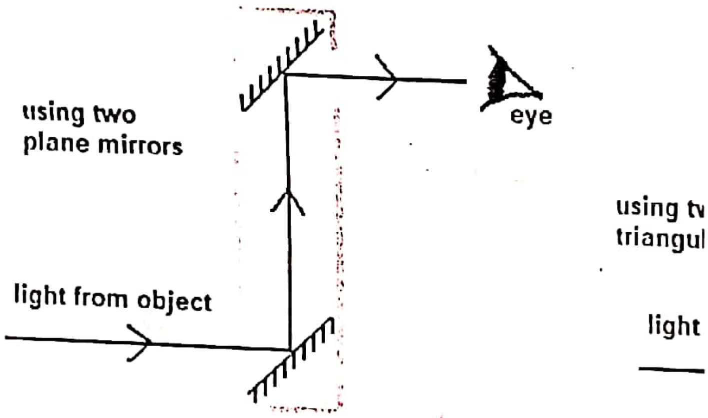
Periscope

It is used to see over the top of an obstacle, and it is used in submarines.

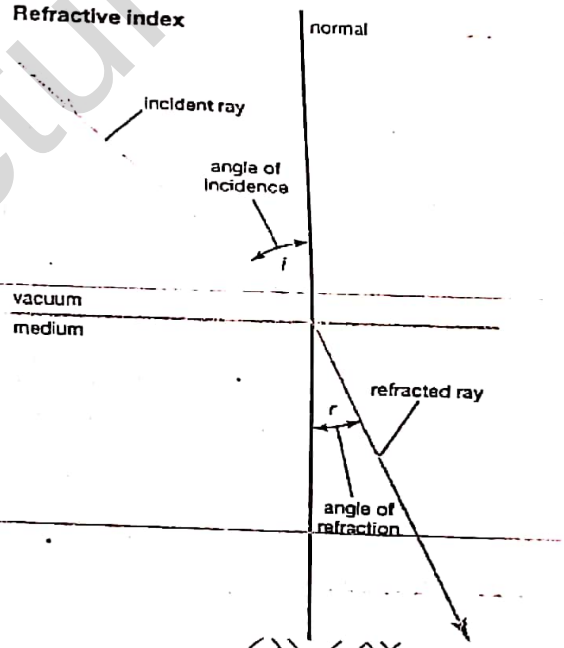
How a periscope works



Refraction of Light

Refraction is the bending of light when it passes from one transparent medium to a different medium.

1. When the ray passes to a denser medium, the ray bends towards the normal (î greater than r̂); also, the speed of light and the wavelength decrease (frequency remains constant).
2. When the ray passes to a less dense medium, the ray bends away from the normal (î smaller than r̂); also, the speed of light and the wavelength increase (but "f" remains constant).
3. If the ray is perpendicular to the boundary, it is not bent but the speed and wavelength change.



Refractive Index

1. The refractive index of a medium is defined as the ratio of the speed of light in air (or in vacuum) to the speed of light in the medium, or

$$n = \frac{V\ air}{V\ medium}$$

2. The refractive index of a medium can also be obtained by: $n = \frac{\sin \hat{i}}{\sin \hat{r}}$

$$n = \frac{\sin(\text{angle in air})}{\sin(\text{angle in medium})}$$

The refractive index of a medium depends upon the density of material and the colour of light.

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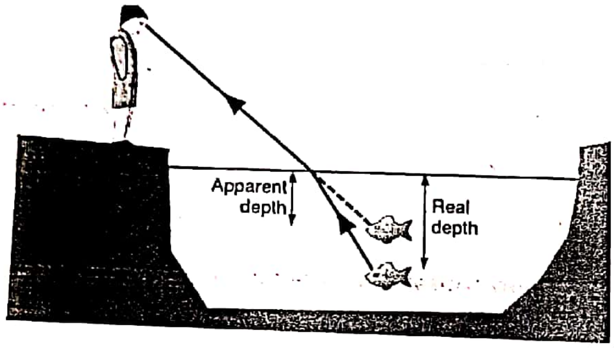
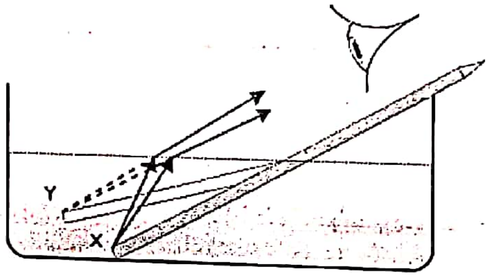
Effect of Refraction

(a) The thickness of a block of glass (or the depth of a lake) appears to be less than the real thickness (or depth).

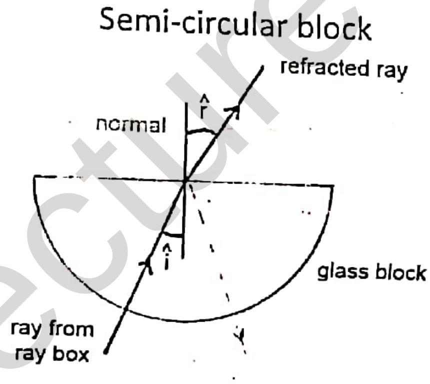
(b) A stick placed in water appears to be bent upwards.





Refractive Index of Glass

Using a semicircular block



1. Draw the outline of the block on the sheet of paper under it and determine the center, 0, of the circle.
2. Sine a ray of light at an angle onto the block and mark the position of the incident ray and refracted ray as it emerges from the block. (notice that the refracted ray emerges from the block in the same direction because it is normal to the circular surface).
3. Remove the block and draw the normal line at 0 and determine the angle of incidence $\hat{i}$ and the angle of refraction $\hat{r}$.
4. Determine the refractive index of glass, where n $= \frac{\sin \hat{i}}{\sin \hat{r}}$

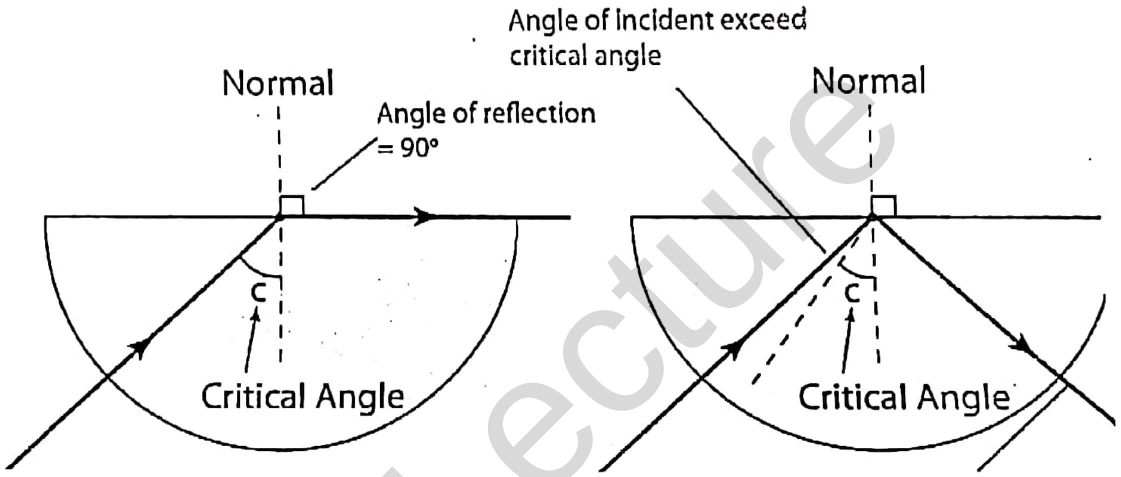
Using a Rectangular block

1. Draw the outline of the block on the sheet of paper under it.
2. Shine a ray of light at an angle onto the glass block and mark the position of the various rays in air and in glass.
3. Remove the block and draw the normal at the points where the ray enters the block and where it leaves the block.
4. Determine the values of the angles $\hat{i}$ and $\hat{r}$, also determine the two angles for the emergent ray. Notice that the two angles in air are equal, and that the two angles in glass are also equal.

5. The refractive index of glass, n $= \frac{\sin \hat{i}}{\sin \hat{r}}$ also note that the emergent ray is parallel to the incident ray.

6. Notice that the displacement, d, of emergent ray is proportional to:
   (a) angle of incidence $\hat{i}$
   (b) the refractive index, n
   (c) width of the block, W

Total internal reflection



Total internal reflection

(a) When light passes at small angles of incidence from a denser medium to a less dense medium, there is a strong refracted ray and a weak reflected ray.
(b) When angle of incidence increases, the angle of refraction also increases. At a certain angle of incidence, called the critical angle, C, the angle of refraction is 90°.

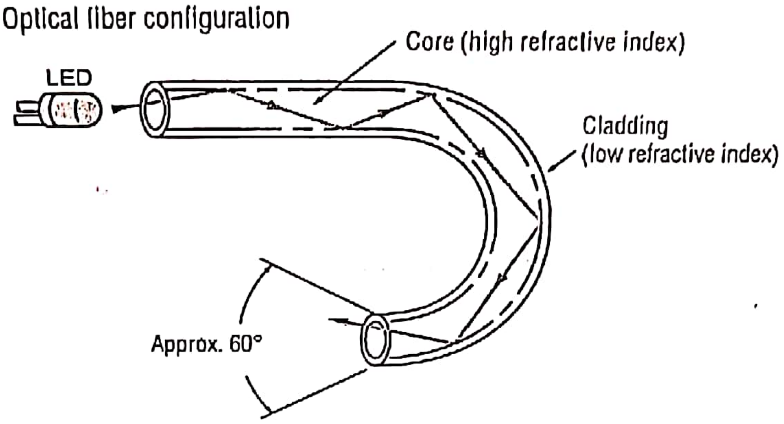
The critical angle C is the angle of incidence in the denser medium which has an angle of refraction equal to 90°.

In case of refraction at critical angle C, we get that: $n = \frac{\sin 90}{\sin \hat{c}}$, or $n = \frac{1}{\sin \hat{c}}$

(c) For angles of incidence greater than "C", all the incident ray is reflected back inside the denser medium, this is called total internal reflection.

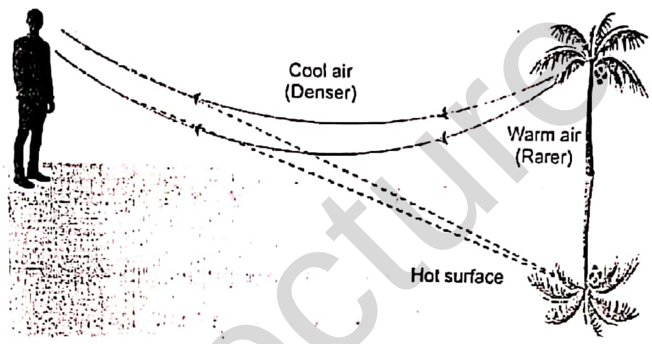
Optical fibers

Optical fibers are made from thin glass or plastic threads. When light strikes the side of tube, it is usually incident at an angle greater than the critical angle of material. It is totally internally reflected several times until it emerges from the far end. They are used in telephone communications and in medical scopes.



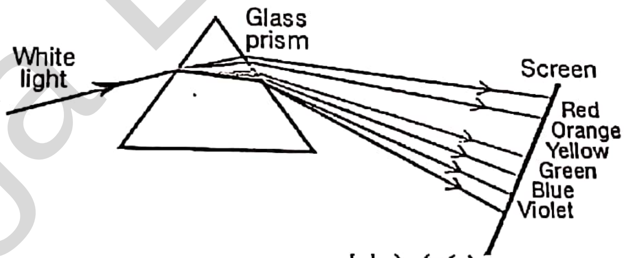
The Mirage

In hot days, the ground appears as if it is wet (illusion), due to total internal reflection on hot air, near the ground.



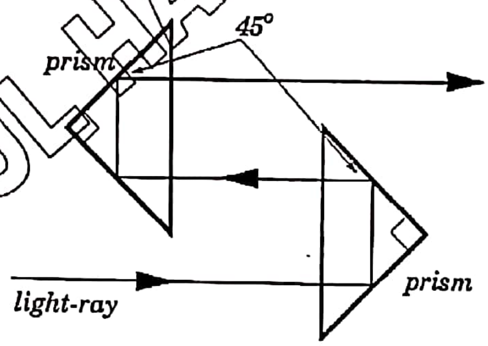
Refraction by a Prism

In a triangular glass prism, refraction occurs at the two surfaces of the prism. The emergent ray is bent towards the base, and the image, I, is displaced towards the apex of prism. The deviation of the ray at the first surface is added to the deviation at the second surface and gives the angle of deviation as shown.



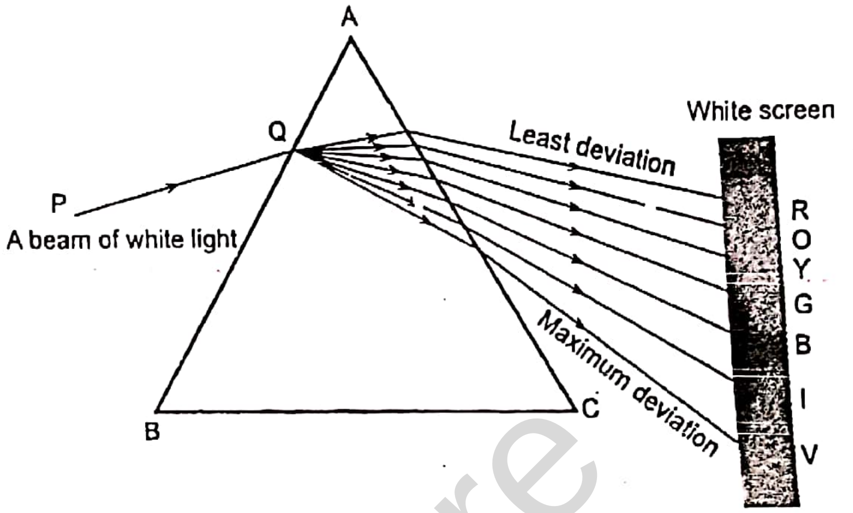
Totally Reflecting Prisms:

45° right-angles glass prisms are used to reflect the light and can replace mirrors. The critical angle of glass is 42° and a ray falling normally on one face hits the other face at 45°. The total internal reflection occurs and the ray is turned through 90°. Light can also be reflected backwards by the prism.



Dispersion of Light

Newton discovered the colours of the light spectrum by allowing sunlight (which is white) to fall on a triangular glass prism. The band of colours obtained is a spectrum and the effect is called dispersion.



1. Dispersion of light is the separation of white light into its component colours (by using a prism).
2. Dispersion occurs because each colour has a different refractive index.
3. White light spectrum has the following colour:
   Red, Orange, Yellow, Green, Blue, Indigo & Violet.
4. Red light has the smallest refractive index
   Violet light has the greatest refractive index.
5. Red light has the smallest frequency (and longest wavelength) Violet light has the highest frequency (and shortest wavelength), Frequency is inversely proportional to the wavelength.
6. All colours travel with the same speed of light in vacuum (but they have different speeds in material media).
7. There are two extra invisible rays which were detected by their effect on the photographic plates. These are:
   a. Infra-red rays which are detected by their heating effect.
   b. Ultra-violet rays which can produce fluorescence in some materials and can darken photographic films.

Lenses

Lenses often have spherical surfaces and are two types:

1. A **convex lens** is thickest in center, it is called a converging lens because it bends the light to meet at appoint.
2. A **concave lens** or diverging lens is thinnest in the center and spreads light out.

Definitions:

(a) **Optical center** of a lens is the center of the lens, C.

(b) **Principal axis** of a lens is the line through C at right angles to the lens.

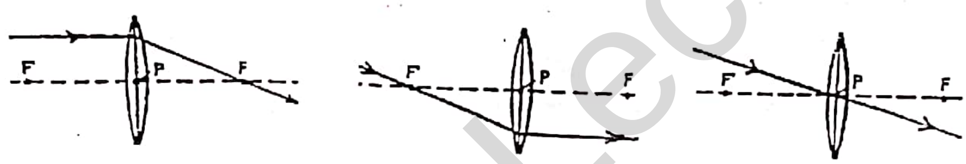
(c) **Principal focus,** F, is the point on the principal axis to which the parallel rays converge after being refracted by the lens. The lens has two principal foci, one on each side, equidistant from C.

(d) Focal length, f, is the distance CF. It is an important property of a lens.

Ray Diagrams

1. A ray parallel to the principal axis is refracted through F.
2. A ray passing through F is refracted parallel to the principal axis.
3. A ray through C passes deviated.

* In diagrams, a thin lens can be represented by a straight line.



Magnification

The linear magnification, m, is given by:

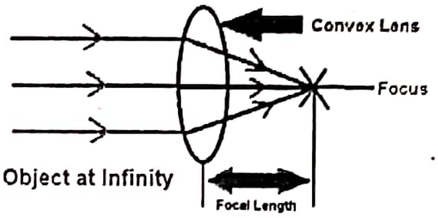
$$m = \frac{\text{height of image}}{\text{height of object}} \quad \text{or} \quad m = \frac{\text{distance of image from lens}}{\text{distance of object from lens}}$$

the magnification of the lens is due to the curvature of its surface; a flat piece of glass does not magnify.

Cylindrical lenses: A cylinder is curved in one direction and is straight in the perpendicular direction. Images formed by cylindrical lenses are magnified in the curved direction but have the same length parallel to the straight direction. (e.g. the cylindrical lens of thermometer enlarges the width of mercury thread but the length of thread remains constant).

Measuring the focal length of a convex lens

1. Lens is set up to receive light beam from a very distant object (sun) so that the rays are parallel.
2. The position of a screen is adjusted until a sharp image is formed on the screen.
3. Measure the distance from lens to screen, it equals "f".



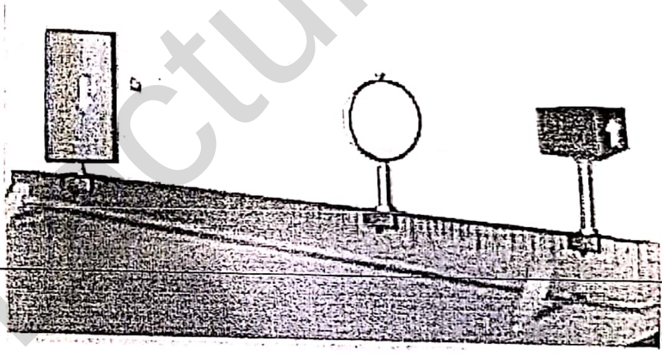
Practical Precaution with Lenses: When taking measurements, notice the following:

1. The source of light, lens, and screen must be lined up in a straight line.
2. Object distance (u) is measured from object to the center of the lens. Image distance (v) is measured from image to the center of the lens.

Properties of image:

The image obtained on a screen is:

1. A real image
2. Inverted (upside down)
3. Laterally inverted (left to right)
4. Larger images are less in brightness than smaller images.



The screen used can be made of (a) a white board, or (b) a tracing paper (translucent) stuck on a frame of stiff card.

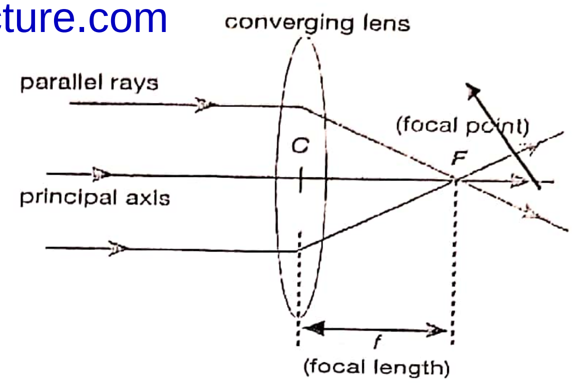
Advantages of using translucent screen: One can view the image from behind the screen.

1. One can measure the size of image from behind the screen without interfering with the rays producing the image.
2. One can line himself behind image to avoid error due to parallax.
3. If needed, one can cover the whole apparatus to get brighter image.

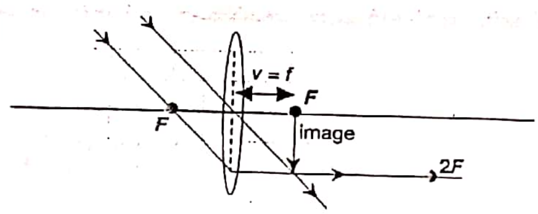
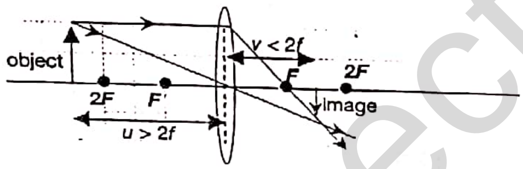
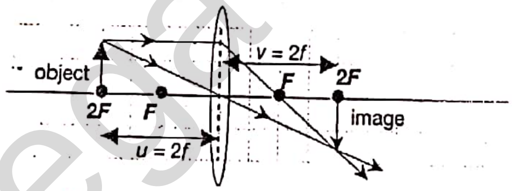
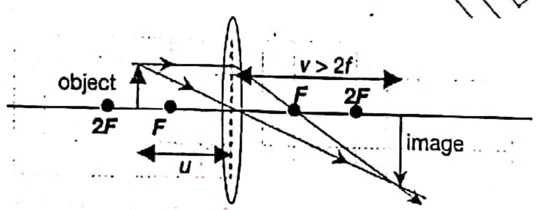
Notes: When focusing strong light from the sun on a screen, do not use a paper screen because it may burn and start a fire; use metal screen. Also, use sun glasses to protect your eyes from bright sun light.

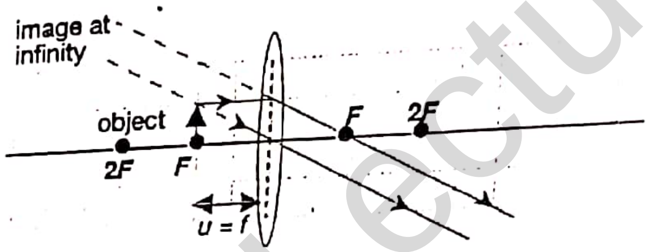
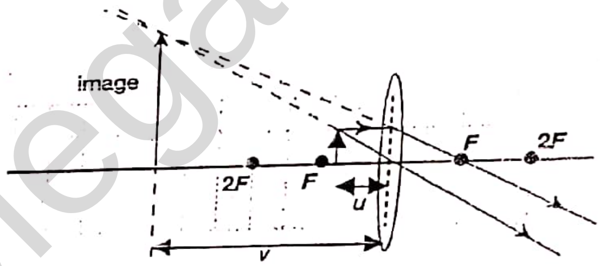
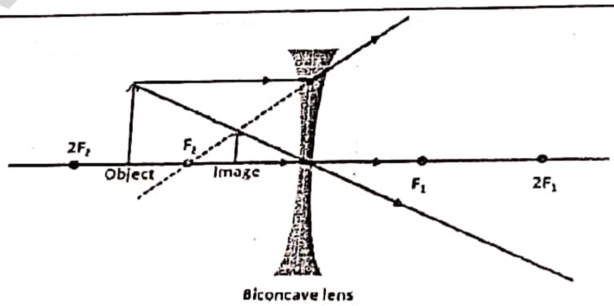
Thin Converging Lens

Action of a thin converging lens on a beam of light Focal length, f, of the lens is the distance between the focal point, F, and the optical Centre, C, of the lens.



Ray diagrams to illustrate the formation of real and virtual images of an object by a lens

Object distance, u	Ray diagram	Image
Object is very far away (u = ∞)		**Type of image:** Real, inverted, diminished **Image distance:** Opposite side of lens; at f **Use:** Objective lens of the telescope.
Object distance is more than 2f (u>2f) (f = focal length)		**Type of image:** Real, inverted, diminished **Image distance:** Opposite side of lens; < 2f **Use:** Camera
Object distance is exactly 2f (u = 2f)		**Type of image:** Real, inverted, same size **Image distance:** Opposite side of lens; at 2f **Use:** Photocopier (same size as object)
Object distance is more than f but less than 2f (f < u < 2f)		**Type of image:** Real, inverted, enlarged **Image distance:** Opposite side of lens; >2f **Use:** Photograph enlarger or projector

Object distance is f (u = f)		***Type of image:*** *Real, inverted, enlarged* ***Image distance:*** *Opposite side of lens; at infinity* ***Uses:*** *To produce a parallel beam of light*
Object distance is less than f (u < f)		**Type of image:** Virtual, upright, enlarged **Image distance:** Same side of lens; >2f **Use:** Magnifying glass
Image in concave lens		**Type of image:** Virtual, upright, smaller **Image distance:** Between f and lens **Use:** Short Sightedness