Focal Length Of Spherical Lenses

Spherical lens

(a) Definition: A piece of a transparent medium bounded by atleast one spherical surface, is called a spherical lens.

(b) Types: There are two types of spherical lenses.

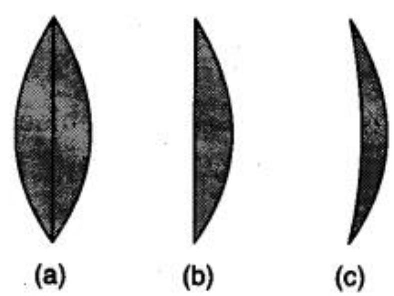
1. **Convex or Converging Lenses:** These are thick in the middle and thin at the edges.
2. **Concave or Diverging Lenses:** These are thin in the middle and thick at the edges.

(c) Different types of convex lenses: The three types of convex lenses are

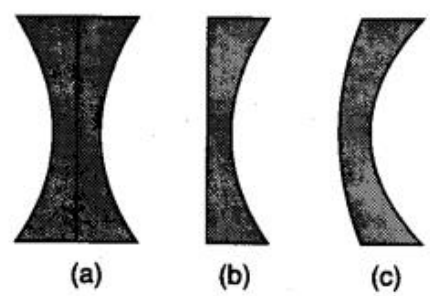
1. double convex
2. Plano-convex
3. concavo-convex

(d) Different types of concave lenses: The three types of concave lenses are

1. double concave
2. Plano-concave
3. convexo-concave



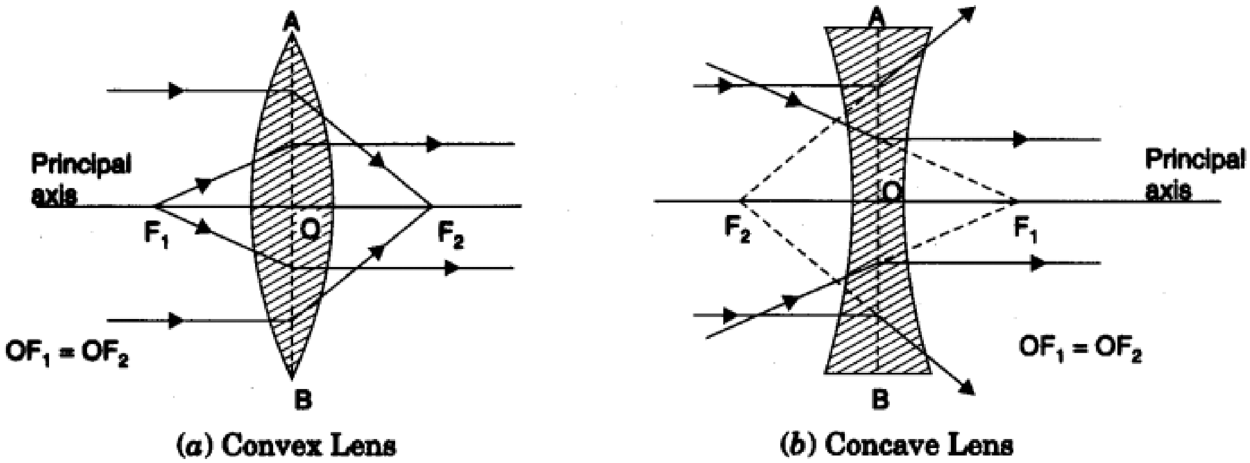
Three types of convex lenses: (*a*) double convex; (*b*) plano-convex; (*c*) concavo-convex.



Three types of concave lenses: (*a*) double concave; (*b*) plano-concave; (*c*) convexo-concave.

Terms associated with spherical lenses

1. **Aperture:** The diameter of the circular edge of the lens, is called the aperture of the lens.
   In diagram AB is the aperture of the lens.
2. **Principal axis:** The straight line passing through the two centres of curvature of the two spherical surfaces of the lens (or through one centre of curvature of one spherical surface and normal to the other plane surface), is called the principal axis of the lens.



Spherical lenses.

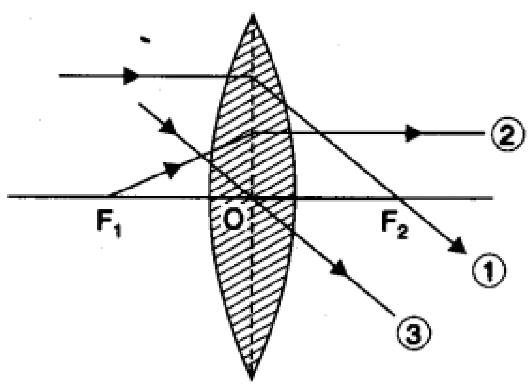
3. **Optical centre:** It is a point on the principal axis of the lens, such that a ray of light passing through it goes undedicated.
   In diagram, O is the optical centre of the lens.
4. **First principal focus:** It is a point on the principal axis of the lens, such that the rays actually diverging from it (in case of a convex lens) or appearing to be going towards it (in case of a concave lens), after refraction from the lens, go parallel to the principal axis.
   In diagram,F_1 is the first principal focus of the lens. (For object at F_1 image at infinity).
5. **Second principal focus:** It is a point on the principal axis of the lens, such that the rays incident on the lens parallel to the principal axis after refraction from the lens, actually meet at this point (in case of a convex lens) or appear to come from it (in case of a concave lens).
   In diagram, F_2 is the second principal focus of the lens (For image at F_2 object at infinity).
6. **Focal length:** The distance between the optical centre of the lens and the principal focus (first or second) of the lens, is called focal length of the lens. It is represented by the symbol f. In diagram,$OF_1 = OF_2 = f$.
7. **Principal section:** A section of the lens cut by a plane passing through the principal focus and optical centre of the lens, is called principal section of the lens. It contains the principal axis.

In diagram, the shaded portion is the principal section of the lens cut by the plane of the book page.

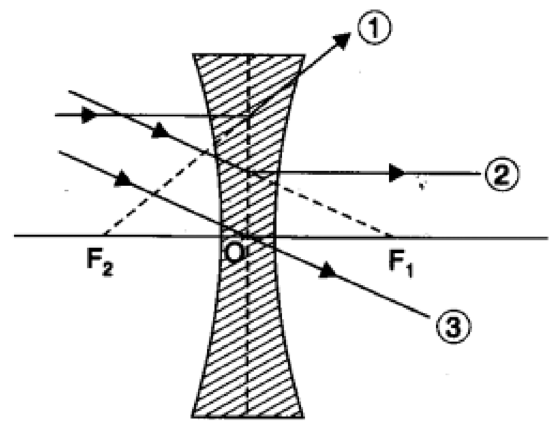
Three special rays

The special rays are:

1. Incident on the lens parallel to principal axis. After refraction from the lens, it actually passes through second principal focus F_2 (in case of a convex lens) or appears to come from the second principal focus F_2 (in case of a concave lens).



(a) Convex Lens



(b) Concave Lens

Three special rays.

2. Incident on the lens through first principal focus F_1 (in case of a convex lens) or in direction of first principal focus F_1 (in case of a concave lens).
   After refraction from the lens, it goes parallel to the principal axis.
3. Incident on the lens in direction of optical centre. It passes undedicated through the lens.

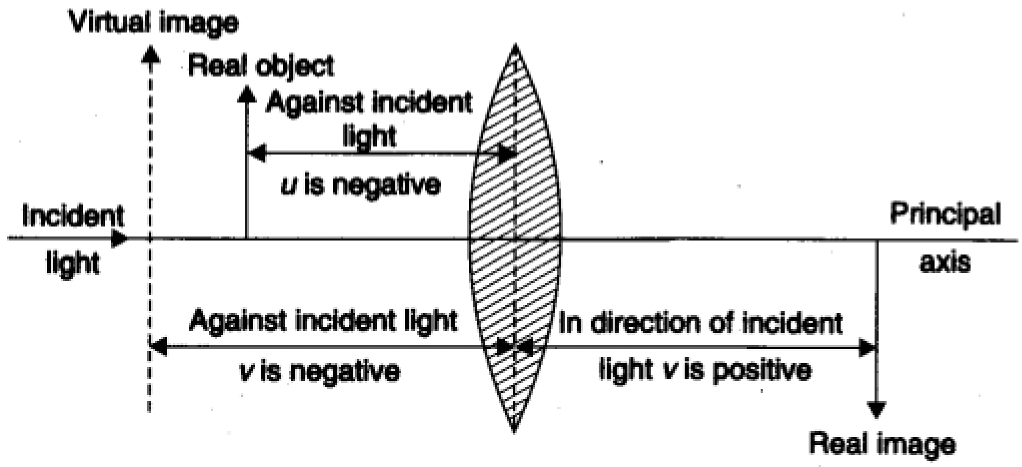
Sign convention

(a) Definition: It is a convention, which fixes the sign of different distances measured. The sign convention followed is the New Cartesian sign convention.

(b) Rules: It gives following rules:

1. All distances are measured from the optical centre of the lens (along the principal axis).
2. The distances measured in the same direction as the direction of incident light, are taken as positive.
3. The distances measured opposite to the direction of incident light, are taken as negative.

4. The distances measured above the principal axis are taken as positive but distances measured below the principal axis are taken as negative.



Sign convention explained.

(c) Facts: According to above mentioned rules of sign convention,

1. Focal length for a convex lens is taken positive and the same for concave lens is taken negative.
2. The distance of an object is always negative.
3. The distance for real image is positive, while that for a virtual image is negative.
4. The size of object is positive and size of real image is negative while size of virtual image is positive.

Lens formula

The equation relating the object distance (u), the image distance (u) and the lens focal length (f), is called lens formula. It is also called Gaussian formula.

The formula is, $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

Assumptions made

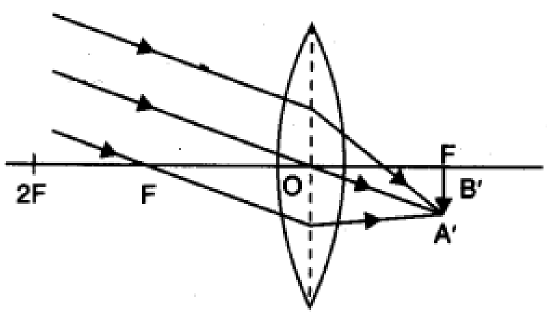
Following assumptions are made in derivation of the lens formula.

1. The lens is thin.
2. The lens has a small aperture.
3. The point object lies on to the principal axis and placed perpendicular.
4. The incident rays make small angles with the lens surface or the principal axis.

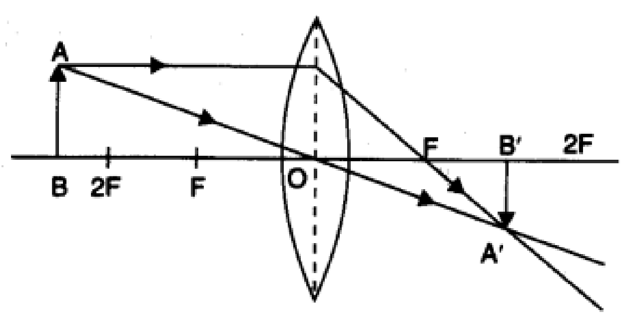
Position, nature and size of image when object is put in different position in front of a convex lens

It is described below in tabular form.

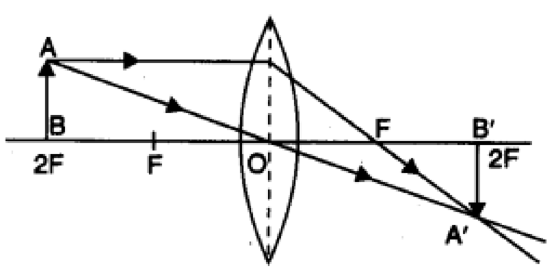
S. No.	Objected Position	Image			Figure
		Position	Nature	Size	
1.	At infinity	At focus F	Real-Inverted	Point sized	8.06 (*a*)
2.	Beyond 2F	Between F and 2F	Real-Inverted	Diminished	8.06 (*b*)
3.	At 2F	At 2F	Real-Inverted	Same	8.06 (*c*)
4.	Between F and 2F	Beyond 2F	Real-Inverted	Enlarged	8.06 (*d*)
5.	At F	At infinity	Imaginary-Inverted	Extremely enlarged	8.06 (*e*)
6.	Between F and optical centre (O)	Behind lens	Virtual-Erect	Enlarged	8.06 (*f*)



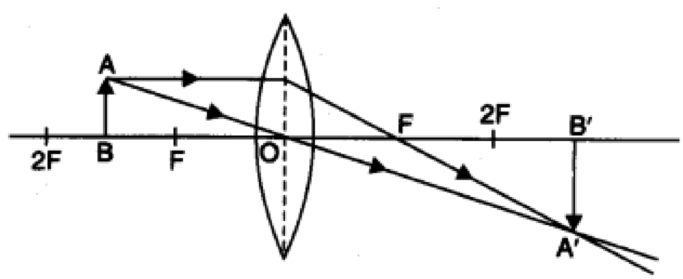
(*a*) Object at infinity.



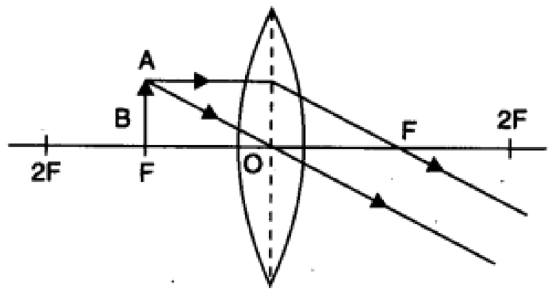
(*b*) Object beyond 2F.



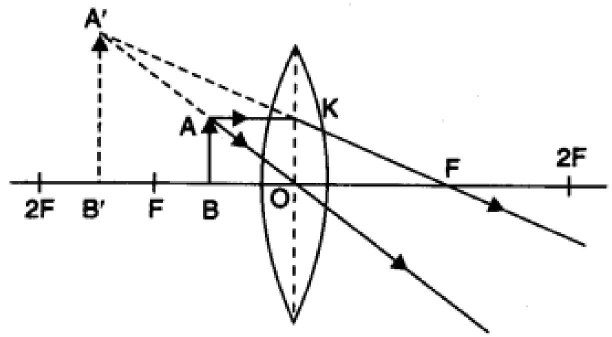
(*c*) Object at 2F.



(*d*) Object between F and 2F.



(e) Object at F.



(f) Object between F and optical centre.

Power of a lens

(a) Definition: It is the capacity or ability of a lens to deviate (converge or diverge) the path of rays passing through it. A lens producing more converging or more diverging is said to have more power and vice-versa.
It is represented by the symbol P.
(b) Relation with focal length: A lens of less focal length produces more converging or diverging rays and is said to have more power.

Hence, $$\text{power} \propto \frac{1}{\text{focal length}} \text{ or } P \propto \frac{1}{f}$$

We have $$P = \frac{1}{f}$$

(Constant of proportionality is taken as 1).

(c) Unit: Unit of power is diopter (D). One diopter is the power of a lens of focal length 1 metre.

$$\text{In general, } P(\text{dioptres}) = \frac{1}{f\ (\text{metre})} = \frac{100}{f\ (\text{cm})}$$

(d) Sign: A converging lens has positive focal length and positive power.
A diverging lens has negative focal length and negative power.

Lens combination

(a) Definition: Two or more thin lenses, placed in contact together to have a common principal axis, form a lens combination.

(b) Focal length: If f_1, f_2,….., f_n be the focal length of individual lens and F be the focal length of the combination.

Then $$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} + \ldots\ldots + \frac{1}{f_n}$$

Note: The lenses forming the combination must be thin to have their optical centres coinciding at one point to represent optical centre of the combination.

(c) Power: If P_1, P_2,….., P_n be the power of individual lenses and P be the power of the combination.

Then,
$$P = P_1 + P_2 + \ldots\ldots + P_n$$

(d) Magnification: If m_1, m_2,….., m_n are the magnification of individual lenses and m is the equivalent magnification of the combination then,

$$m = m_1 \times m_2 \times m_3 \ldots \times m_n$$

Chromatic aberration of a lens

(a) Definition: The defect or drawback of a lens due to which it makes a coloured image of an object illuminated with white light, is called chromatic aberration. It is due to dispersion of white light by lens (just like a prism does).

(b) Remedy: It is removed by combining a convex and a concave lens of suitable focal length and material.
The combination of two lenses is called an achromatic combination (a chromic doublet).