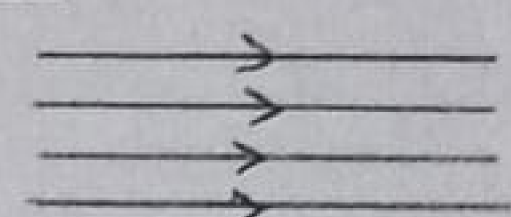
LIGHT – REFLECTION AND REFRACTION

- **LIGHT** is a form of energy that causes the sensation of sight. An object reflects the light that falls on it and this reflected light when received by our eyes enables us to see things.
- Light has a **DUAL CHARACTER** i.e. it can behave as a wave or as a particle. Some of the phenomenon like diffraction (i.e bending of light around the corners of tiny objects), interference, polarisation etc can be explained when we consider light has a wave character. On the other hand, the phenomenon like reflection, refraction and casting of shadows of object by light can be explained by particle nature of light. Modern theory of light i.e. Quantum theory of light combines both wave and particle nature of light.
- Light travels in a **straight line**. The fact that a small source of light casts a sharp shadow of an opaque object tells us that light travels in a straight line.
- **RAY AND BEAM OF LIGHT** – A ray of light is the straight line along which light travels. The arrow head put on the straight line tells us the direction in which the light is travelling. A bundle of light rays is called a **BEAM OF LIGHT**. A narrow beam of light is called **PENCIL OF LIGHT**.

Ray of light.



Beam of light

- **OBJECT** – Anything which gives out light rays is called an object. It can possess its own light (e.g. sun, candle etc) or it can receive the light from an external source and then reflect it e.g. moon. On the basis of size it can be of two types: very small objects (called point objects) or large objects (called extended objects).

MEDIUM – A medium is a substance through which light propogates or tries to do so. Three types of media of light are –

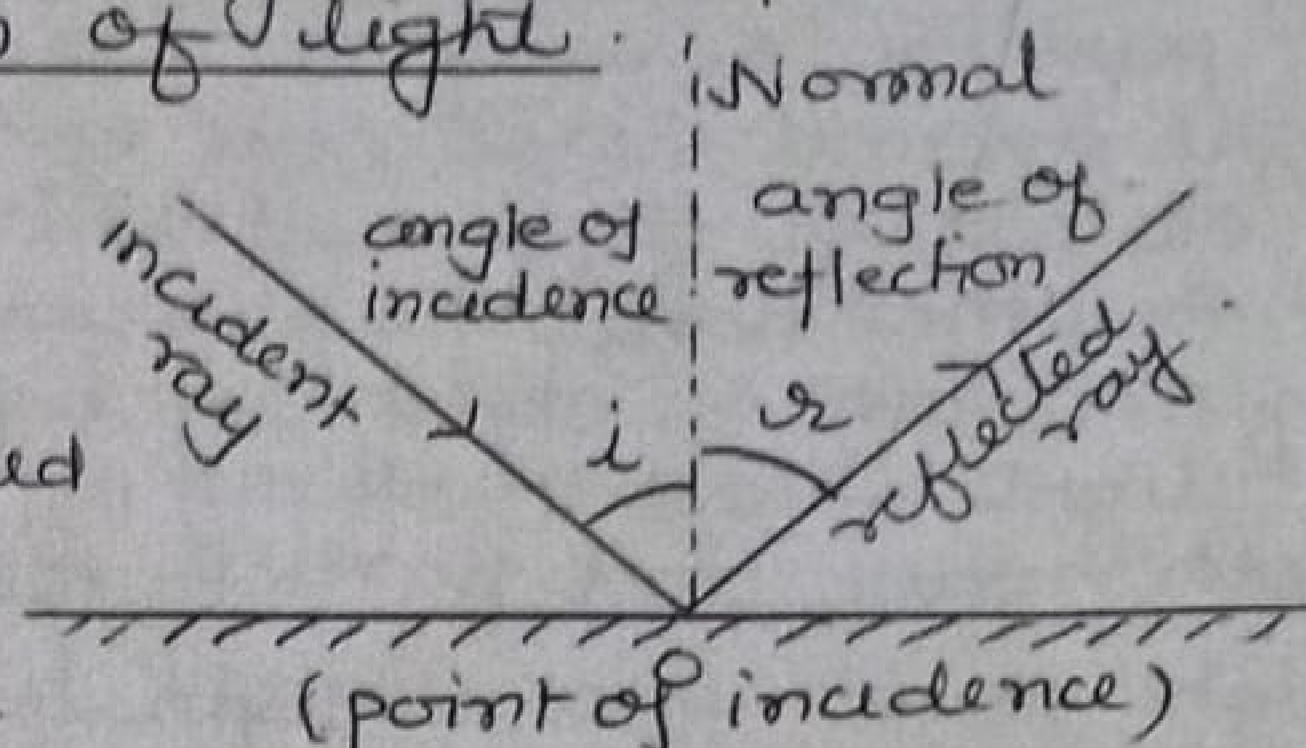
(i) Transparent medium – through which light propagates easily e.g. air, water, glass etc.
(ii) Translucent medium – through which light propagates partially e.g. paper.
(iii) Opaque medium – through which light cannot propagate e.g. wood, metals etc

IMAGE – An image is formed when the light rays coming from an object meet (or appear to meet) at a point after reflection from mirror or refraction from a lens. The images are of two types: Real image and virtual image.

REAL IMAGE	VIRTUAL IMAGE
A real image is formed when the light rays coming from an object actually meet at a point after reflection or refraction.	A virtual image is formed when light rays coming from an object appear to meet at a point when produced backwards after reflection or refraction.
Real image is always inverted.	Virtual image is always erect
Real image can be obtained on screen.	Virtual image cannot be obtained on a screen

- **REFLECTION OF LIGHT** – When the light falls on the surface of an object, it can be –
(i) absorbed – in case of black body.
(ii) transmitted – in case of transparent object
(iii) reflected – in case of mirror.
The process of sending back the light rays which falls on the surface of an object is called reflection of light.

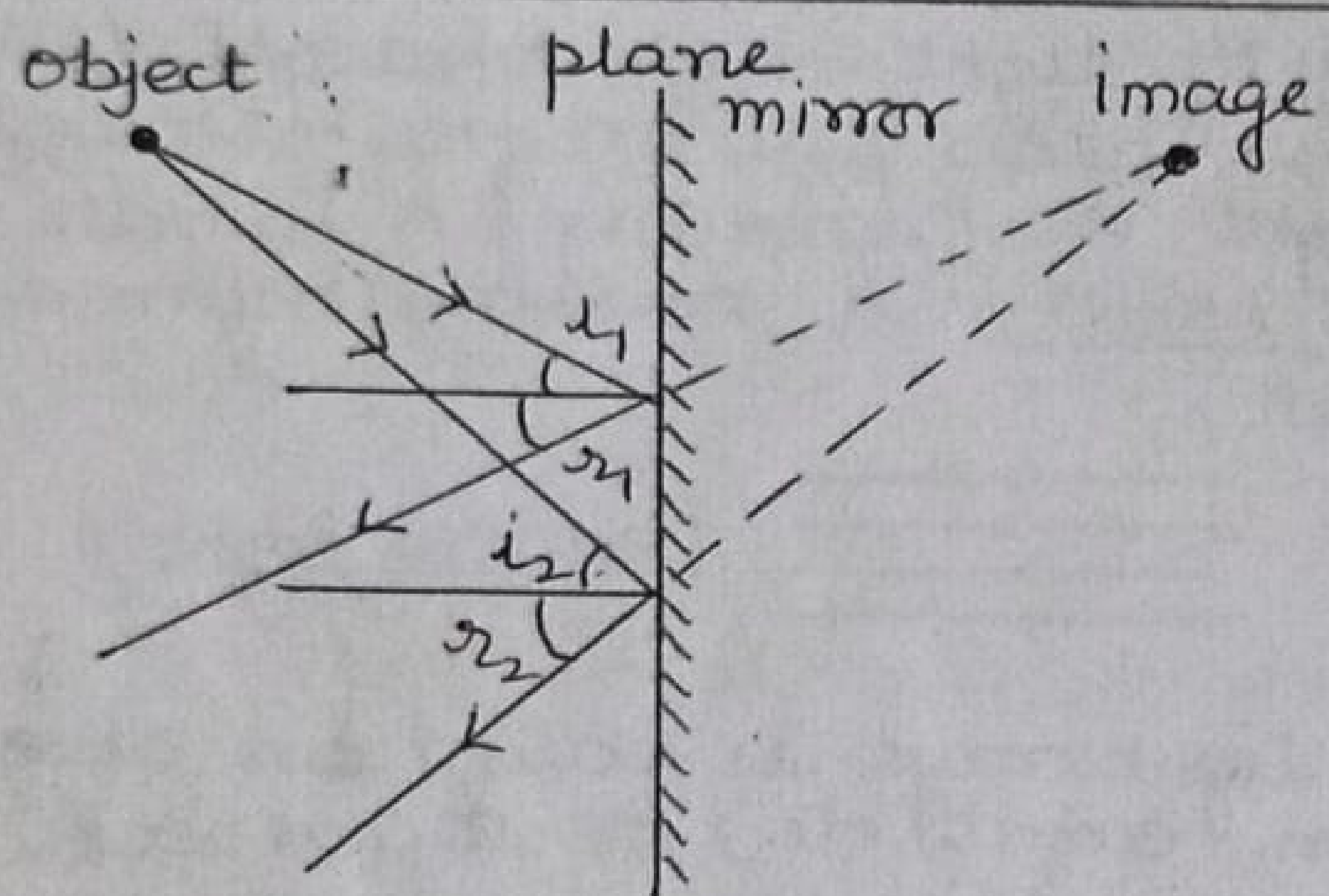
- **LAWS OF REFLECTION OF LIGHT** –

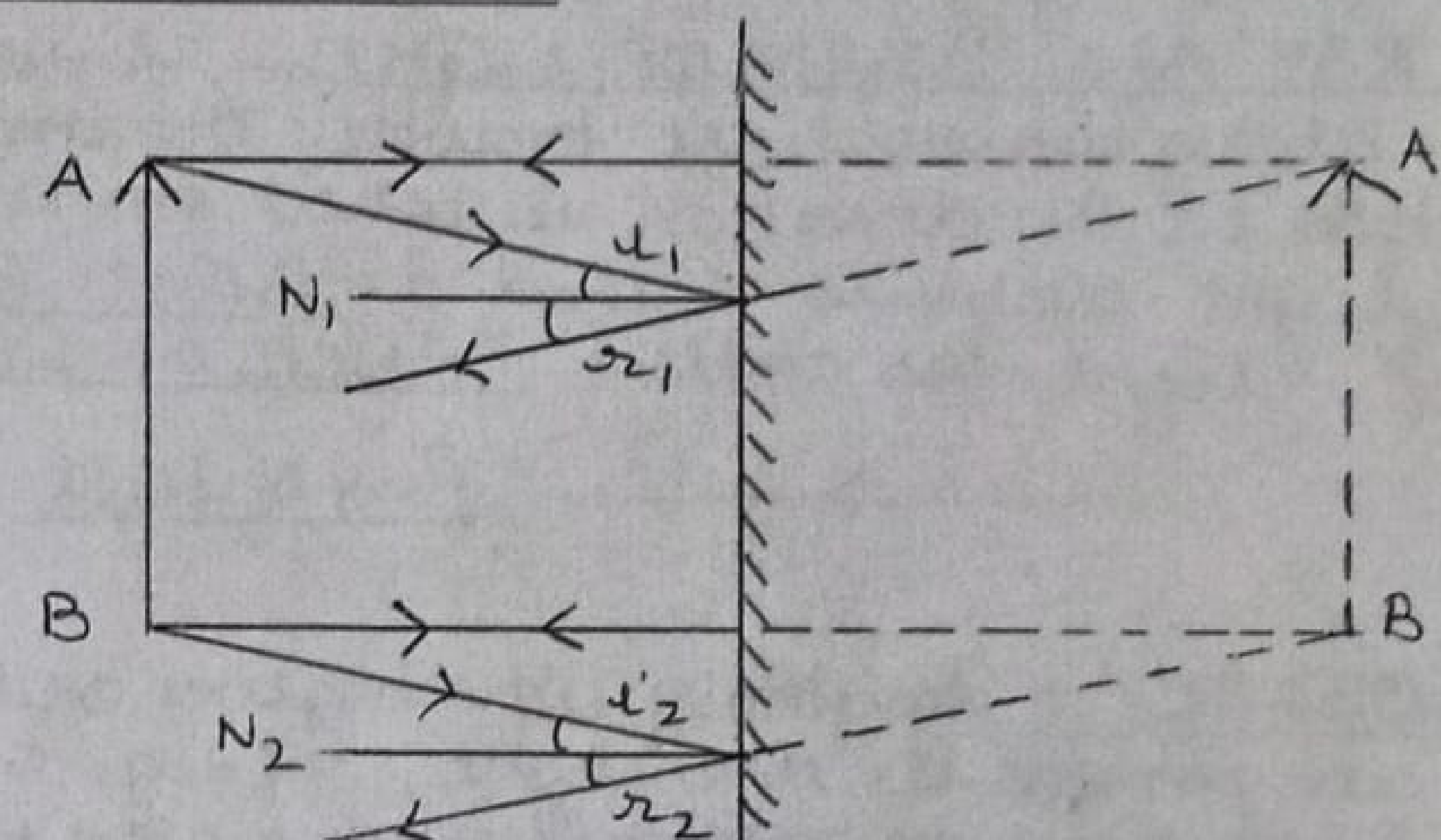


First law – The angle of incidence is equal to angle of reflection i.e. $\angle i = \angle r$

Second law – The incident ray, the reflected ray and the normal (at the point of incidence), all lie in the same plane.

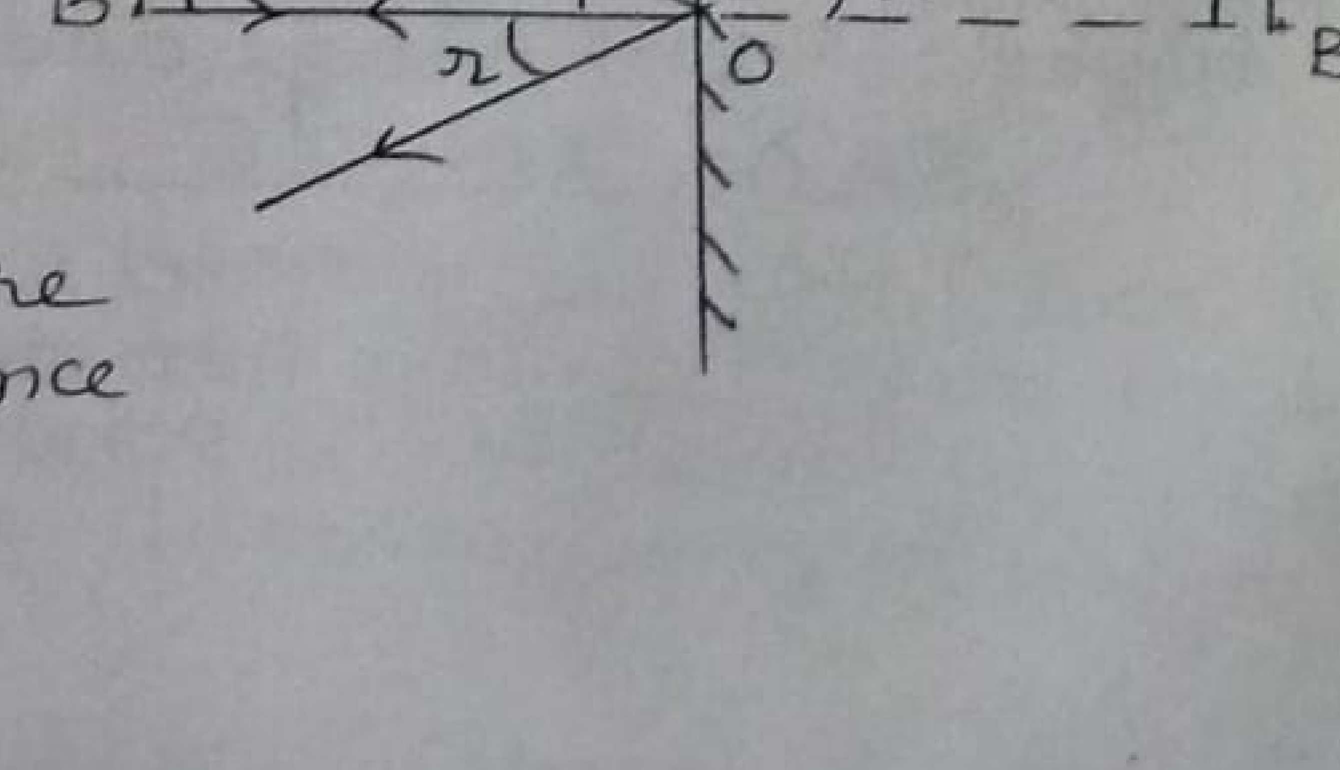
- **IMAGE FORMATION OF POINT OBJECT (OR EXTENDED OBJECT) BY PLANE MIRROR** –





Characteristics of an image formed by a plane mirror –
(i) The image formed in a plane mirror is virtual and erect.
(ii) The image is of the same size as the object.
(iii) It is formed at the same distance behind the mirror as the object is in front of the mirror.
(iv) The image formed is laterally inverted (or sideways reversed).

– Show that the image of an object formed by a plane mirror is of the same size and at the same distance as that of object.



In $\triangle AOC$ and $\triangle A'OC$.

$\angle CAO = \angle CA'O$ $(\because \angle i = \angle r)$

$\angle ACO = \angle A'CO$ (both are $90°$)

OC is common.

$\therefore \triangle AOC$ and $\triangle A'OC$ are congruent and $\boxed{AC = A'C}$

i.e. distance of the object in front of the plane mirror is equal to the distance of image behind the mirror.

In $\triangle ABO$ and $\triangle A'B'O$

$\angle AOB = \angle A'OB'$ $(\because \angle i = \angle r)$

$\angle ABO = \angle A'B'O$ (both are $90°$)

and $AO = A'O$

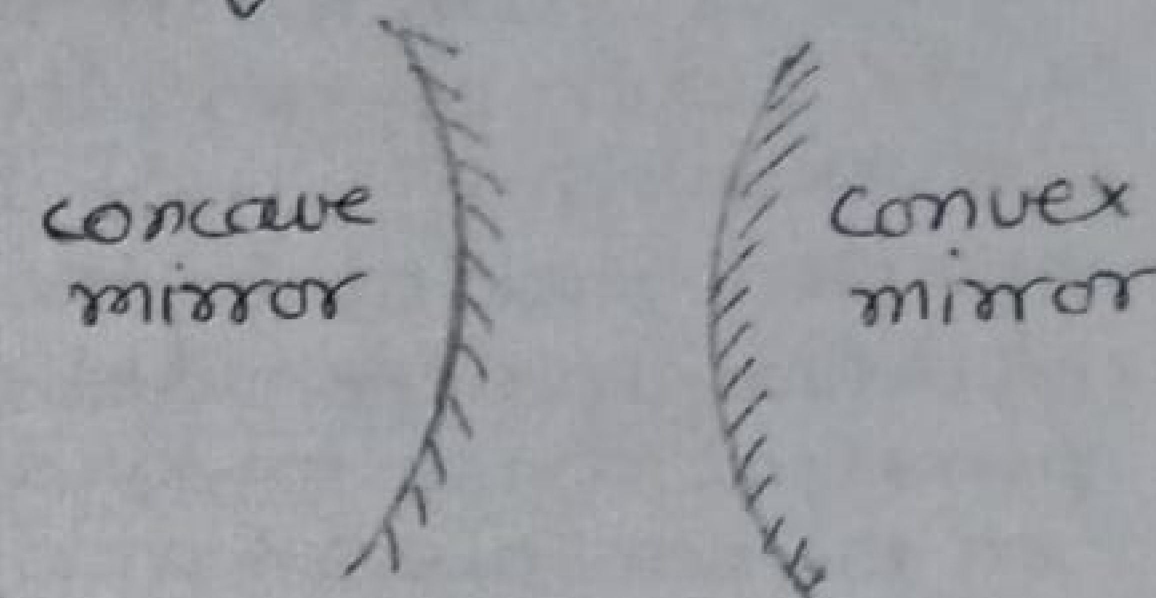
$\therefore \triangle ABO$ and $\triangle A'B'O$ are congruent and $\boxed{AB = A'B'}$

i.e size of object = size of image

REFLECTION OF LIGHT FROM SPHERICAL MIRRORS – A **SPHERICAL MIRROR** is that mirror whose reflecting surface is the part of a hollow sphere of glass. The spherical mirrors are of two types:- Concave mirror and convex mirrors.

(i) **Concave mirror** – is one whose reflecting surface is curved inwards i.e. faces towards the centre of the sphere.

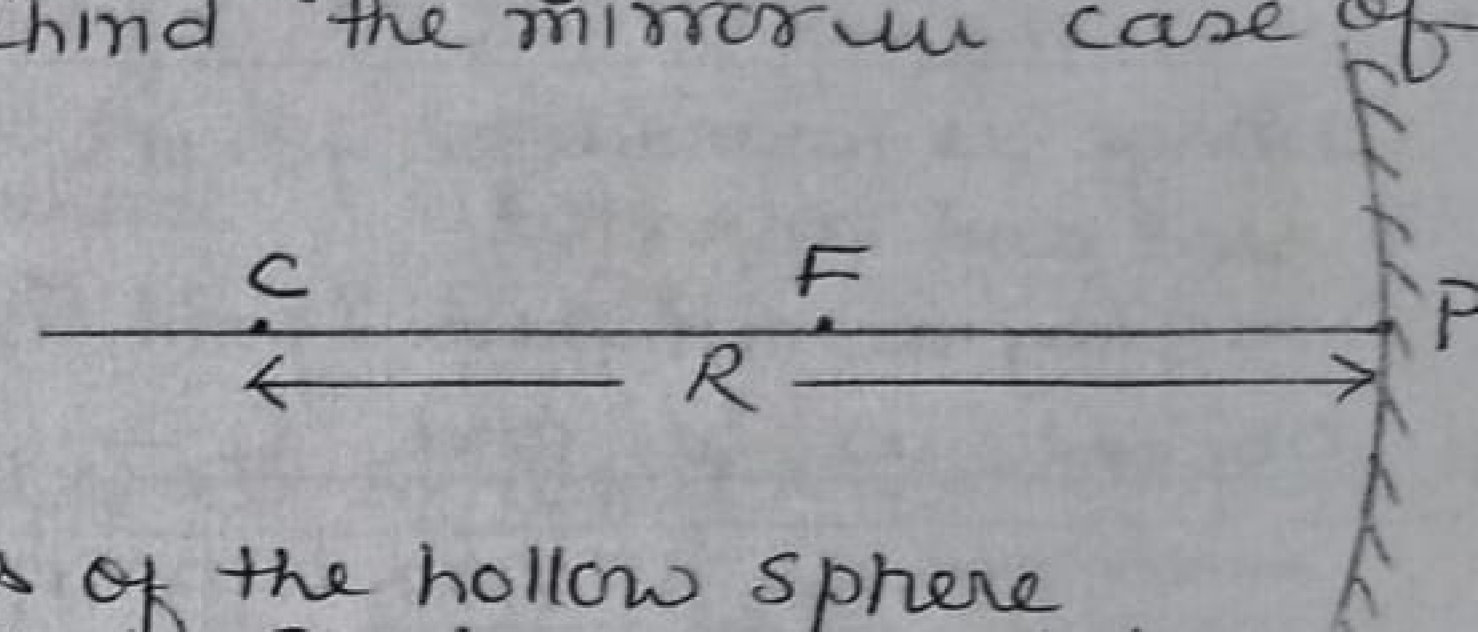
(ii) **Convex mirror** – is one whose reflecting surface is curved outwards.



TERMINOLOGY USED FOR SPHERICAL MIRRORS –

(i) **Centre of curvature** – of a spherical mirror is the centre of hollow sphere of glass of which the mirror is a part. It is represented by the letter C. It lies outside the reflecting surface. For concave mirror it lies in front of it and behind the mirror in case of convex mirror.

(ii) **Pole** – The centre of reflecting surface of a spherical mirror is called pole. It is represented by letter P. It lies on the surface of the mirror.



(iii) **Radius of curvature** – is the radius of the hollow sphere of glass of which the mirror is a part. It is represented by letter R and is equal to PC.

(iv) **Principal axis** – is the straight line passing through the centre of curvature and pole of a spherical mirror. It is normal to the mirror at its pole.

(v) **Aperture of the mirror** – is the portion of the mirror from which the reflection of light actually takes place. It represents the size of mirror.

(vi) **Principal focus of a concave mirror** – is a point on the principal axis at which all the light rays which are parallel and close to the axis converge actually after reflection. A concave mirror has real focus. It is represented by letter F.

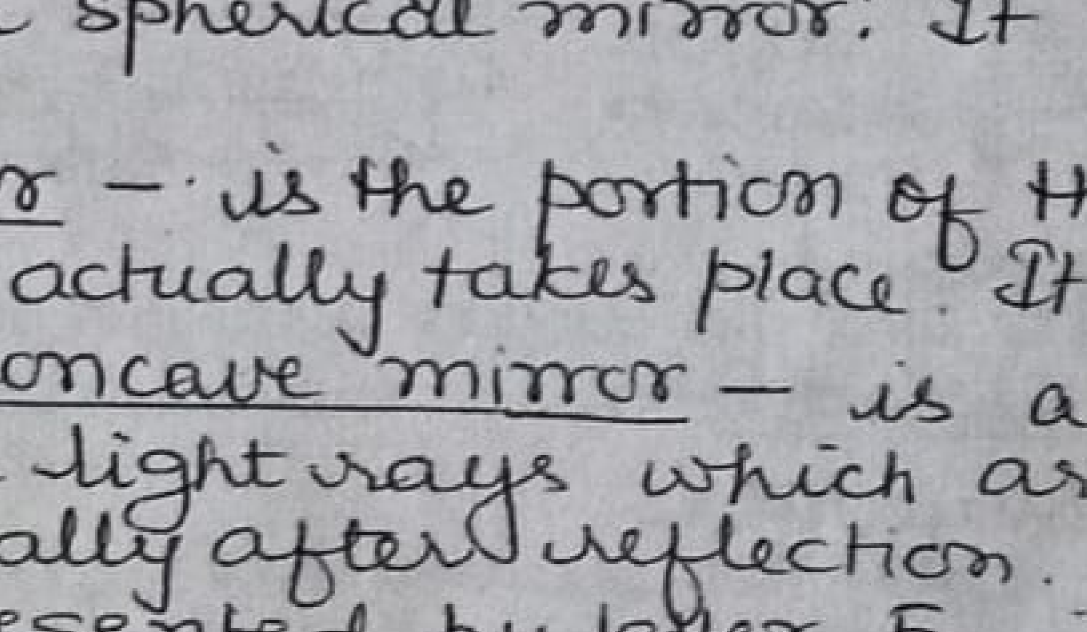
(vii) **Principal focus of a convex mirror** – is a point on the principal axis at which a beam of light rays, initially parallel to the axis, appears to diverge after being reflected from the convex mirror. A convex mirror has virtual focus situated behind the mirror.

(viii) **Focal length** – of a spherical mirror is the distance between its pole and principal focus. It is represented by 'f'. and –

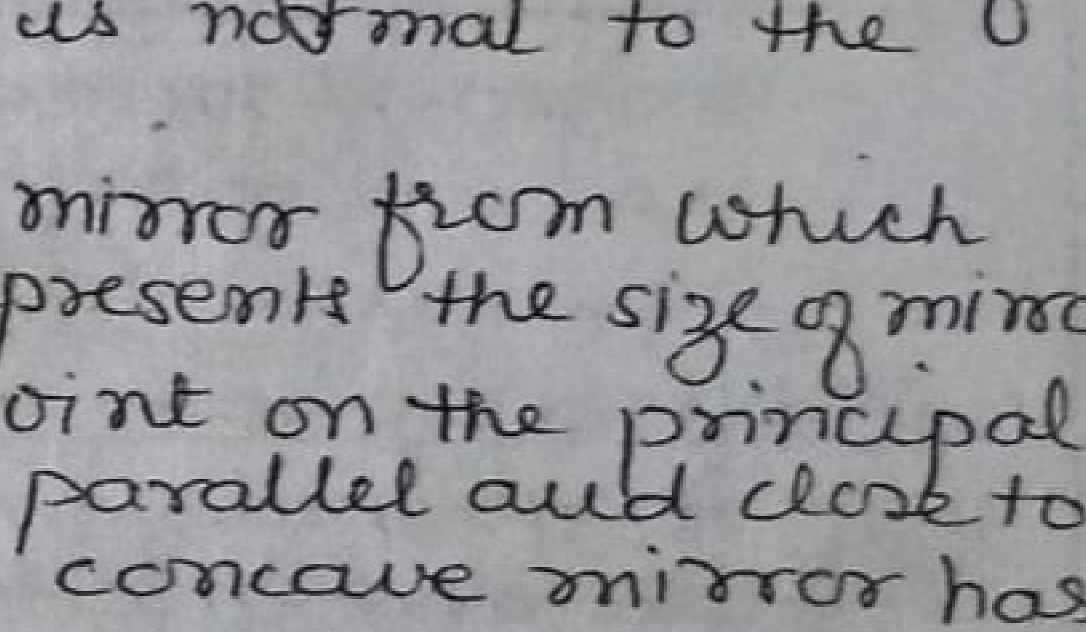
$$f = R/2$$

RULES FOR OBTAINING IMAGES FORMED BY SPHERICAL MIRRORS

(i) A ray parallel to principal axis, after reflection will pass through the principal focus in case of concave mirror or appear to diverge from the principal focus in case of convex mirror.

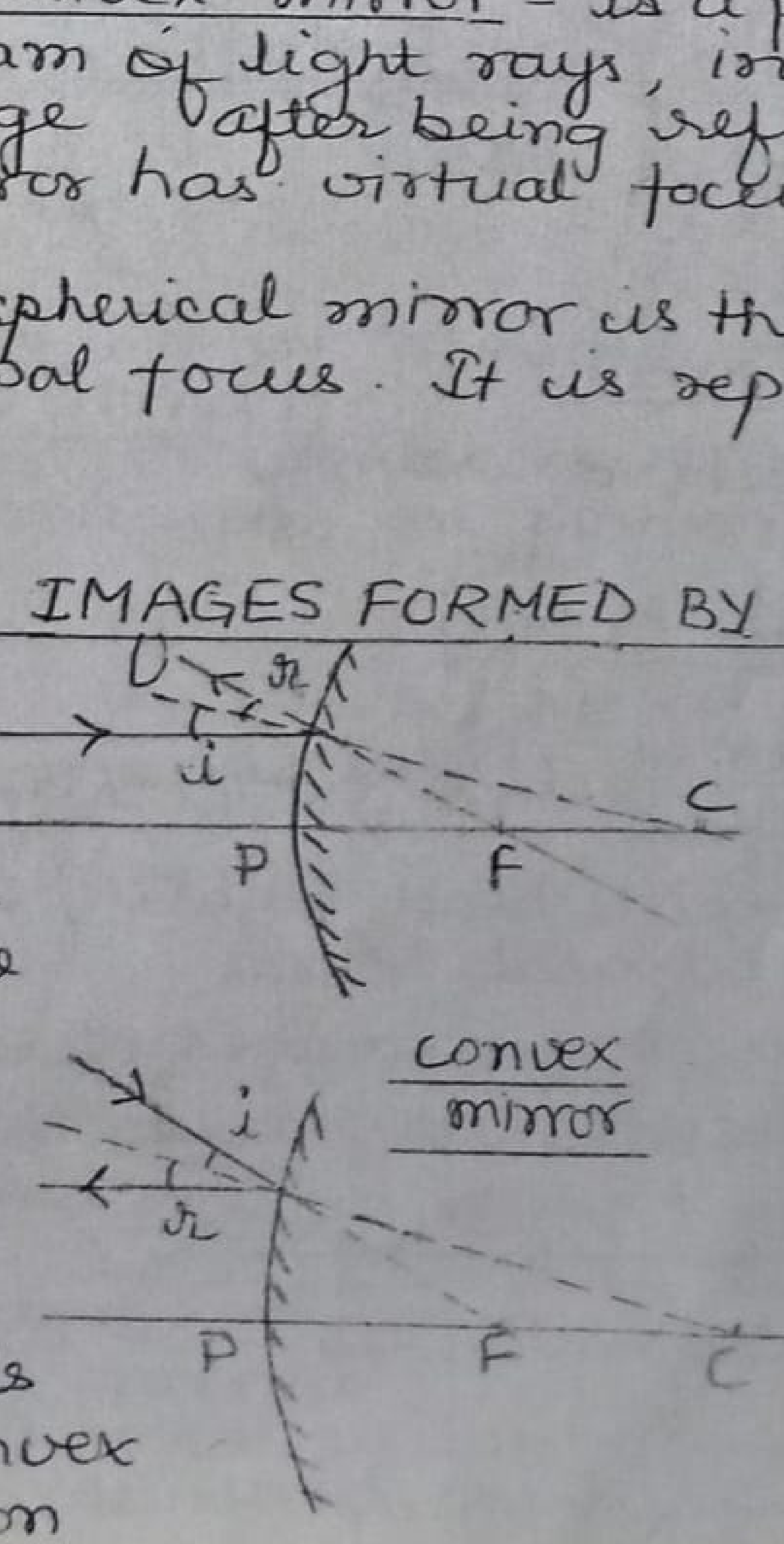


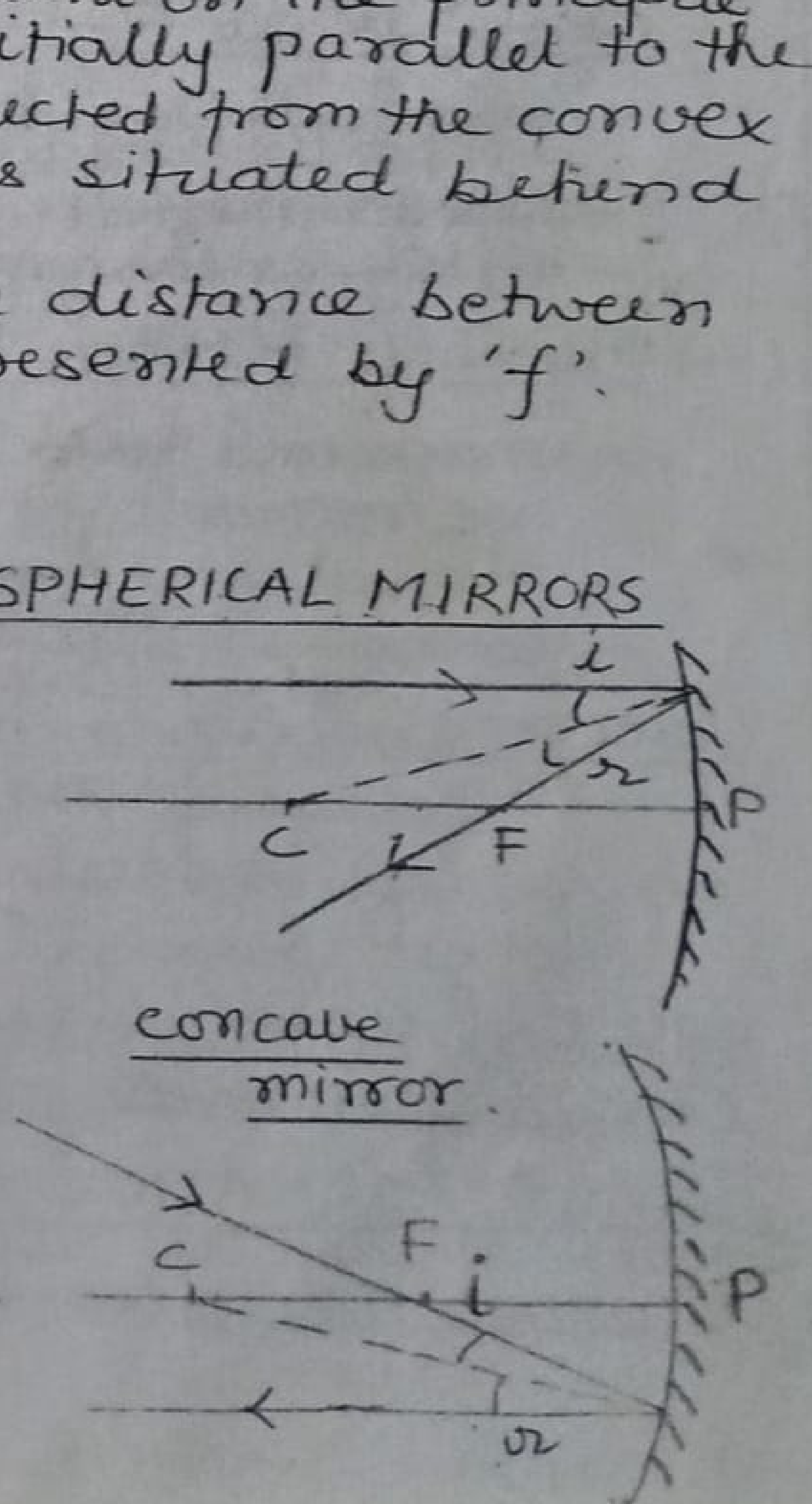
convex mirror



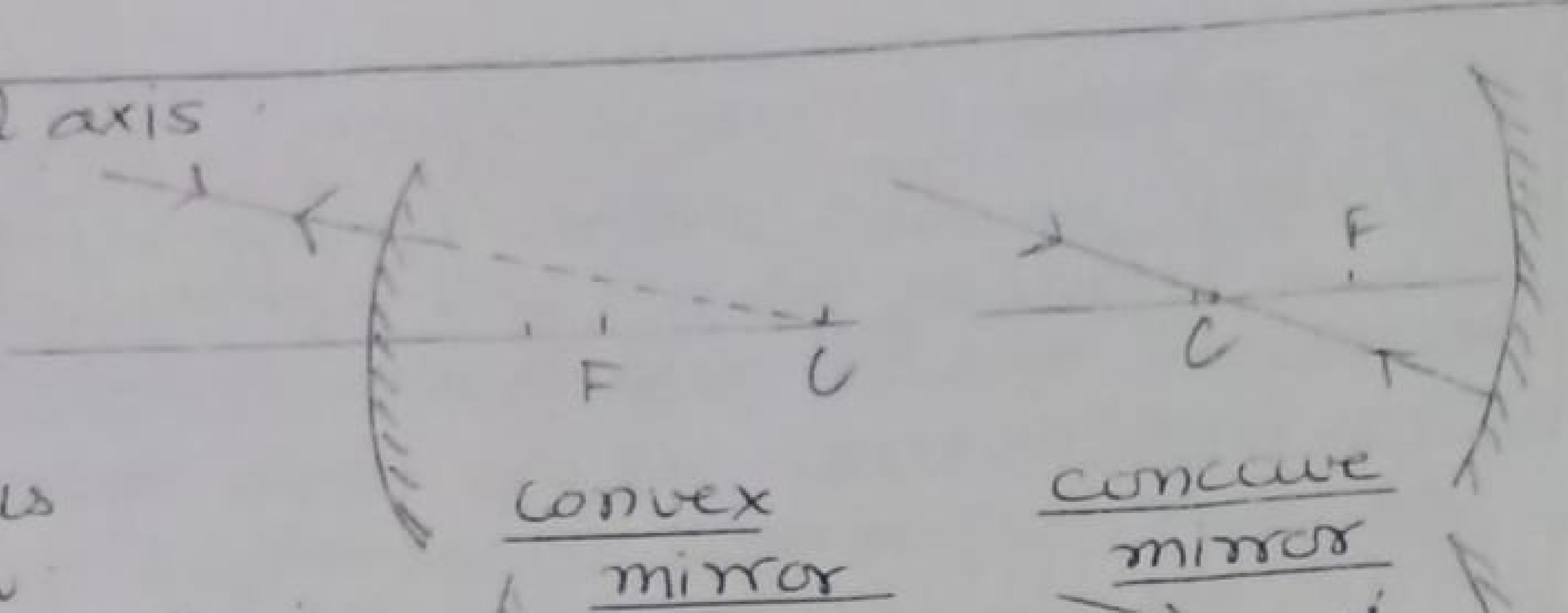
concave mirror

(ii) A ray passing through the principal focus of a concave mirror or a ray which is directed towards the principal focus of a convex mirror, after reflection





will emerge parallel to principal axis
(iii) A ray passing through the centre of curvature of a concave mirror or directed in the direction of the centre of curvature of a convex mirror after reflection is reflected back along the same path



(iv) A ray incident obliquely to the principal axis, towards a point P on the concave mirror or a convex mirror is reflected obliquely and follows laws of reflection.

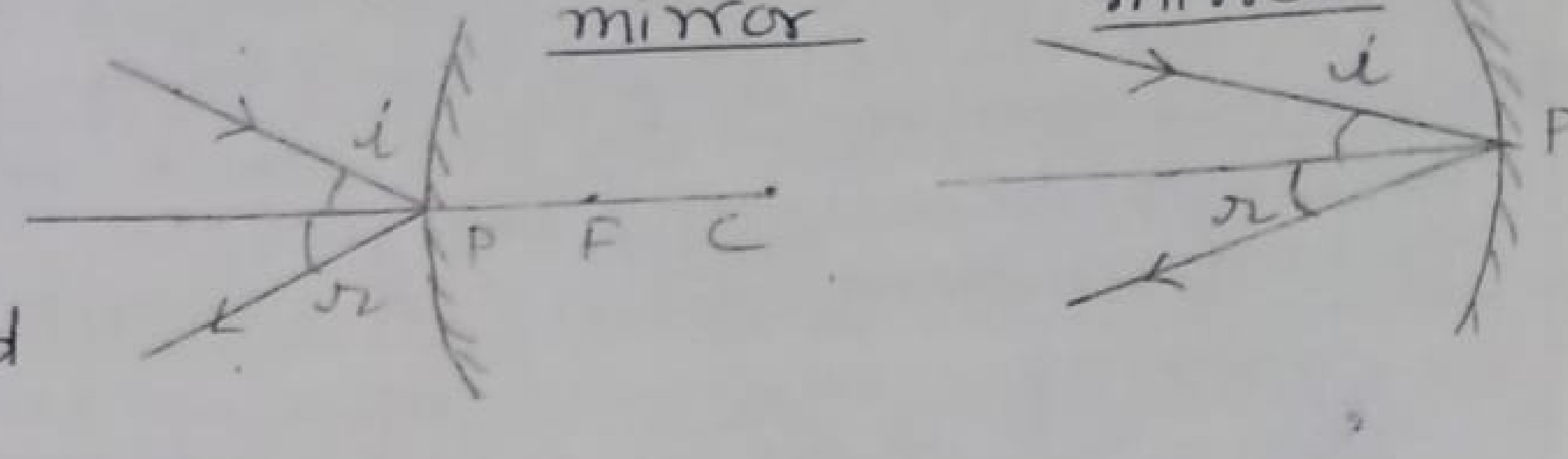
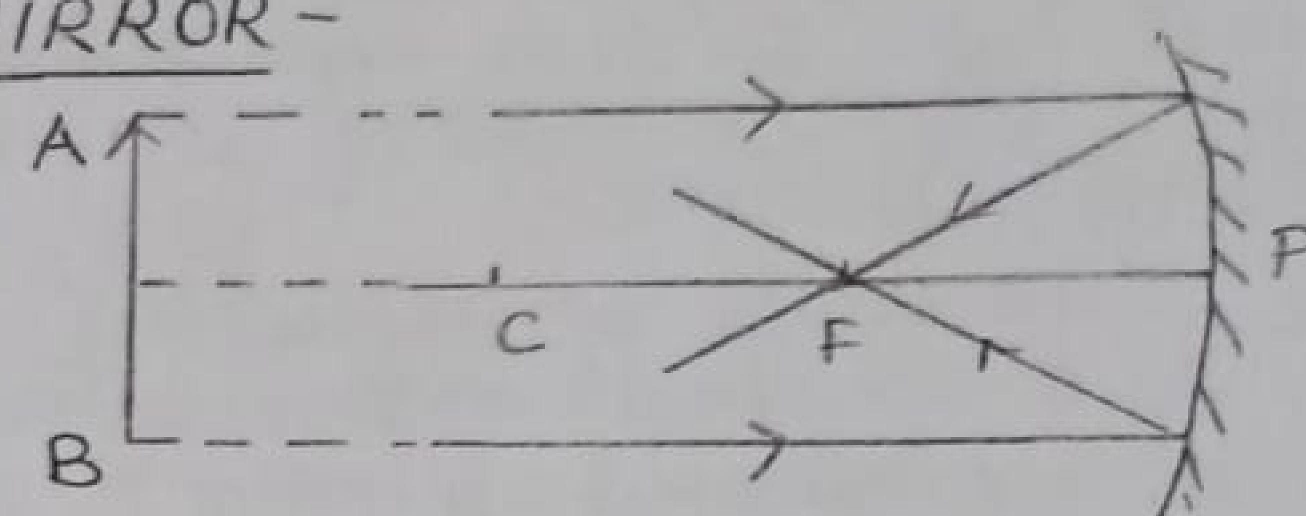
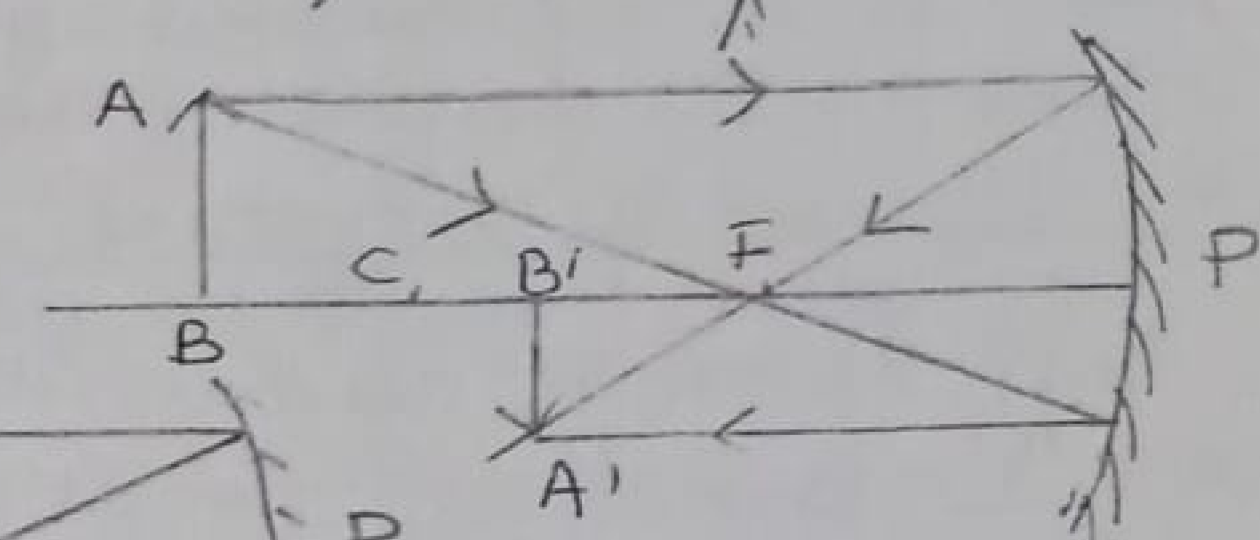


IMAGE FORMATION BY CONCAVE MIRROR -

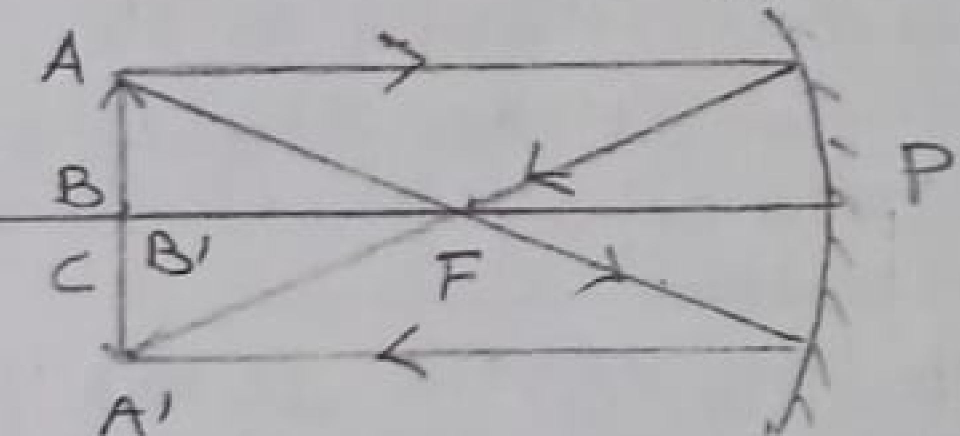
(i) when the object is at infinity -
- image is formed at focus.
- real and inverted.
- highly diminished (point sized).



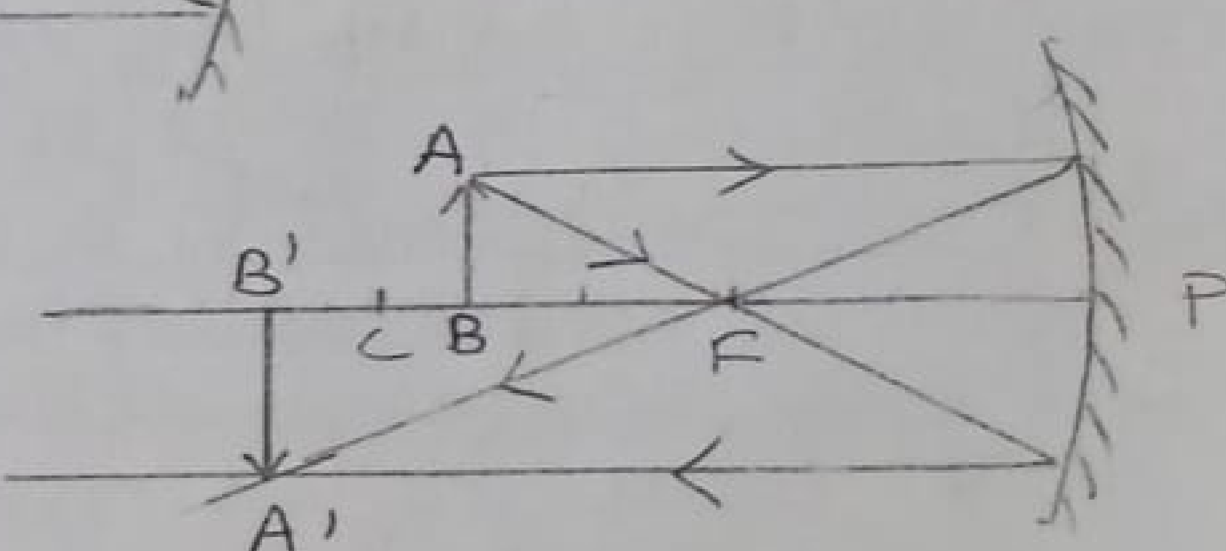
(ii) Object is beyond C -
- image is formed between C and F
- real and inverted
- diminished



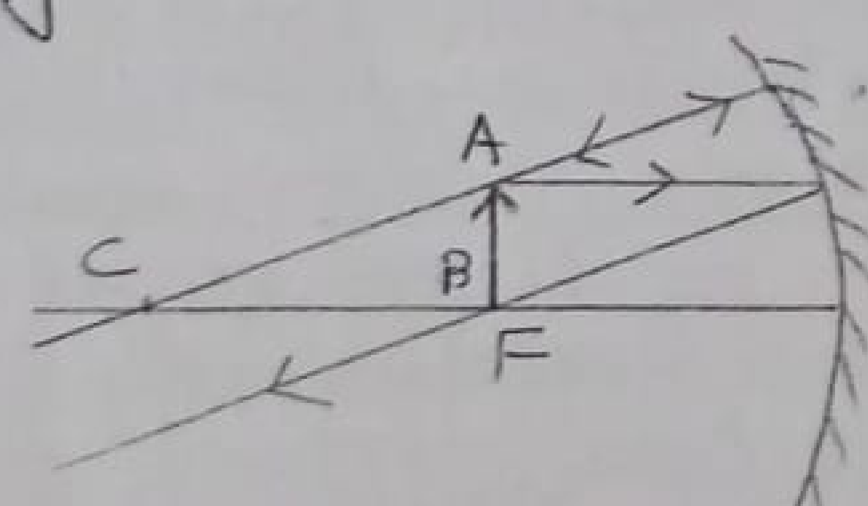
(iii) Object is at C -
- image will form at C
- real and inverted.
- same size as that of object.



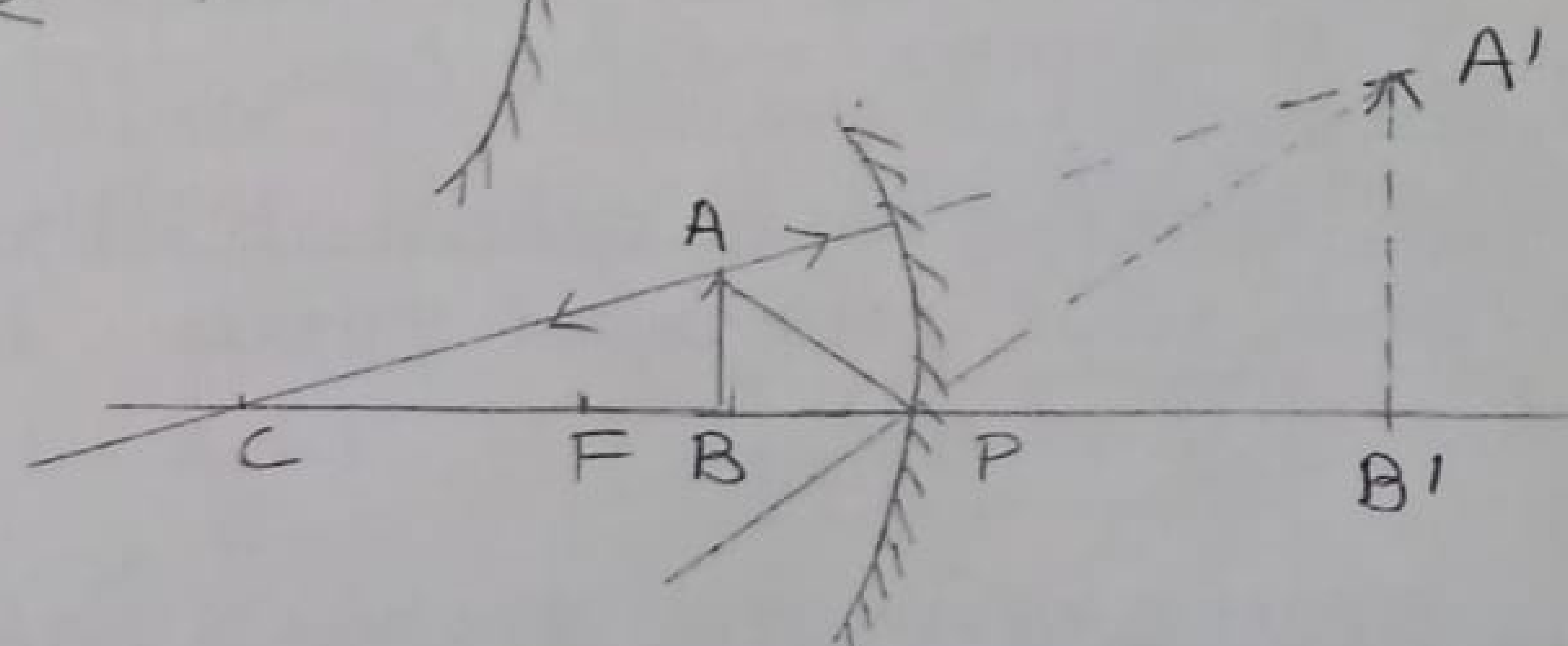
(iv) Object is between C and F -
- image will form beyond C
- real and inverted
- larger in size.



(v) Object is at F -
- image will form at infinity
- real and inverted
- highly enlarged.



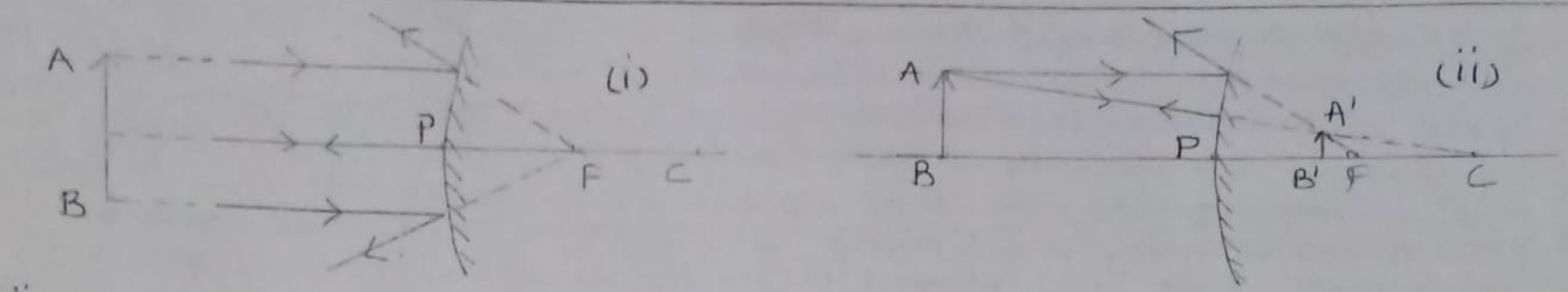
(vi) Object is between F and P -
- image will form behind the mirror
- virtual and erect
- larger in size



Use of concave mirror - (i) as shaving mirrors to see a larger image of the face.
(ii) As reflectors in vehicle head lights, search lights and torches to get powerful parallel beams
(iii) by dentist to see larger images of teeth of patients.
(iv) To concentrate sunlight to produce heat in solar furnaces.

IMAGE FORMATION BY CONVEX MIRROR -.

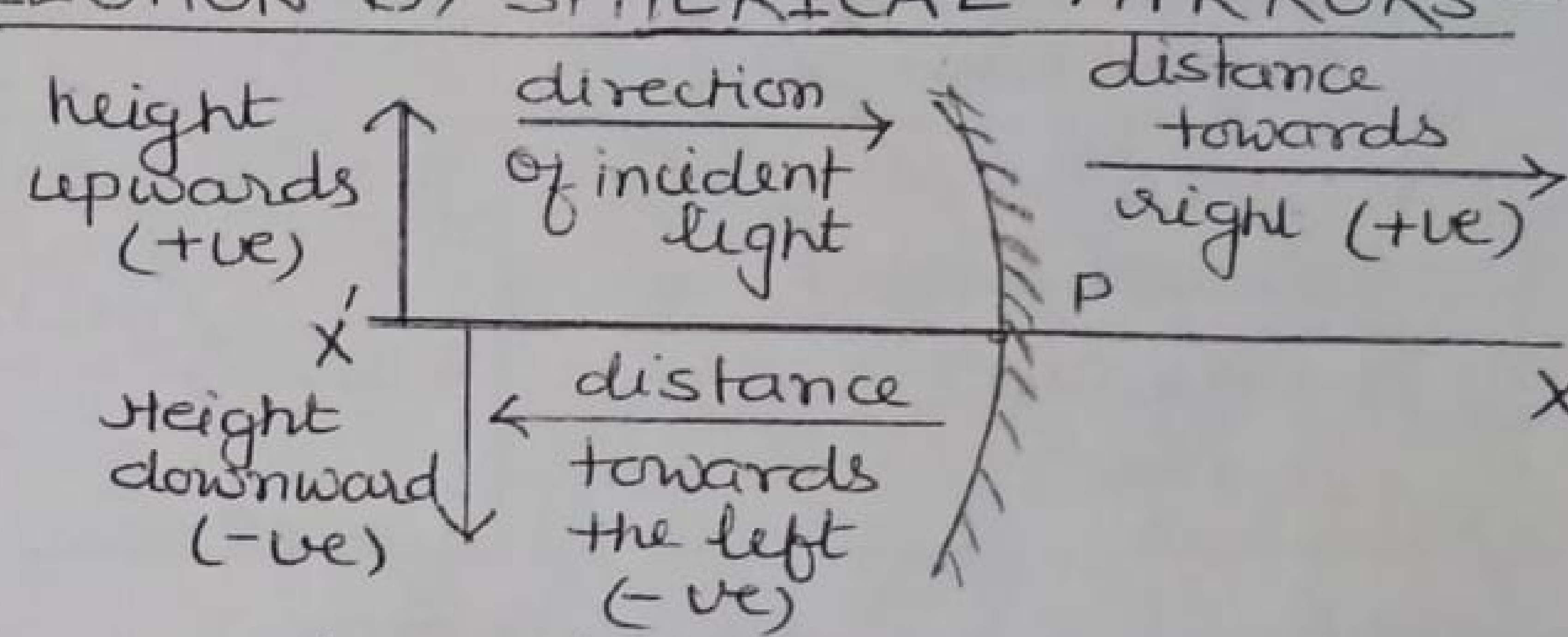
(i) when the object is at infinity - Image will form behind the mirror at focus
- virtual and erect
- highly diminished point sized.



(ii) when the object is placed anywhere between pole and infinity —
- image will form behind mirror between P and F
- virtual and erect
- smaller in size.

Use of convex mirror - it is used as rear view mirrors in vehicles to see the traffic behind to facilitate safe driving due to the following reasons -
(i) it always produces an erect image of the objects.
(ii) the image form is highly diminished.
(iii) as it is curved outwards, it gives a wider field of view (of the traffic behind.

SIGN CONVENTION USED FOR REFLECTION BY SPHERICAL MIRRORS -



Pole of the mirror is taken as origin and principal axis is taken as X-axis.
- the object is always placed on left side of mirror.
- all distances parallel to the principal axis are measured from the pole of the mirror.
- all distances measured to the right of the origin are taken as positive while those measured to the left of the origin are taken as negative.
- distances measured perpendicular to and above the principal axis are taken as positive while below the principal axis are taken as negative.

MIRROR FORMULA AND MAGNIFICATION —

Mirror formula ; $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ where u = object distance
v = image distance
f = focal length.

- u is always negative, f is negative for concave mirror and +ve for convex mirror.
- v is always positive for convex mirror but for concave mirror it will depend upon the position of the image.

Magnification : $m = \frac{h_i}{h_o} = \frac{\text{height of the image}}{\text{height of the object}}$

magnification is also given by another formula i.e. $m = \frac{-v}{u}$
- for real image m is -ve while for virtual image it is +ve.

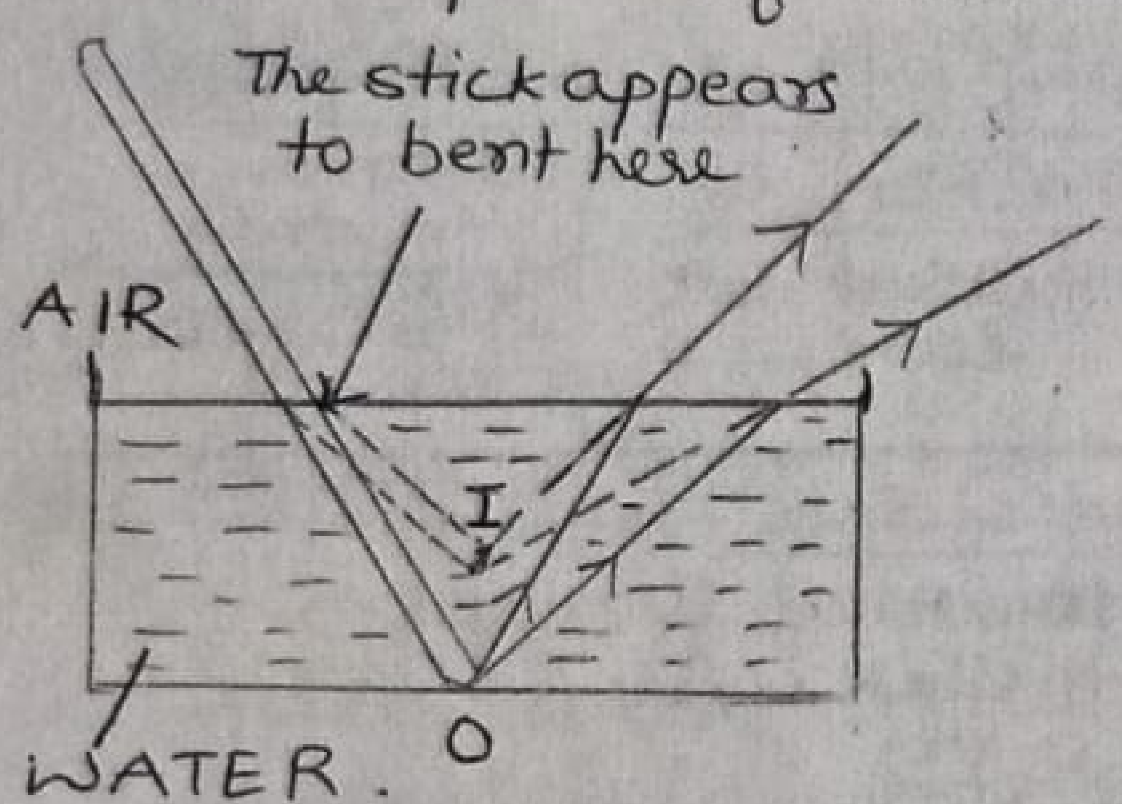
REFRACTION OF LIGHT - Refraction is defined as change in direction of propogation of light when it passes from one medium to another.

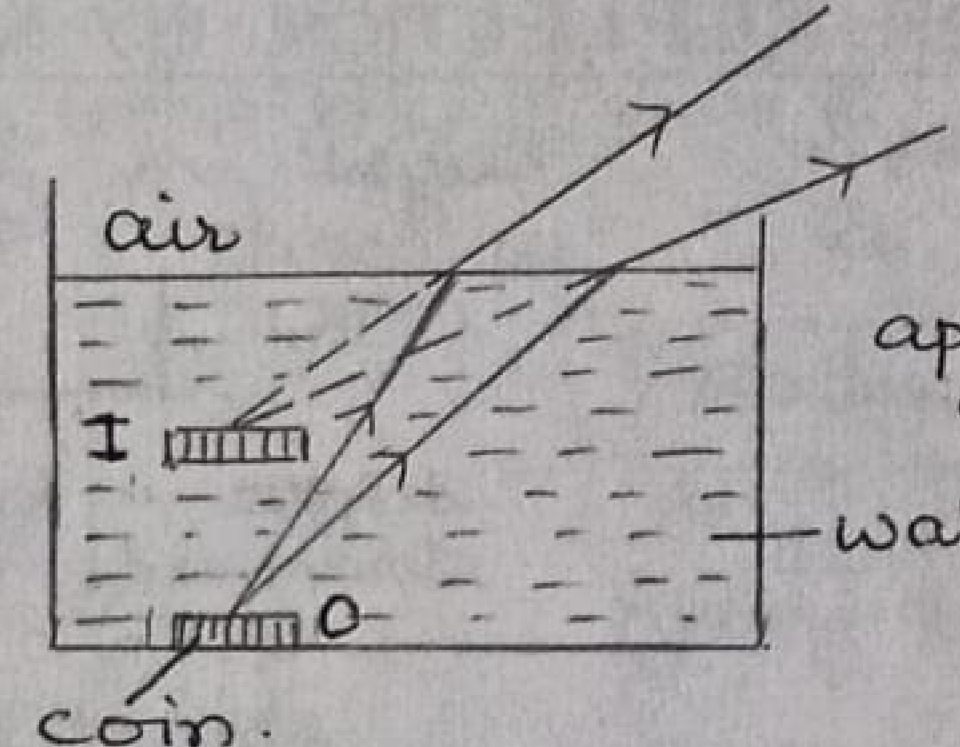
Cause of refraction - The refraction of light is due to change in the speed of light as it enters from one transparent medium to another.

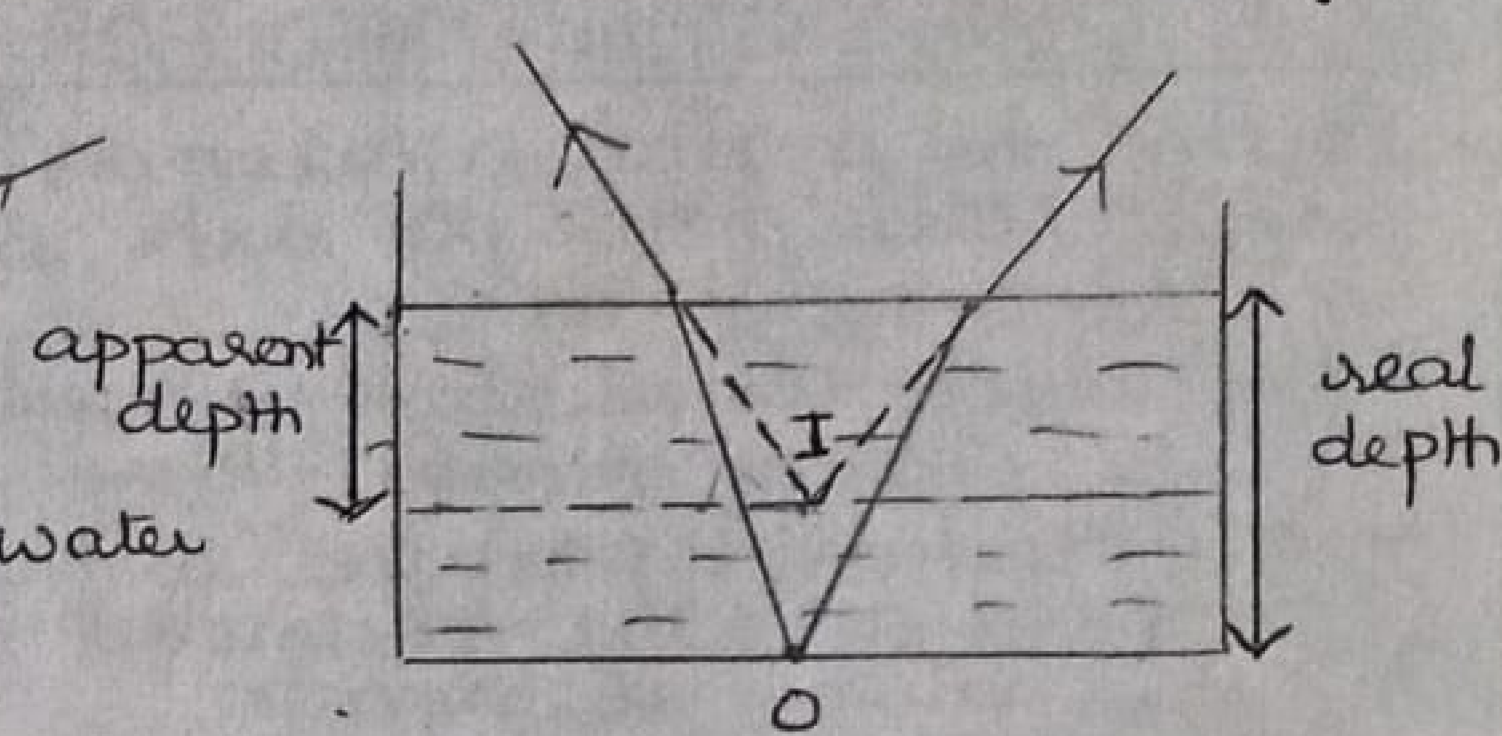
- A medium in which the speed of light is more known as

OPTICALLY RARER medium. e.g. air is an optically rarer medium as compared to glass and water and the medium in which the speed of light is less known as OPTICALLY DENSER medium e.g. glass is an opically denser medium than air and water.
- It is important to note that optical density is not the same as mass density e.g. mass density of kerosene is less than water but its optical density is more than water
- It has been found that -
(i) when a ray of light travels from rarer medium to denser medium, it slows down and bends towards the normal at the point of incidence.
(ii) when a ray of light goes from denser medium to rarer medium it speeds up and bends away from the normal.

Effects of refraction of light -
(i) a stick or pencil held obliquely and partly immersed in water appears to be bent at the water surface.
(ii) an object (or coin) placed under water appears to be raised.
(iii) a pool of water appears to be less deep than it actually is.

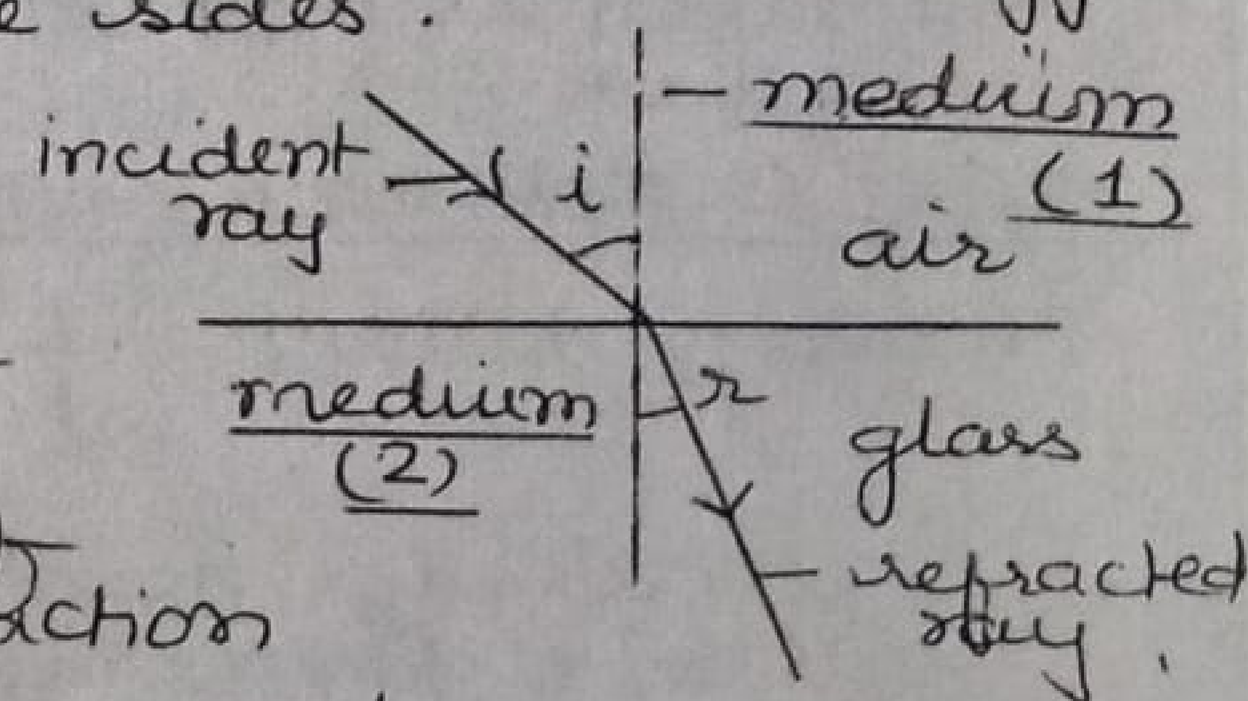






(iv) when a thick glass slab is placed over some printed matter, the letter appear raised when viewed from top.
(v) a lemon kept in water in a glass tumbler appears to be bigger than its actual size when viewed from the sides.

LAWS OF REFRACTION - (1) The incident ray, refracted ray and the normal at the point of incidence, all lie in the same plane.



(2) Snell's law - The ratio of sine of angle of incidence to the sine of angle of refraction is a constant for the light of a given colour and a given pair of media -

i.e. $\sin i / \sin r = \text{constant}$.

This constant value is called the REFRACTIVE INDEX of the second medium with respect to first.

REFRACTIVE INDEX - of a medium is a measure of light bending ability of that medium. The value of refractive index for a given pair of media depends upon the speed of light in the two media. The refractive index of second medium with respect to first i.e.

$$n_{21} = \frac{\text{speed of light in medium 1}}{\text{speed of light in medium 2}} = v_1/v_2$$

and the refractive index of first medium with respect to second i.e. $n_{12} = v_2/v_1$

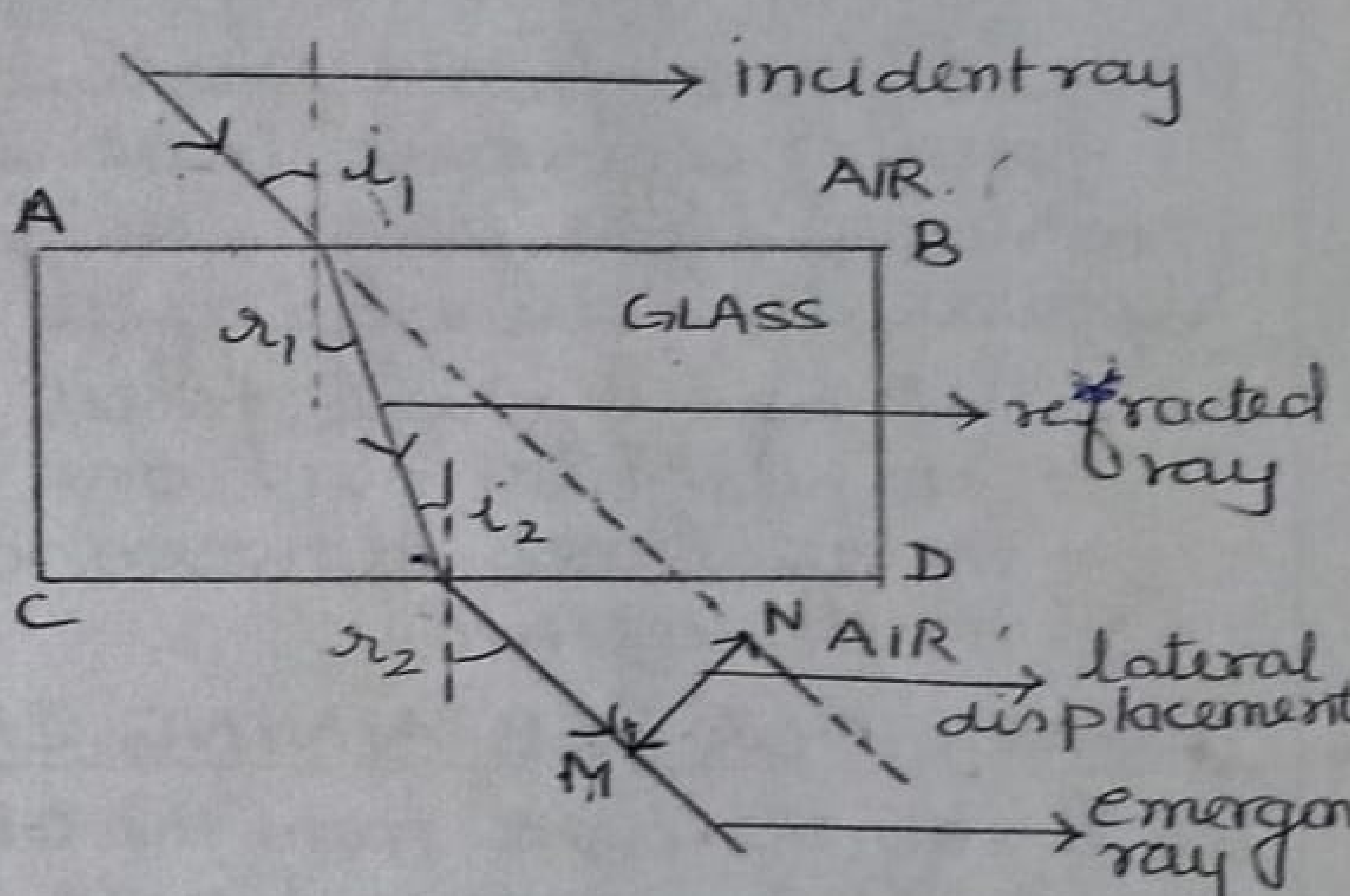
If the medium 1 is vacuum or air, then the refractive index of medium 2 is considered with respect to vacuum. This is called **ABSOLUTE REFRACTIVE INDEX** of the medium, represented as n_2.
In general, refractive index of the medium, n_m –

$$n_m = \frac{\text{Speed of light in air}}{\text{Speed of light in the medium}} = \frac{c}{v} \quad (\text{where } c = 3 \times 10^8 m/s)$$

The absolute refractive index of a medium is simply called its refractive index.
- The refractive index of water, $n_w = 1.33$. This means that the ratio of the speed of light in air and the speed of light in water is equal to 1.33.

REFRACTION THROUGH A RECTANGULAR GLASS SLAB –

- In this experiment, it was found that: $\angle i_1 = \angle r_2$ and emergent ray is always parallel to the direction of the incident ray. because the extent of bending of the ray of light at the opposite parallel faces AB (air glass interface) and CD (glass air interface) of the rectangular glass slab is equal and opposite.



OR By applying Snell's law –

$n_{ga} = \sin i_1 / \sin r_1$ — (i)

and $n_{ag} = \sin i_2 / \sin r_2 = \sin r_1 / \sin r_2$ ($\angle r_1 = \angle i_2$ ∵ these are alternate interior angles)

or $n_{ga} = \sin r_2 / \sin r_1$ — (ii)

From eq (i) and (ii), we get – $\frac{\sin i_1}{\sin r_1} = \frac{\sin r_2}{\sin r_1}$

or $\sin i_1 = \sin r_2$ or $\angle i_1 = \angle r_2$.

Thus the emergent ray is parallel to incident ray but emergent ray is laterally displaced from the original path of the incident ray be a perpendicular distance MN, known as **LATERAL DISPLACEMENT**.

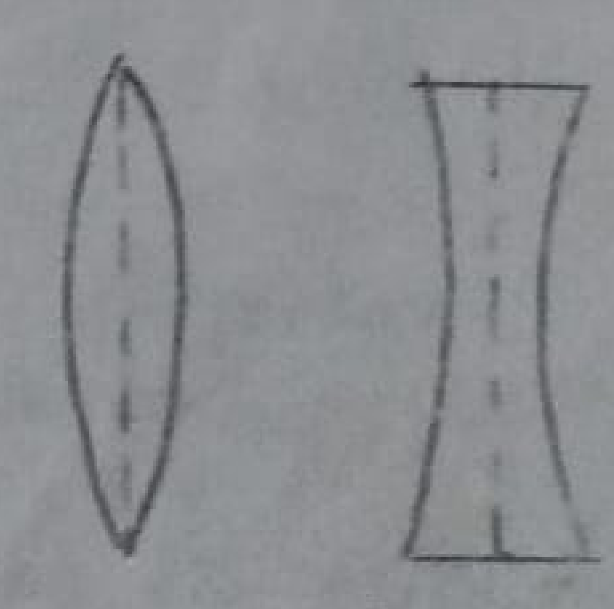
Lateral displacement depends upon –
(i) angle of incidence
(ii) thickness of the glass slab.
(iii) refractive index of the medium

REFRACTION BY SPHERICAL LENSES –

A transparent material bound by two surfaces, of which one or both surfaces are spherical, forms a **LENS**. Lenses are of two types –

(i) **Biconvex lens or convex lens.** – has two spherical surfaces, bulging outwards. It is thicker in the middle as compared to edges
- It is a converging lens

(ii) **Biconcave or concave lens** – has two spherical surfaces curved inwards. It is thicker at the edges than at the middle
It is a diverging lens.



convex lens   Concave lens

TERMINOLOGY USED FOR SPHERICAL LENSES –

(i) Optical centre – is the centre point of lens. It is represented by the letter O.

(ii) Principal axis – is the line passing through the optical centre of the lens and perpendicular to both the faces of the lens.

(iii) Principal focus and focal length of convex lens – Principal focus of a convex lens is a point on its principal axis to which light rays parallel to the principal axis converge after passing through the lens – it has real focus.

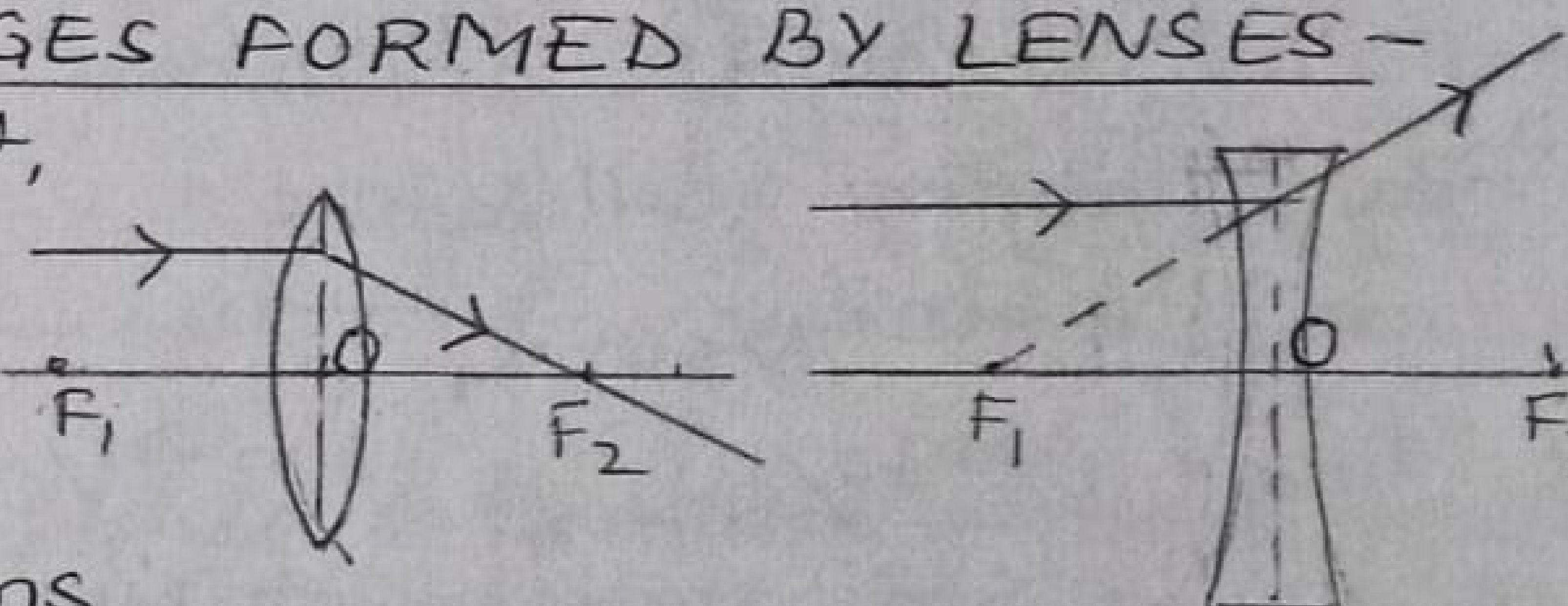
- the lens has two foci which are at equal distances from the optical centre, one on either side of the lens.
- the distance between the optical centre and focus is called focal length of lens.

(iv) Principal focus and focal length of concave lens – Principal focus of a concave lens is a point on its principal axis from which light rays, originally parallel to principal axis, appear to diverge after passing through concave lens.

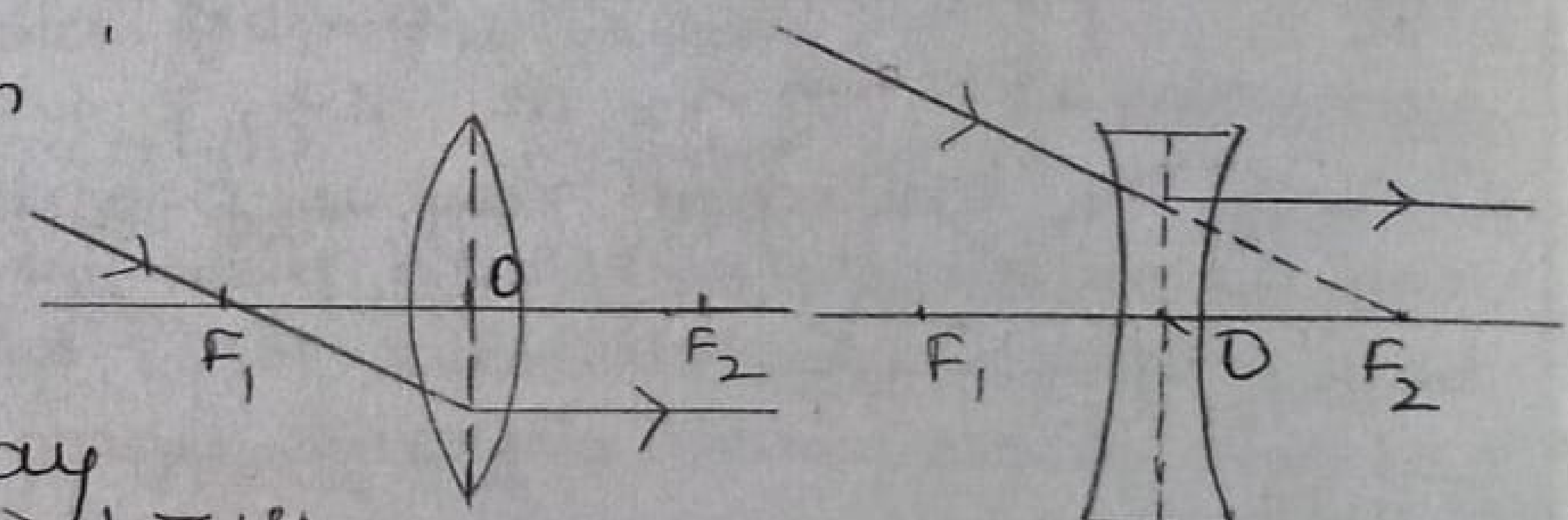
- it has virtual focus
- it has two foci one on each side of concave lens
- the distance between optical centre and focus is called focal length.

RULES FOR OBTAINING IMAGES FORMED BY LENSES –

(i) A ray of light from the object, parallel to principal axis after through refraction from a convex lens passes through focus on other side of lens. while in case of concave lens it appears to diverge from the principal focus located on the same side of lens.



(ii) A ray of light passing through a principal focus after refraction from a convex lens will emerge parallel to principal axis.
In case of concave lens, a ray of light appearing to meet at focus will emerge out parallel to principal axis.



(iii) A ray of light passing through the optical centre of a lens will emerge without any deviation.

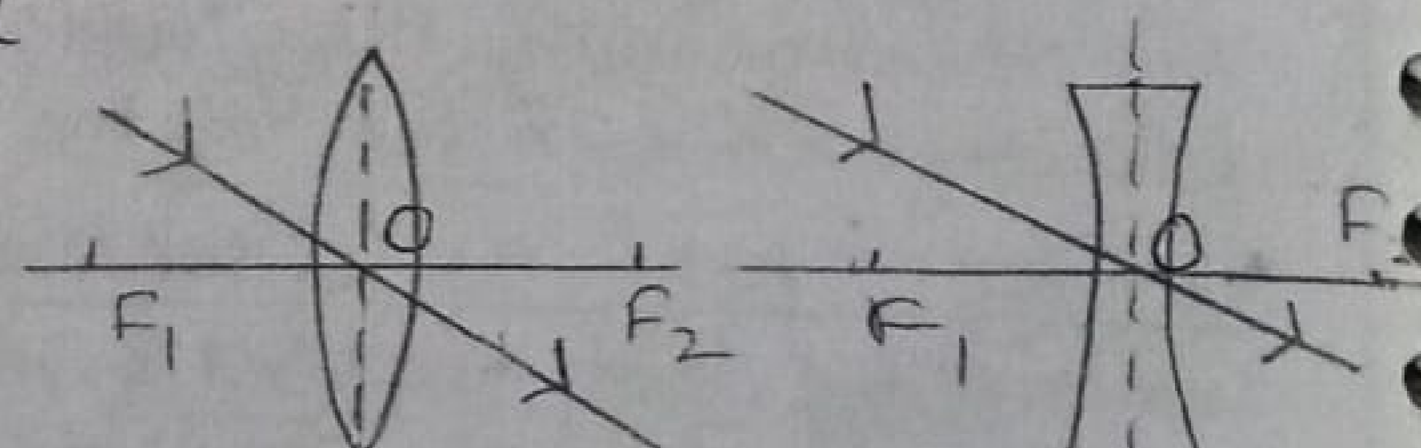
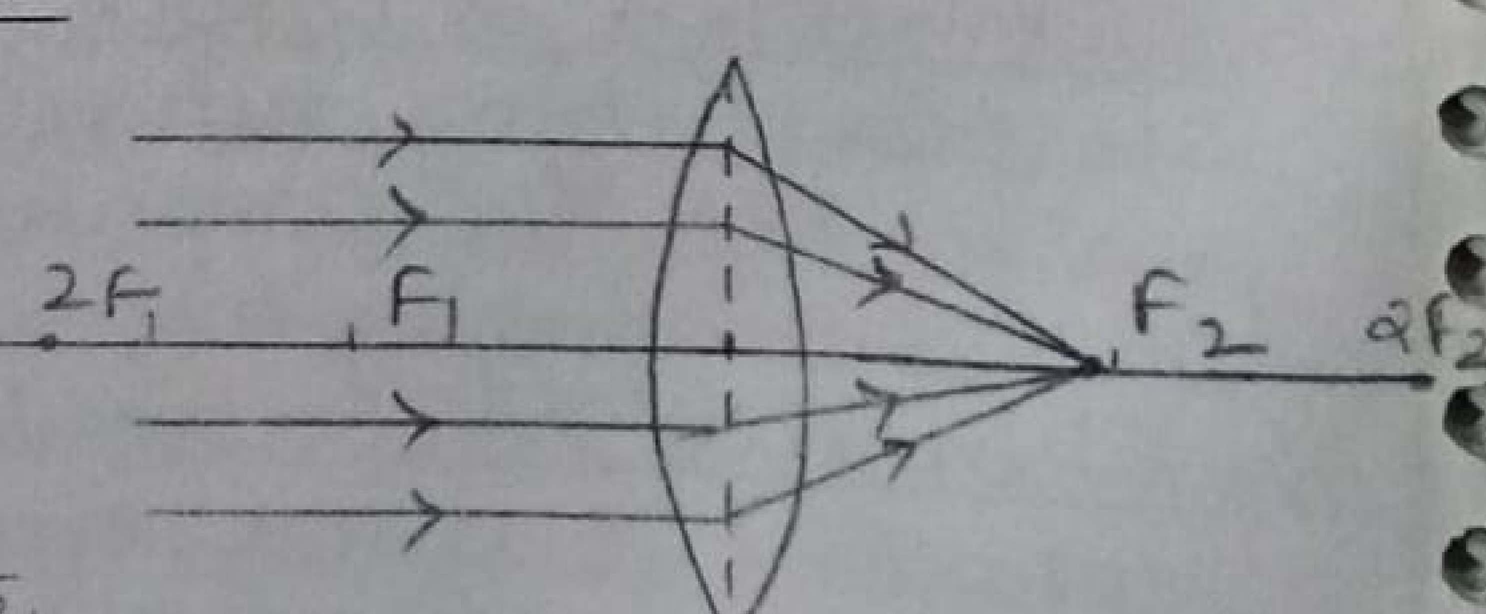


IMAGE FORMATION BY CONVEX LENS –

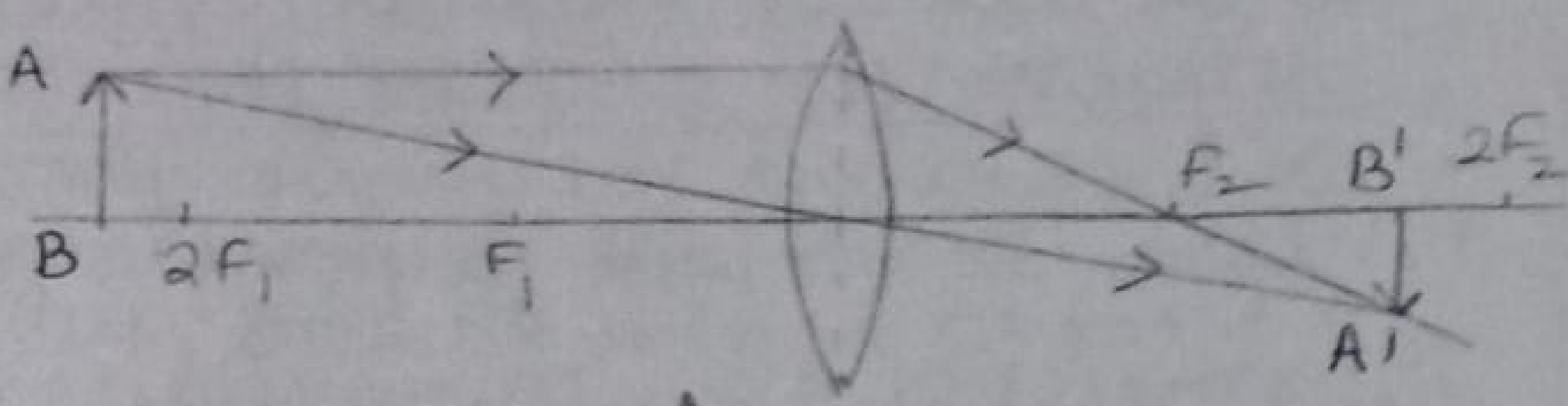
(i) When the object is at infinity.

- image is formed at focus
- real and inverted
- highly diminished point sized

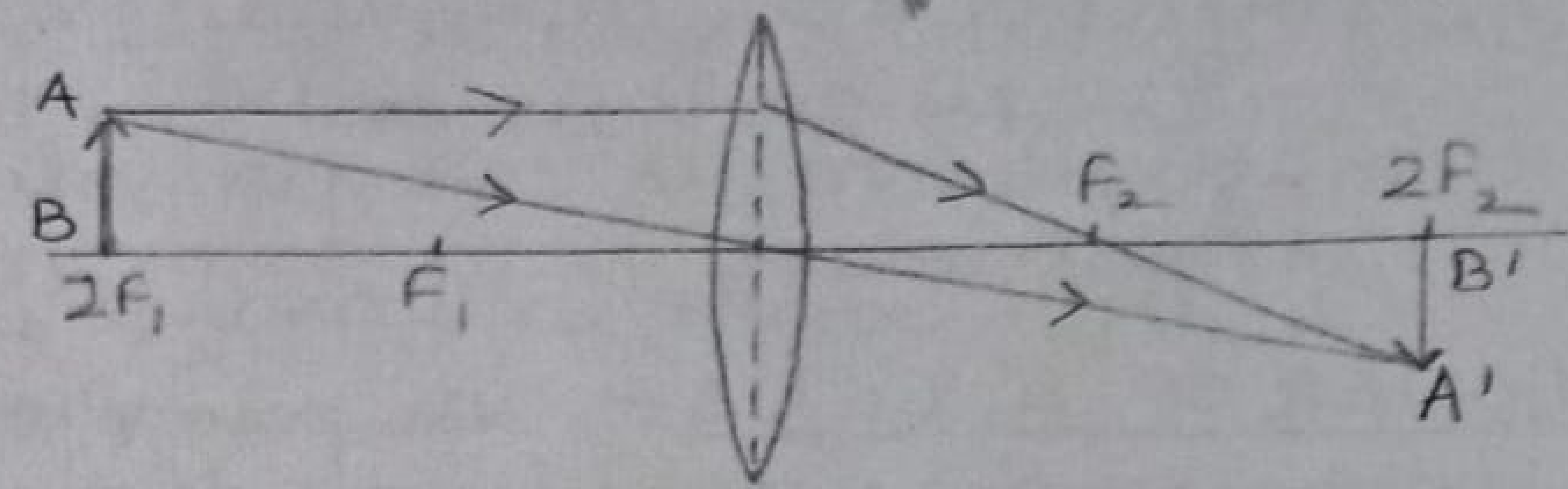


- this is also used to find approximate focal length of a convex lens by concentrating sun light on paper.

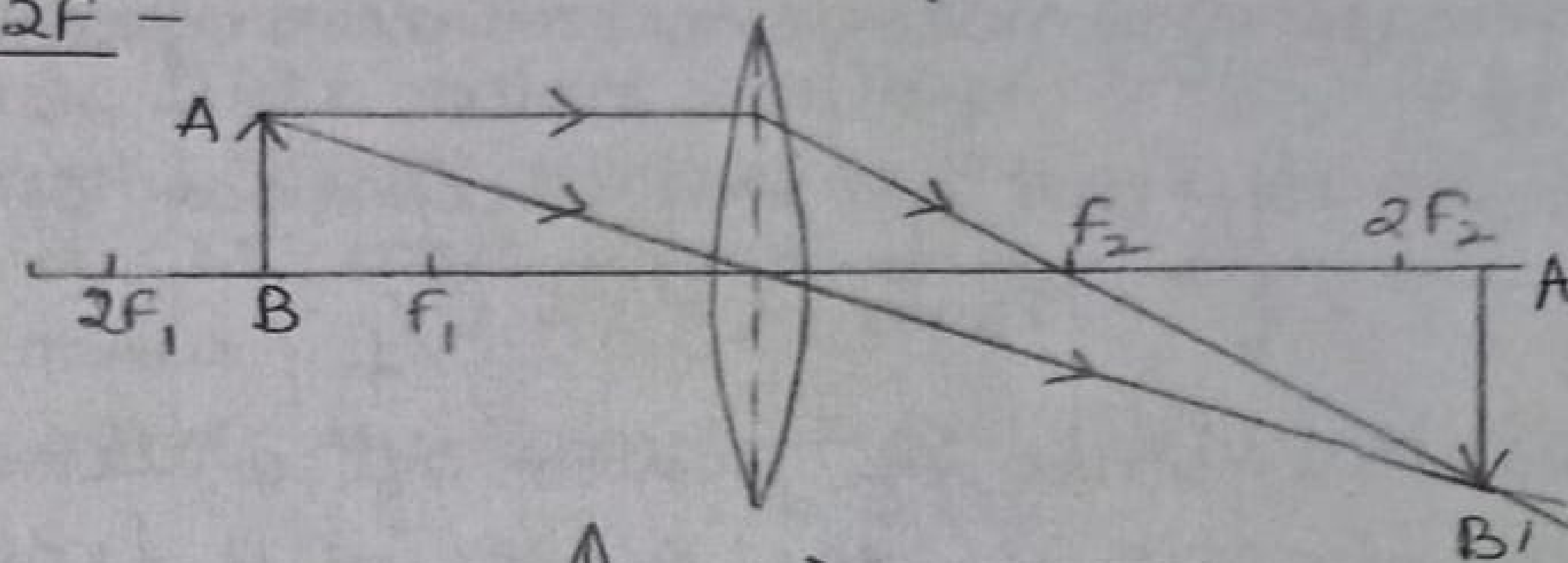
(ii) Object is beyond 2F -
- image is formed between F and 2F
- real an inverted
- smaller in size than object.



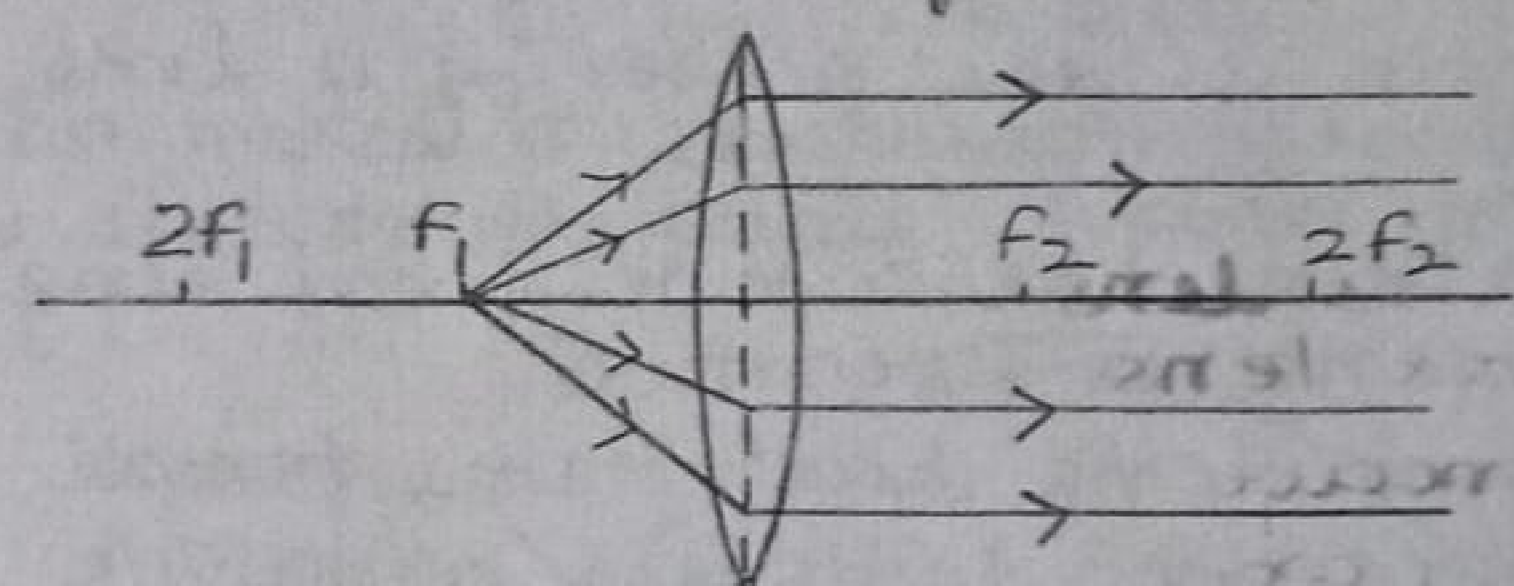
(iii) Object is at 2F -
- image is formed at 2F
- real and inverted.
- same size as that of object.



(iv) Object is between F and 2F -
- image is formed beyond 2F
- real and inverted
- larger in size.



(v) Object is at F -
- image will form at infinity
- real and inverted
- highly enlarged.



(vi) Object is between F and optical centre -
- image will form on the same side as the object
- virtual and erect.
- enlarged.

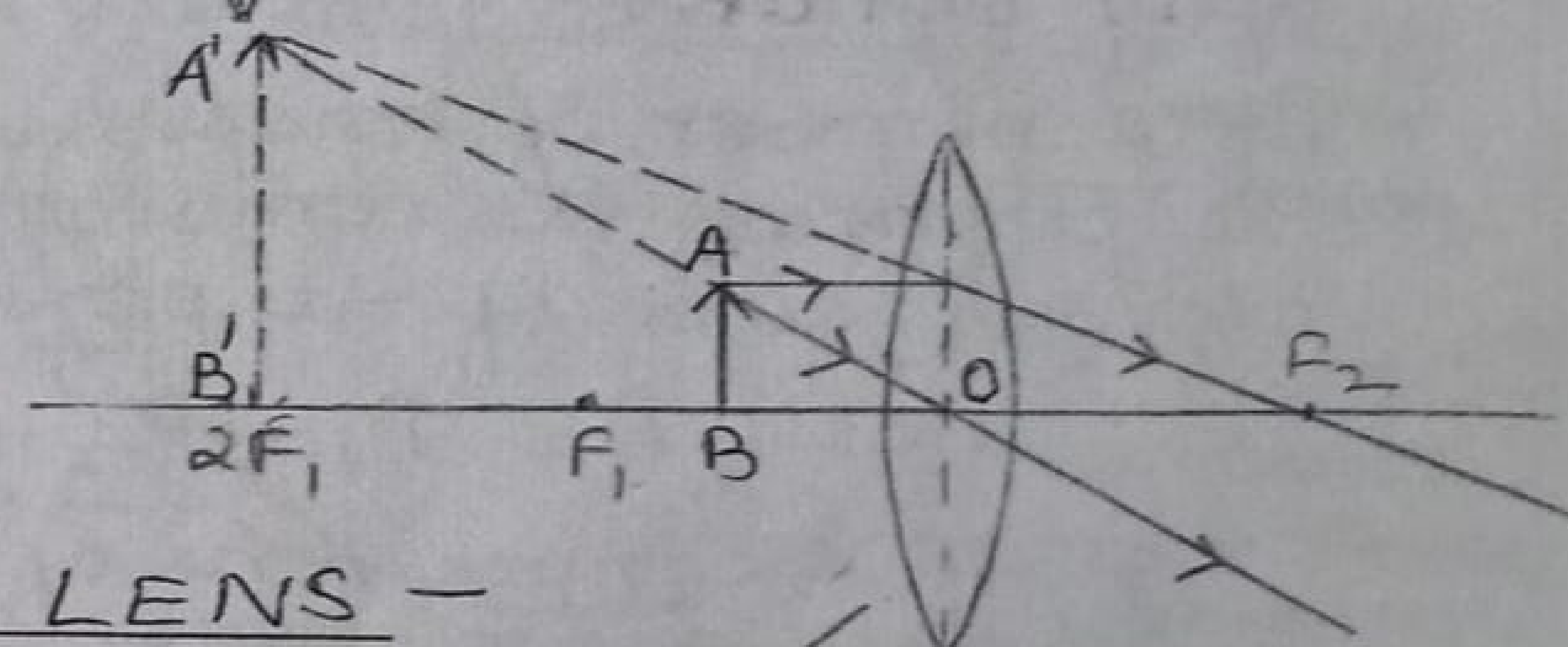
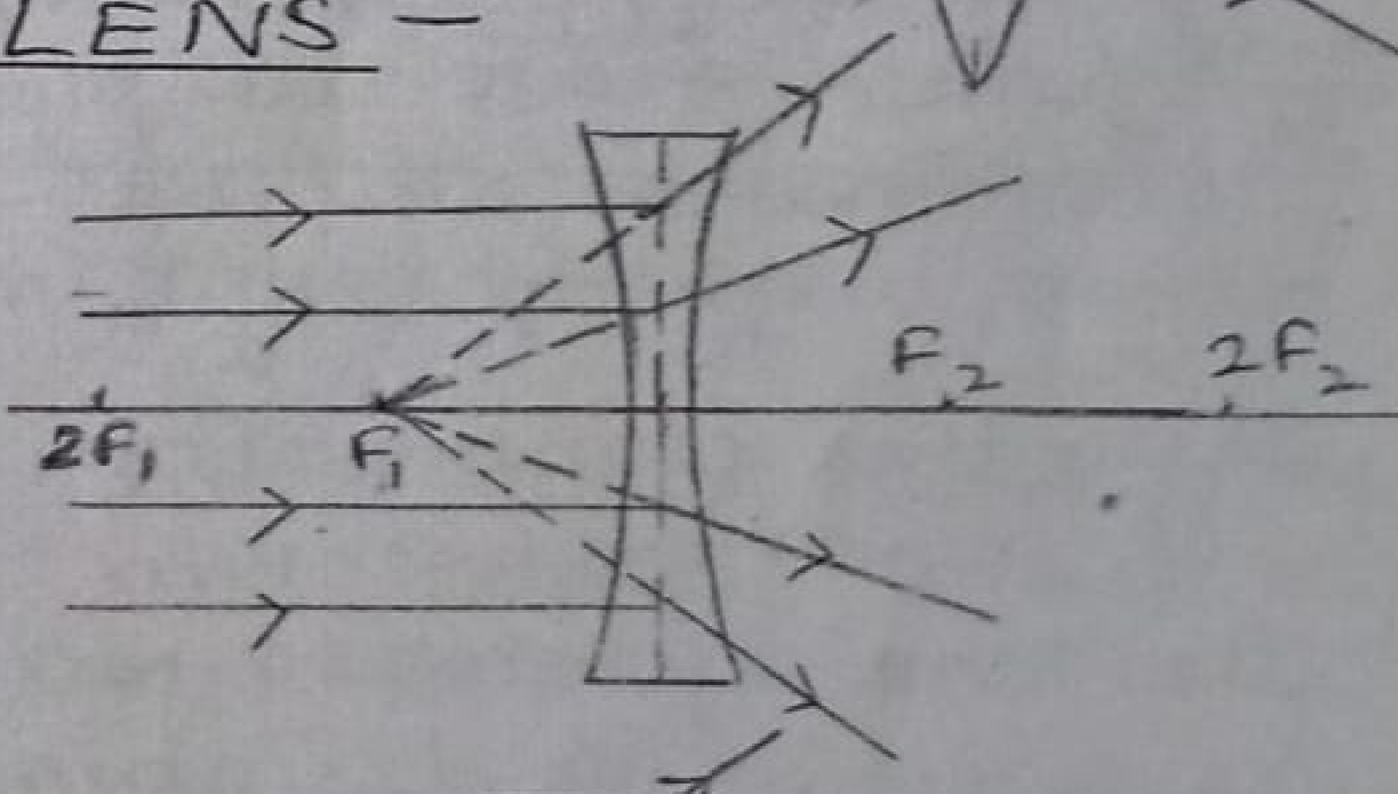
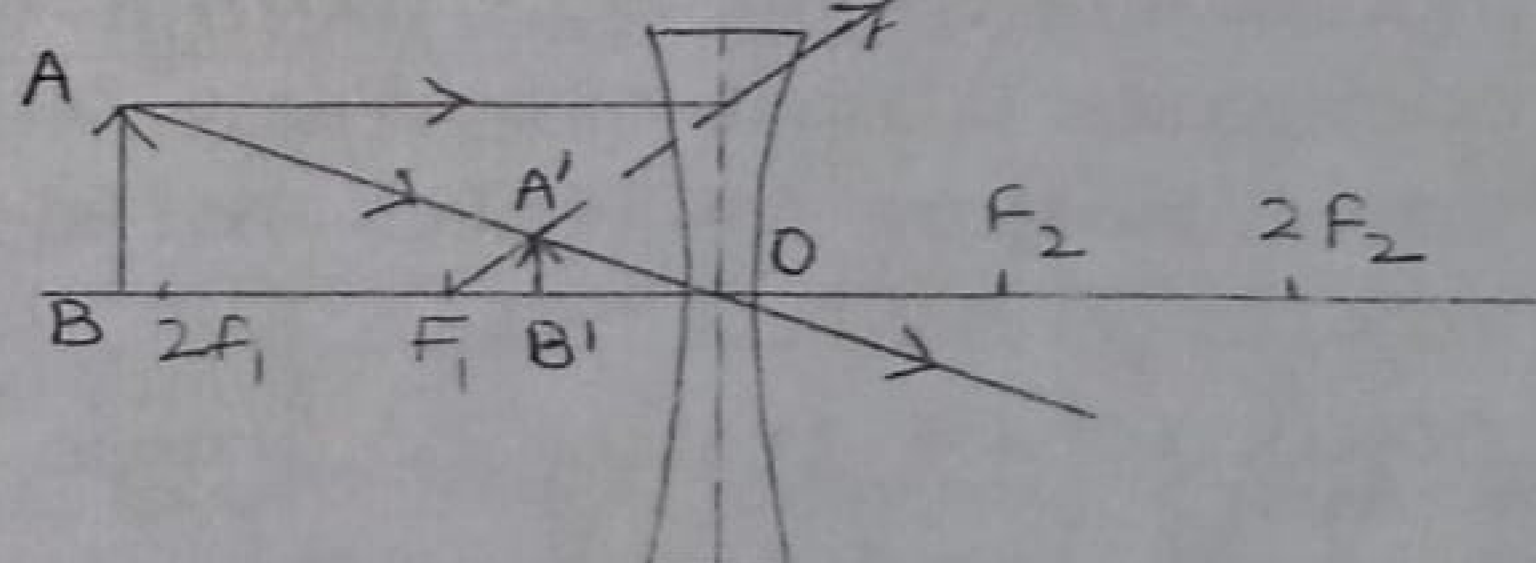


IMAGE FORMATION BY CONCAVE LENS -

(i) when the object is at infinity -
- image will form at focus (F_1)
- virtual and erect
- diminished.



(ii) when the object is anywhere between infinity and optical centre -
- image is formed between F and optical centre and on the same side as that of object
- virtual and erect
- smaller in size



SIGN CONVENTION FOR SPHERICAL LENSES - For lenses, similar sign conventions are used as for spherical mirrors except that all measurements are taken from optical centre.

LENS FORMULA AND MAGNIFICATION -

- Lens formula: $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ where u is object distance, v is image distance and f is focal length

- u is always negative, f is positive for convex lens and negative for concave lens.
- v is always negative for concave lens but for convex lens it will depend upon the position of image.

Magnification: $m = \frac{h_i}{h_o} = \frac{v}{u}$.

magnification is -ve for real image and +ve for virtual image.

- **POWER OF A LENS** – The power of a lens is a measure of the degree of convergence or divergence of light rays falling on it.
- It is defined as the reciprocal of its focal length in metres.

i.e. Power (P) = $1/f$

- The S.I. unit of power of a lens is DIOPTRE (D)

One dioptre is the power of a lens whose focal length is 1 metre.

- A convex lens has a +ve focal length, so the power of a convex lens is positive.
- A concave lens has -ve focal length, so the power of a concave lens is negative.
- If a number of lenses are placed in close contact, then the power of the combination of lenses is equal to the algebric sum of the power of individual lenses.

i.e. $P = P_1 + P_2 + P_3 + ----$

e.g. if a convex lens of power +4D and a concave lens of power -10D are placed in contact, then the power of combination will be –

$$P = P_1 + P_2 = +4 + (-10) = -6D$$

Thus this combination will behave like a concave lens of power -6D.

- The lens systems consisting of several lenses in contact are used in designing the optical instruments like cameras, microscopes and telescopes etc. The use of combination of lenses increases the sharpness of the image and is also free from many defects which otherwise occur while using a single lens.

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