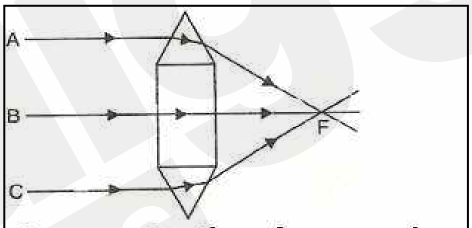
X PHYSICS SHORT NOTES

5. Refraction Through a Lens

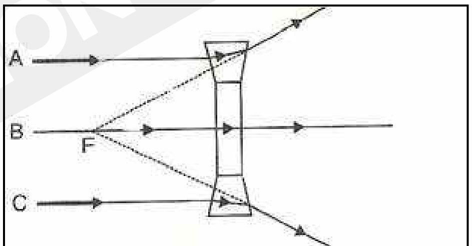
A) LENS & REFRACTION OF LIGHT THROUGH LENS.

- **Lens:**
  - **Definition:** A lens is a transparent refracting medium bounded by one or two spherical surfaces.
  - **Kinds of lenses:** Lenses are of two types:
    - Converging or Convex lens
    - Diverging or Concave lens
- **Action of lens as a set of prism:**
  - **Refraction through a convex lens:**
    - The central part has parallel sides hence the ray passes undeviated.
    - The prism forms a convex lens and converges the parallel light beam.



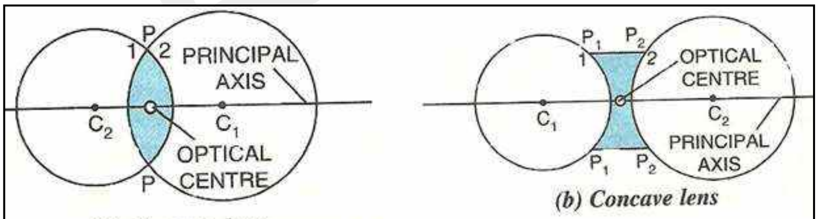
Convergent action of a convex lens

  - **Refraction through a concave lens:**
    - The central part has parallel sides hence the ray passes undeviated.
    - The prism forms a concave lens and diverges the parallel light beam.



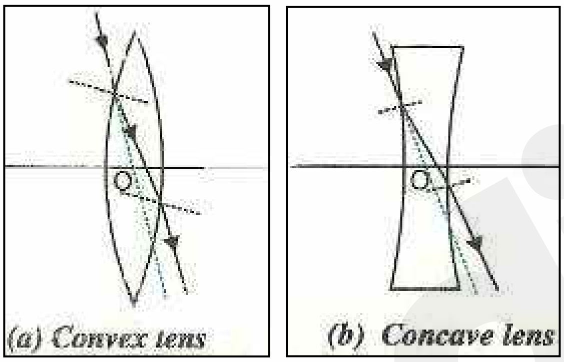
Divergent action of a concave lens

- **Technical terms related to a lens:**



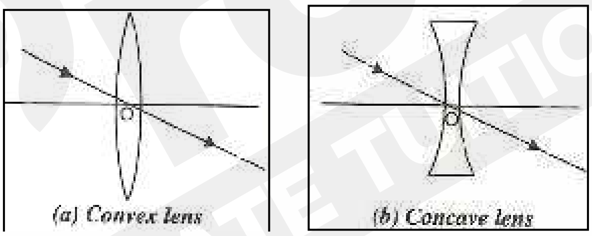
(a) Convex lens
(b) Concave lens
centre of curvature, principal axis and optical centre

- **<u>Centre of curvature</u>:** The center of the sphere, which forms the lens surface, is called the center of curvature of that surface of the lens.
- **<u>Radius of curvature</u>:** The radius of the sphere, which forms lens surface, is called the radius of curvature of that surface of the lens.
- **<u>Principal axis</u>:** The line joining the centers of curvature of the two surfaces of the lens is called the principal axis.
- **<u>Optical center</u>:** It is a point on the principal axis of the lens such that an incident ray of light emerges parallel to its direction of incidence after passing through this point.
  - **<u>If the lens is thick</u>:** The light ray while passing through the optical centre is slightly displaced parallel to its original direction as follows:



(a) Convex lens (b) Concave lens

  - **<u>If the lens is thin</u>:** The light ray passing through the optical centre passes undeviated as follows:

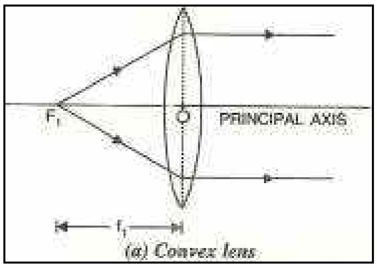


(a) Convex lens (b) Concave lens

  - **<u>Definition of optical centre of thin lens</u>:** The optical centre of a thin lens is the point on the principal axis of a lens, such that an incident ray of light, passes undeviated through it.

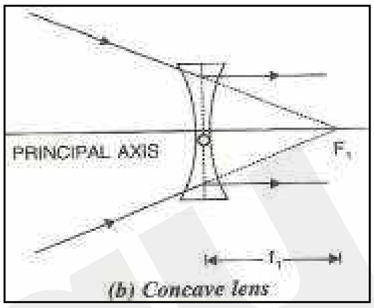
- **<u>Principal foci</u>:**
  - Two principal foci are situated at equal distances from the optical center one on either side of the lens.
  - They are called first focus F_1 and second focus F_2.
  - **<u>First focal point</u>:**

- **<u>For a convex lens</u>**: The first focal point is a point F_1 on the principal axis of the lens such that the **rays of light starting from it or passing through it**, after refraction through the lens, become parallel to the principal axis of the lens.



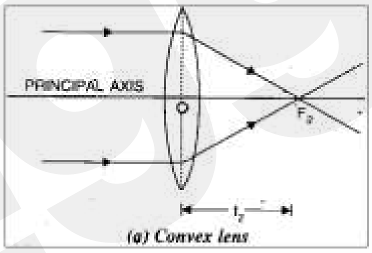
(a) Convex lens

- **<u>For a concave lens</u>:** The first focal point is a point F_1 on the principal axis of the lens such that **the incident ray of light appears to meet at it**, after refraction from the lens and becomes parallel to the principal axis of the lens.



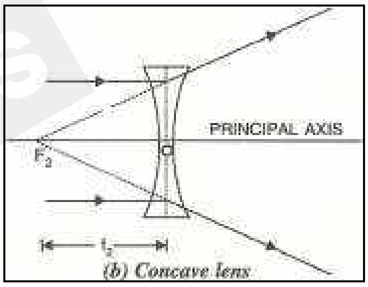
(b) Concave lens

- **<u>Second focal point</u>:**
  - **<u>For a convex lens</u>:** The second focal point is a point F_2 on the principal axis of the lens such that the ray of light incident parallel to the principal axis, after refraction, **passes through it**.



(a) Convex lens

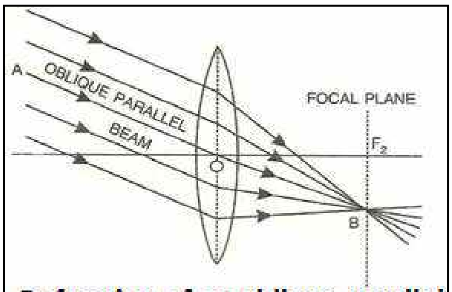
  - **<u>For a concave lens</u>:** Second focal point is a point F_2 on the principal axis of the lens such that the ray of light incident parallel to the principal axis, **appears to to diverge from this point, after refraction**.



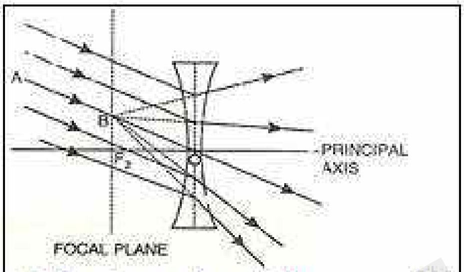
(b) Concave lens

- **<u>The focal length of the lens</u>:**
  - There are two focal lengths of a lens.
    - **<u>First focal length (f_1)</u>:** It is the distance from the optical centre of the lens to its **first focal point F_1.**
    - **<u>Second focal length(f_2)</u>:** It is the distance from the optical centre of the lens to its **second focal point F_2.**

  - **<u>The factors on which the focal length of a lens depends:</u>**
    - The refractive index of material of lens – **Directly proportional**:
      - The refractive index is relative to the surrounding medium.
      - Ex: If a lens is placed in water (denser) instead of air (rarer) the focal length **increases**.
    - The radii of curvature of lens – **Inversely proportional:**
      - A **thick** lens has **less** focal length.
      - A **thin** lens has **greater** focal length for the same material.
  - If a part of the lens is covered:
    - Its focal length remains unchanged and
    - The intensity of light entering the lens decreases due to which the intensity of the image formed by it also decreases.

- **The focal plane of the lens**:
  - **First focal plane:** A plane passing through the **first focal point** and is normal to the principal axis of the lens is called the **first focal plane**.
  - **Second focal plane:** A plane passing through the **second focal point** and is normal to the principal axis of the lens is called the **second focal plane**.
- 

Refraction of an oblique parallel beam by a convex lens



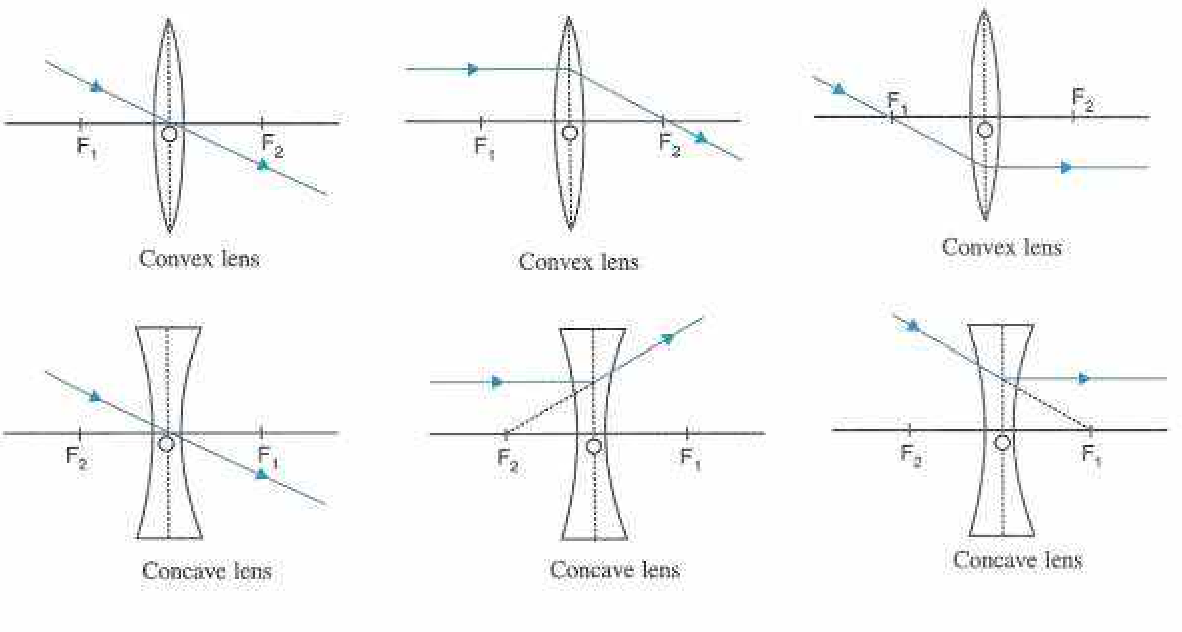
Refraction of an oblique parallel beam by a concave lens

➢ **Difference between concave and convex lens in their:**
- **Appearance and.**
- **Action on the incident light.**

Convex lens	Concave lens
1. It is thick in the middle and thin at the periphery.	1. It is thin in the middle and thick at the periphery.
2. It converges the incident rays towards the principal axis.	2. It diverges the incident ray away from the principal axis.
3. It has a real focus.	3. It has a virtual focus.

B) FORMATION OF IMAGE BY A LENS

➢ **Principal rays in the construction of a ray diagram:**



Three principal (or construction) rays

- **<u>Characteristics and location of images for a convex lens</u>:**

  - **<u>Case (i)</u>: <u>When the object is at infinity (i.e., a very distant object)</u>**

    f = 2 cm   u = at infinity   ht. of O = ---
    2f = 4 cm   v = at F_2 ht. of I = ?

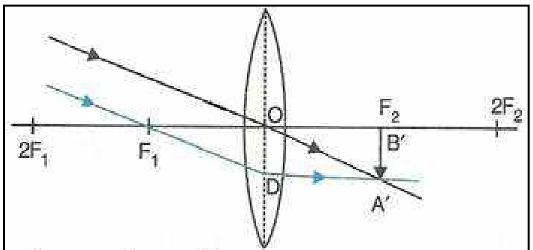


Image formation by a convex lens for very distant object

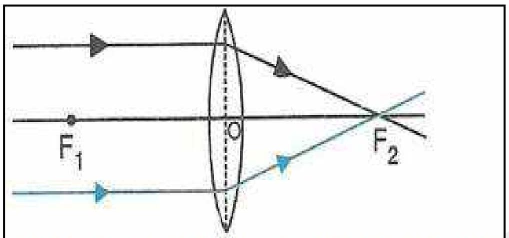


Image formation by a convex lens for an object at infinity

<u>Nature of image</u>: Real, Inverted and highly diminished.
<u>Position of image</u>: At F_2.
<u>Magnification</u>: Cannot be calculated as object is at infinity.
<u>Application</u>: Convex lens is used either as a camera lens or a burning glass.

  - **<u>Case (ii)</u>: <u>When the object is beyond 2F_1</u>.**

    f = 2cm   u = beyond 2F_1 ht. of O = 2cms
    2f = 4 cm   v = between F_2 and 2F_2 ht. of I = ?

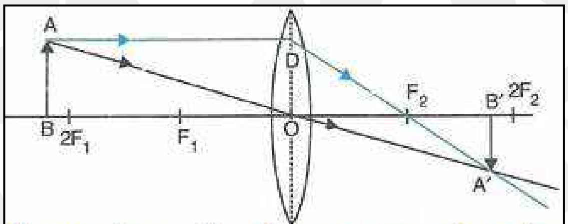


Image formation by a convex lens for the object beyond 2F_1

<u>Nature of image</u>: Real, Inverted and diminished.
<u>Position of image</u>: Between F_2 and 2F_2.
<u>Magnification</u>: $-\frac{v}{u} = \frac{ht\ of\ I}{ht\ of\ O}$
<u>Application</u>: Convex lens used as camera lens when the object, not very far, is to be photographed.

  - **<u>Case (iii): When the object is at 2F_1</u>.**

    f = 2cm   u = At 2F_1 ht. of O = 2cms
    2f = 4 cm   v = At 2F_2 ht. of I = 2cms

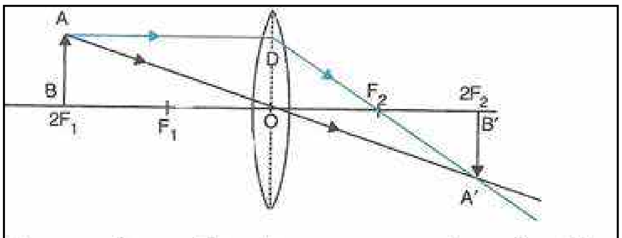


Image formation by a convex lens for the object at 2F_1

Nature of image: Real, Inverted and of the same size as the object.

Position of image: At $2F_2$.

Magnification: $-\frac{v}{u} = \frac{ht\ of\ I}{ht\ of\ O} = \frac{2}{2} = 1$

Application: This case is used in a terrestrial telescope for erecting the image formed by the objective lens.

- **Case (iv): When the object is between F_1 and $2F_1$.**

f = 2cm　u = between F_1 and $2F_1$　ht. of O = 2cms

2f = 4 cm　v = beyond $2F_2$　ht. of I = ?

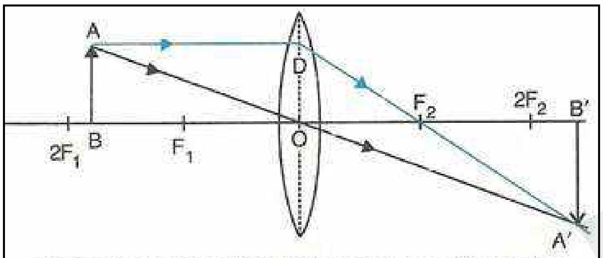


Image formation by a convex lens for the object between F_1 and $2F_1$

Nature of image: Real, Inverted and magnified.

Position of image: Beyond $2F_2$.

Magnification: $-\frac{v}{u} = \frac{ht\ of\ I}{ht\ of\ O}$

Application: This type of image formation is used in cinema and slide projectors.

- **Case (v): When the object is at F_1.**

f = 2 cm　u = At F_1　ht. of O = 2cms

2f = 4 cm　v = At infinity　ht. of I = --

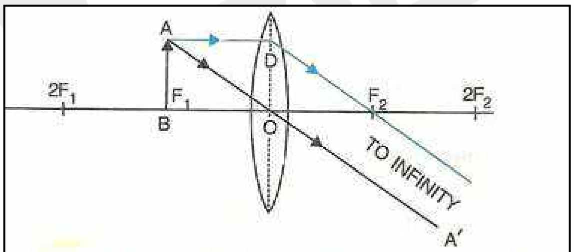


Image formation by a convex lens for the object at F_1

Nature of image: Real, Inverted and highly magnified.

Position of image: At infinity.

Magnification: Cannot be calculated.

Application: The above arrangement is used in the collimator of a spectrometer to obtain a parallel beam of light by placing the source of light at the focus of convex lens.

- **Case (vi): When the object is between the lens and the focus (i.e., between O and F_1):**

  f = 2cm   u = between F_1 and optical centre   ht. of O = 2cms

  2f = 4 cm   v = beyond F_1, on same side behind the object   ht. of I = ?

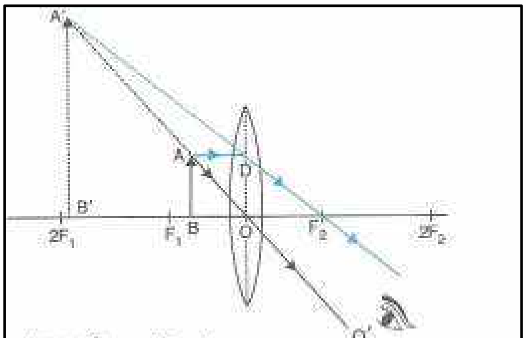


Image formation by a convex lens for the object between the optical centre and the focus

  Nature of image: Virtual, erect and magnified.

  Position of image: Beyond F_1, on same side behind the object.

  Magnification: $+\frac{v}{u} = \frac{ht\ of\ I}{ht\ of\ O}$

  Application: This type of image formation is used while using a convex lens as a reading lens, magnifying glass or a simple microscope, in which a magnified virtual image of a tiny object is formed which is distinctly seen by the eye because the eye lens converges the rays to form a real image on the retina.

➤ **Characteristics and location of images for a concave lens:**

- **Case (i): When the object is at infinity.**

  f = 2cm   u = At infinity   ht. of O = ---

  2f = 4 cm   v = At F_2 ht. of I = ?

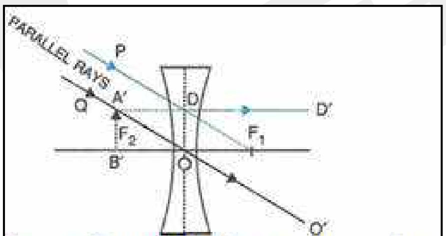


image formation by a concave lens when the object is at a very large distance

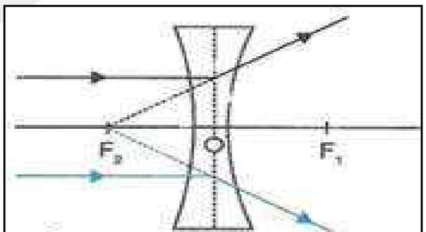


image formation by a concave lens when the object is at infinity

  Nature of image: Virtual, erect and diminished.

  Position of image: At F_2.

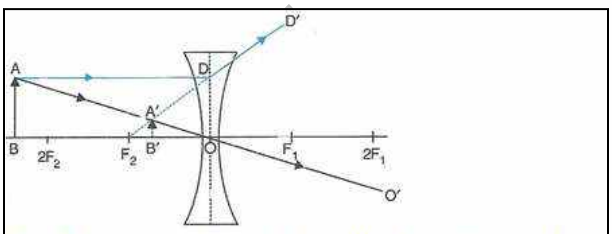
  Magnification: Cannot be calculated as object at infinity.

  Application: Used in Galilean telescope.

- **Case (ii): When the object is between infinity and the optical centre of the concave lens.**

  f = 2cm u = between infinity to optical centre (anywhere) ht. of O = 2cms.

  2f = 4 cm v = between F_2 and optical centre ht. of I = ?



Ray diagram for image formation by a concave lens when the object is between infinity and the lens

Nature of image: Virtual, erect and diminished.

Position of image: Between F_2 and optical centre.

Magnification: $+\frac{v}{u} = \frac{ht\ of\ I}{ht\ of\ O}$

Application: Used in spectacles by short sighted person.

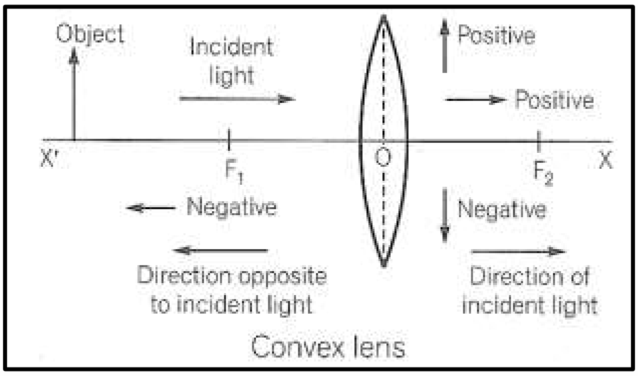
➢ **Difference between the image formed by a convex and a concave lens:**

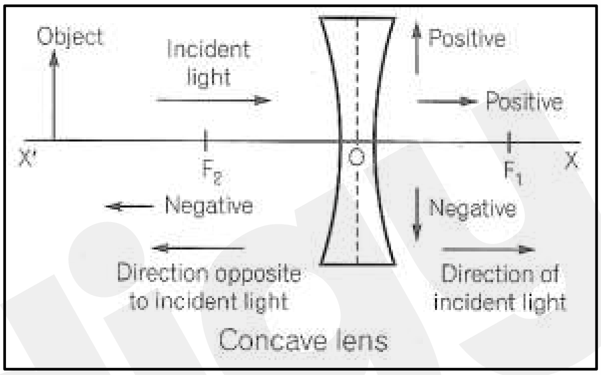
Image by a convex lens	Image by a concave lens
1. The image can be real as well as virtual. Real- if the object is **beyond** the focus, Virtual - if the object is **before** the focus.	1. The image is always virtual for all the positions of the object in front of the lens.
2. The image can be magnified, of same size as well as diminished. Magnified – when object is **before** 2F. Same size – when object is **at** 2F. Diminished – when object is **beyond** 2F.	2. The image is always diminished.
3. The image can be inverted or erect. Inverted – when object is beyond focus, Erect – when object is within focal distance.	3. The image is always erect.

C) SIGN CONVENTION AND LENS FORMULA.

➢ **Sign Convention of Measurement of Distances:**

We follow the cartesian sign convention to measure the distance in a lens.





➢ **Lens Formula:** $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$

- **Definition:** The Lens formula is the equation relating to the distance of object (u), distance of image (v) and focal length (f) of a lens.
- Lens formula is same for both - convex and concave lens.
- It is : $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$
- According to sign convention:
  - **For a convex lens:**
    - *u* is always negative.
    - *f* is always positive.
    - *v* is **positive** for the **real** image.
    - *v* is **negative** for the **virtual** image.
  - **For a concave lens:**
    - *u*, *v* and f all are negative.
    - The numerical value of *u* is always greater than *v*.

➢ **Linear Magnification:**

- **Definition:** The linear magnification is the ratio of length of image (I) perpendicular to the principal axis, to the length of object (O).
- Linear magnification, m = $\frac{Length\ of\ image\ (I)}{Length\ of\ object\ (O)} = \frac{v}{u}$

➢ **Power of Lens:**

- **Definition:** The power of a lens is a measure of deviation produced by it in the path of rays refracted through it.
- Unit of power of lens is dioptre (D).
- Power of lens in dioptre is the reciprocal of focal length in metre.
- Power of lens (in D) $= \frac{1}{focal\ length\ (in\ metre)}$.

FORMULAE:

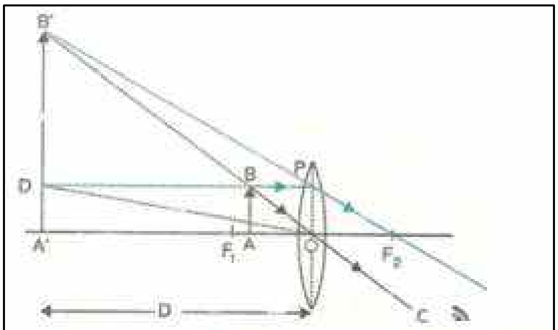
1. **Power of lens (in D)** $= \dfrac{1}{\text{focal length (in meters)}}$
2. $\dfrac{1}{f} = \dfrac{1}{v} - \dfrac{1}{u}$
3. **Real image, m** = −
4. **Virtual image, m** = +
5. **Magnification** $= \dfrac{\text{height of image (I)}}{\text{height of the object (O)}}$
6.

Concave always virtual	Convex virtual	Convex real
− u − v − f	− u − v + f	− u + v + f

B) MAGNIFYING GLASS AND APPLICATION OF LENSES.

- **Scope:**
  - Power of a lens (concave and convex).
  - Simple direct numerical problems.
  - Magnifying glass or simple microscope.
  - Location of image and its magnification from ray diagram only (formulae and numerical problems **not included**).
  - Application of lenses.

- **Magnifying Glass or Simple Microscope:**
  - **Definition:** A magnifying glass is a convex lens of short focal length fitted in a steel (or plastic) frame provided with a handle.
  - **Principle:** The principle of a simple microscope (or magnifying glass or reading glass) is when an object is placed between the optical centre and the focus of a convex lens, the image obtained is erect, virtual and magnified and formed on the same side of the object, but behind the object.
  - **Ray diagram for location of image in magnifying glass:**



Ray diagram for location of image in a magnifying glass

- **Magnifying power:**
  - **Definition:** When the object is placed at the least distance of distinct vision (D) = 25 cm; then the Magnifying power, $m = 1 + \frac{D}{f}$, where f is the focal length of the lens.
  - **Uses:**
    - A simple microscope or magnifying glass is used to see small letters and figures.
    - It is used by watchmakers to see small parts of the watch.
    - In optical instruments such as a travelling microscope, spectrometer, etc., a reading glass is provided above the Vernier scale to enable one to read the scale accurately.