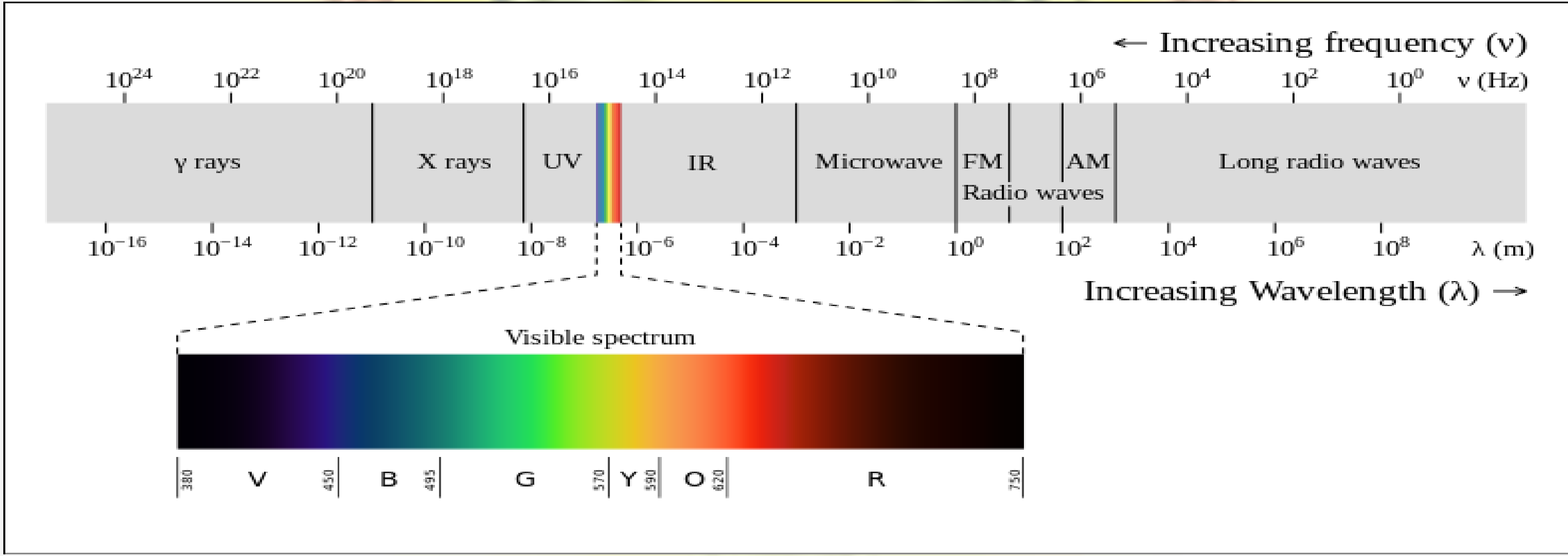
Light

- What is light? – An electromagnetic radiation that can be perceived by a human eye and that helps human to see things.
- It does not require any medium (also known as travesrse wave), to travel unlike sound, that is why light also travels through the vacuum of space.
- Light has a speed of 3×10^8 ms^{-1}

EM SPECTRUM



← Increasing frequency (ν)
10^{24} 10^{22} 10^{20} 10^{18} 10^{16} 10^{14} 10^{12} 10^{10} 10^{8} 10^{6} 10^{4} 10^{2} 10^{0} ν (Hz)
γ rays
X rays
UV
IR
Microwave
FM
AM
Radio waves
Long radio waves
10^{-16} 10^{-14} 10^{-12} 10^{-10} 10^{-8} 10^{-6} 10^{-4} 10^{-2} 10^{0} 10^{2} 10^{4} 10^{6} 10^{8} λ (m)
Increasing Wavelength (λ) →
Visible spectrum
380 V 450 B 495 G 570 Y 590 O 620 R 750

Reflection of Light

- The bouncing of rays of light from a finely polished surface, i.e., mirror, is called the reflection of light
- There are three laws that light obeys also known as the 'Laws of Reflection'
  - The angle of incidence is equal to the angle of reflection
  - The incident ray, the normal to the mirror at the point of incidence and the reflected ray, all lie in the same plane.

The ancient Greek mathematician Euclid gave these laws of reflection in about 300 BCE.

Reflection of Light

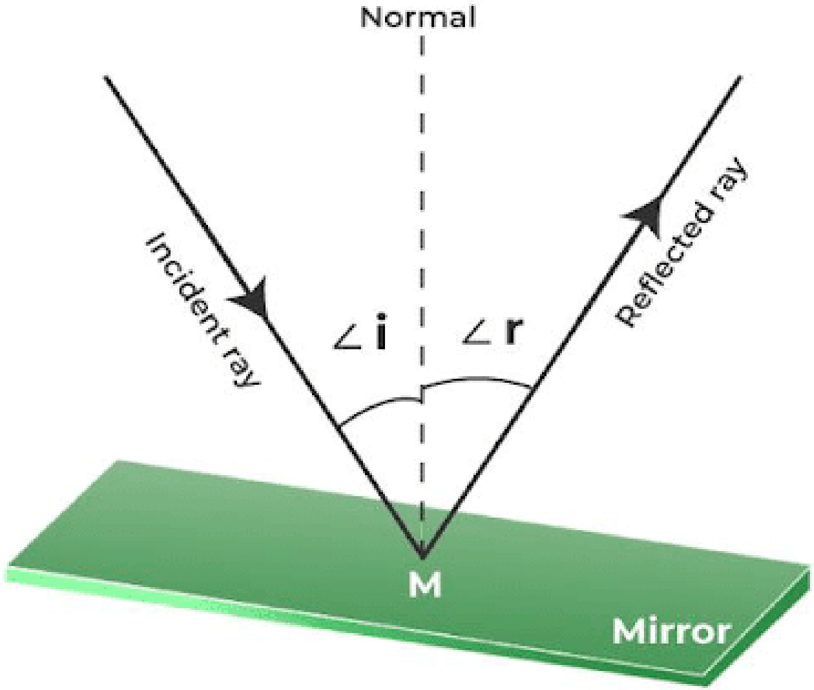


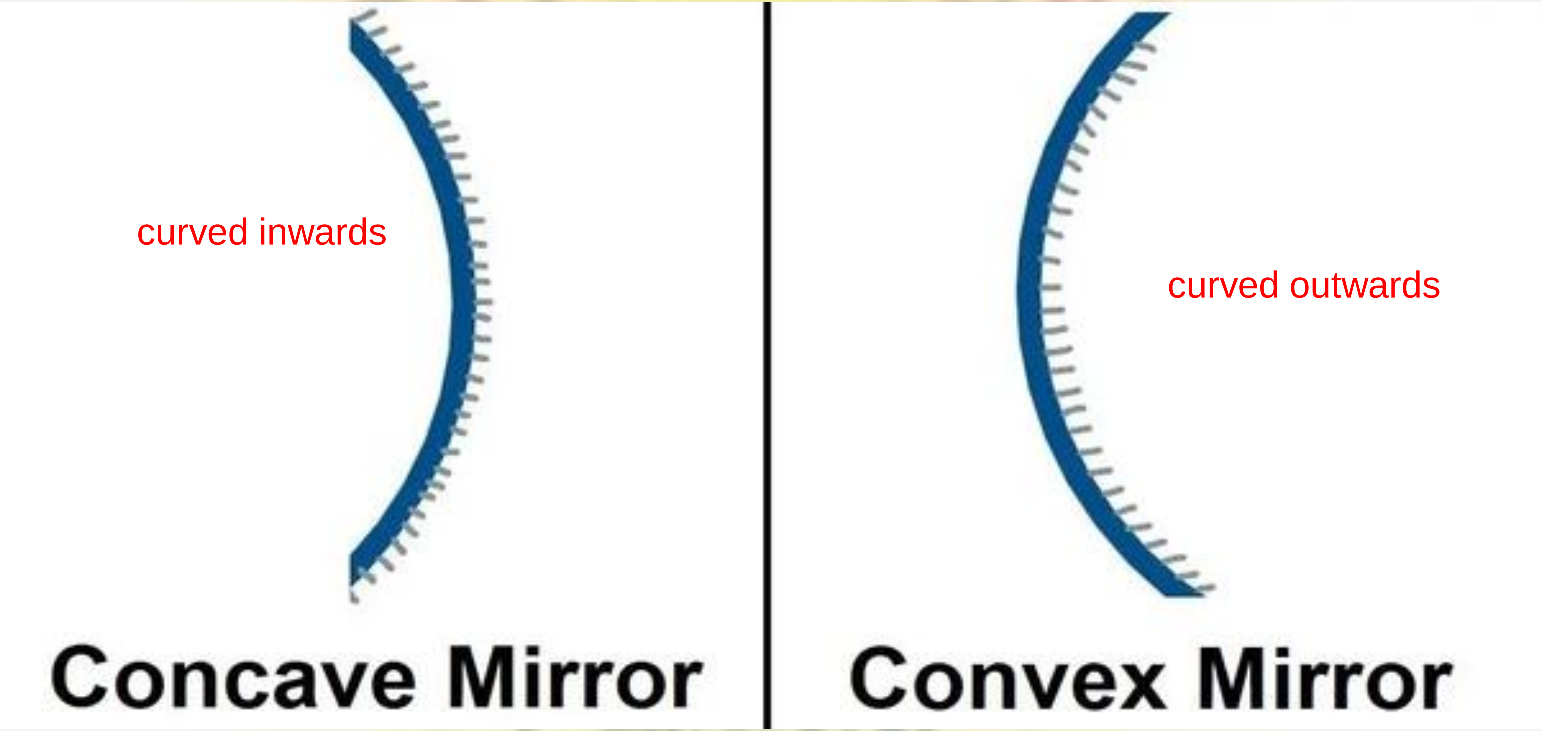
Image by a Plane Mirror

- Image formed by a plane mirror is always virtual and erect.
- The size of the image is equal to that of the object.
- The image formed is as far behind the mirror as the object is in front of it.
- The image is laterally inverted.

Note: number of images formed by two inclined mirror is given by, n = 360/angle between mirrors

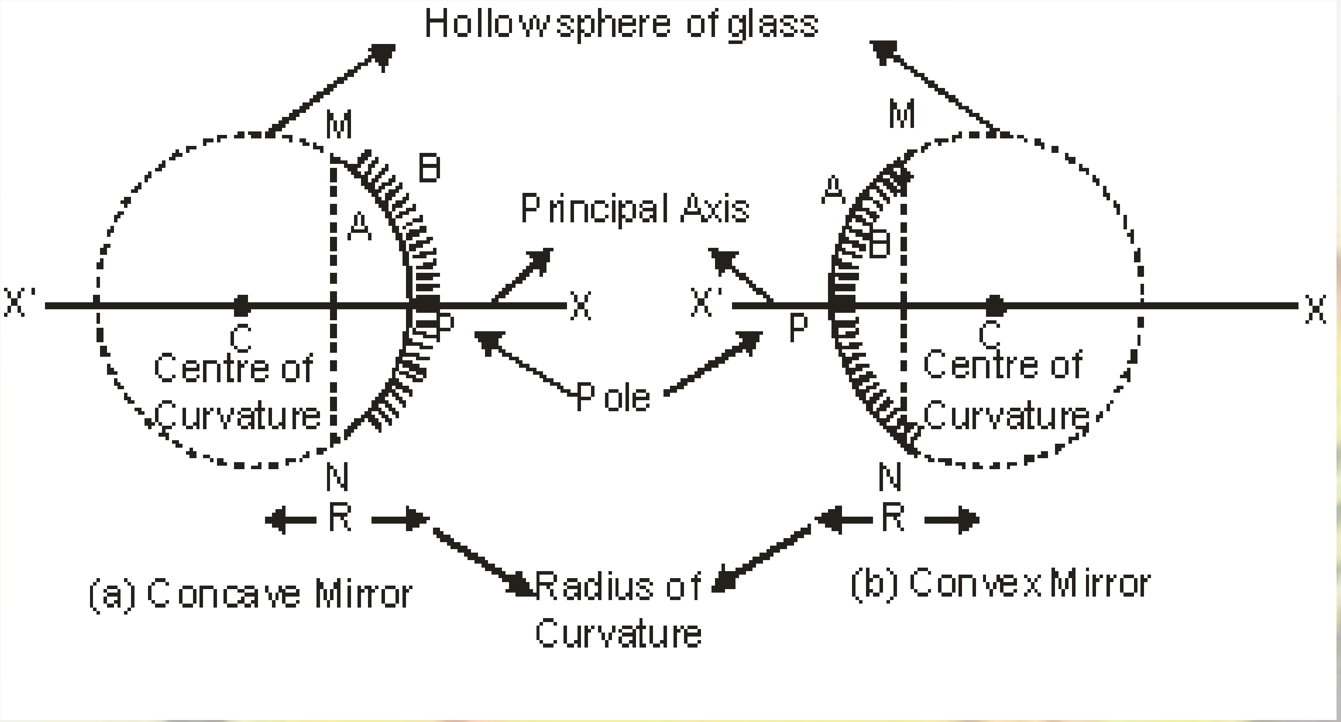
Spherical Mirrors

- Concave mirror - A spherical mirror, whose reflecting surface is curved inwards, that is, faces towards the centre of the sphere.
- Convex mirror – A spherical mirror, whose reflecting surface is curved outwards, that is faces away from the centre of the sphere.


curved inwards
curved outwards
Concave Mirror
Convex Mirror

Few terms to remember

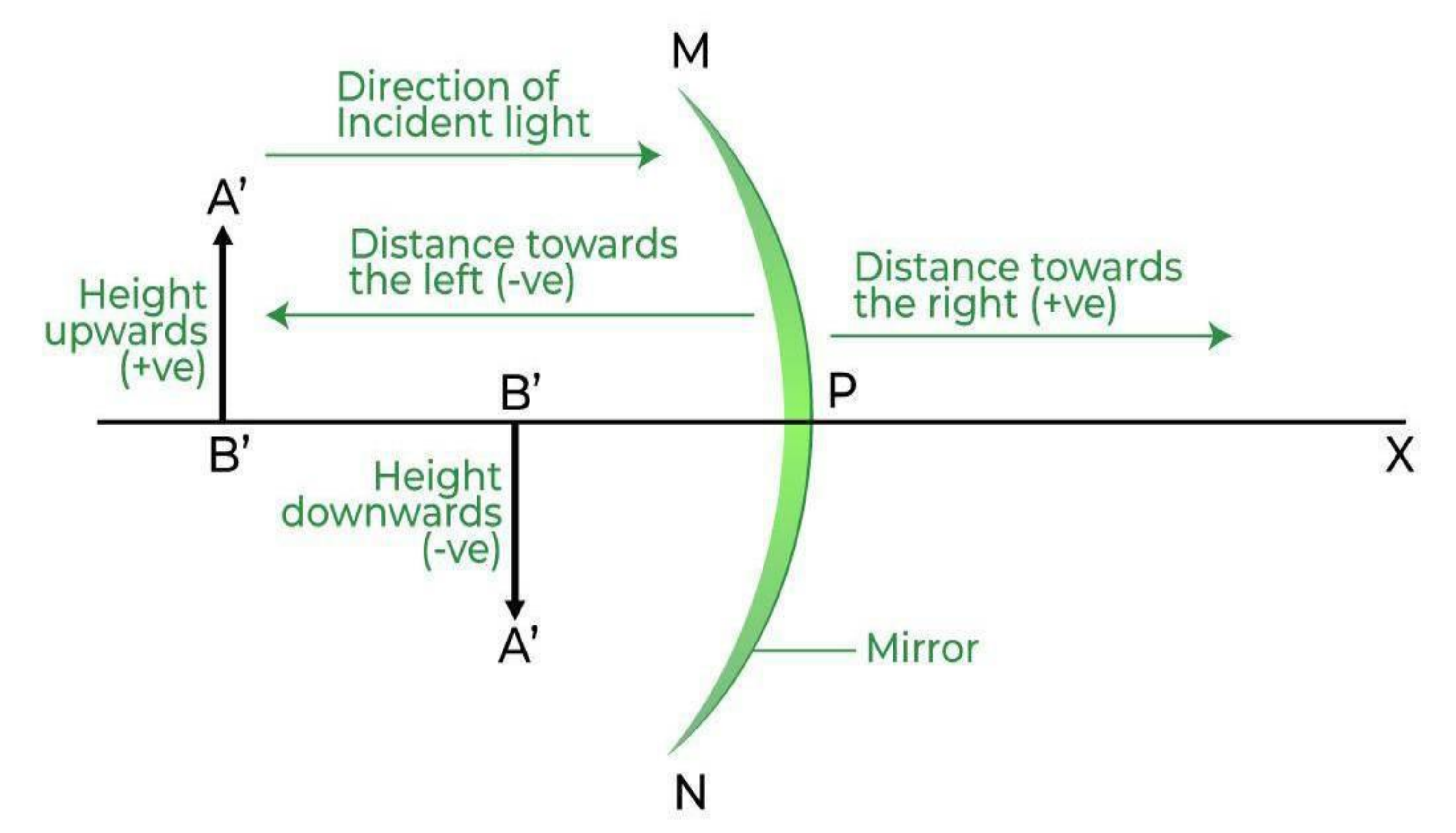
- Centre of the reflecting surface of a spherical mirror is called the pole, denoted by P.
- The reflecting surface of a spherical mirror forms a part of a sphere and has a centre called the centre of curvature, denoted by C.
- The radius of the sphere of which the reflecting surface of a spherical mirror forms a part, is called the radius of curvature, denoted by R
- A point on the spherical mirror's principal axis where parallel light rays intersect (meet) or emerge to deviate after reflection, is called the focus, denoted by F.



Distance between pole and the focus is called the Focal length, f.

Relation between R and f; R=2f or f=R/2

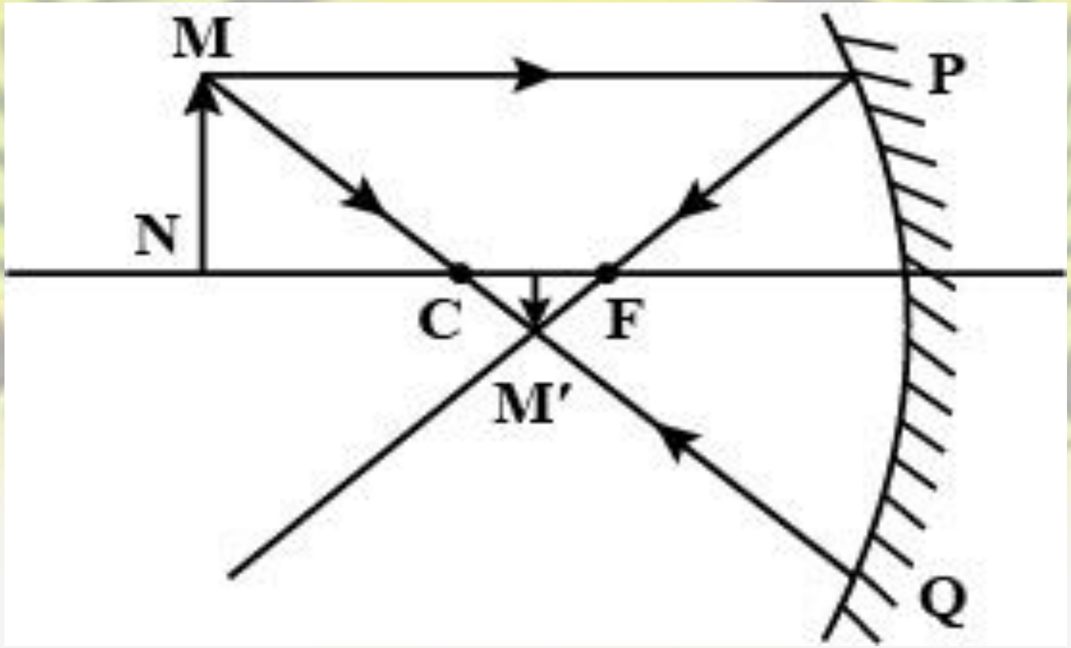
Sign Convention for reflection by Spherical mirror



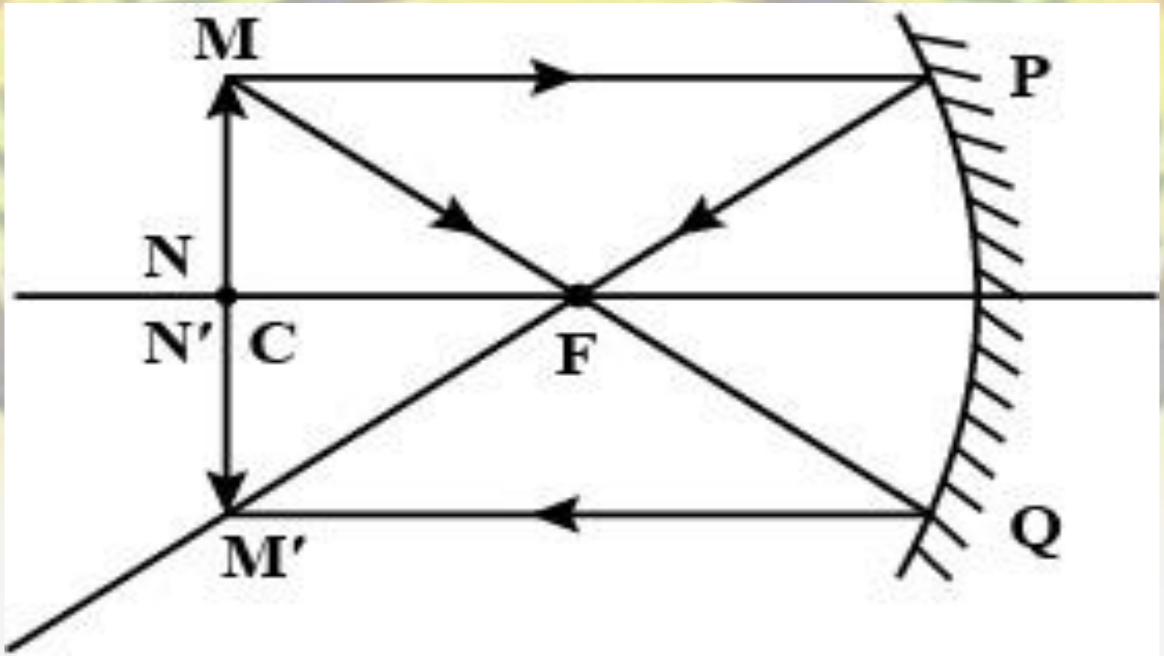
Representation of image formation by concave mirror using ray diagram

- When object is at infinity, the image is formed at the principal focus and the image formed is highly diminished, point sized, real and inverted.

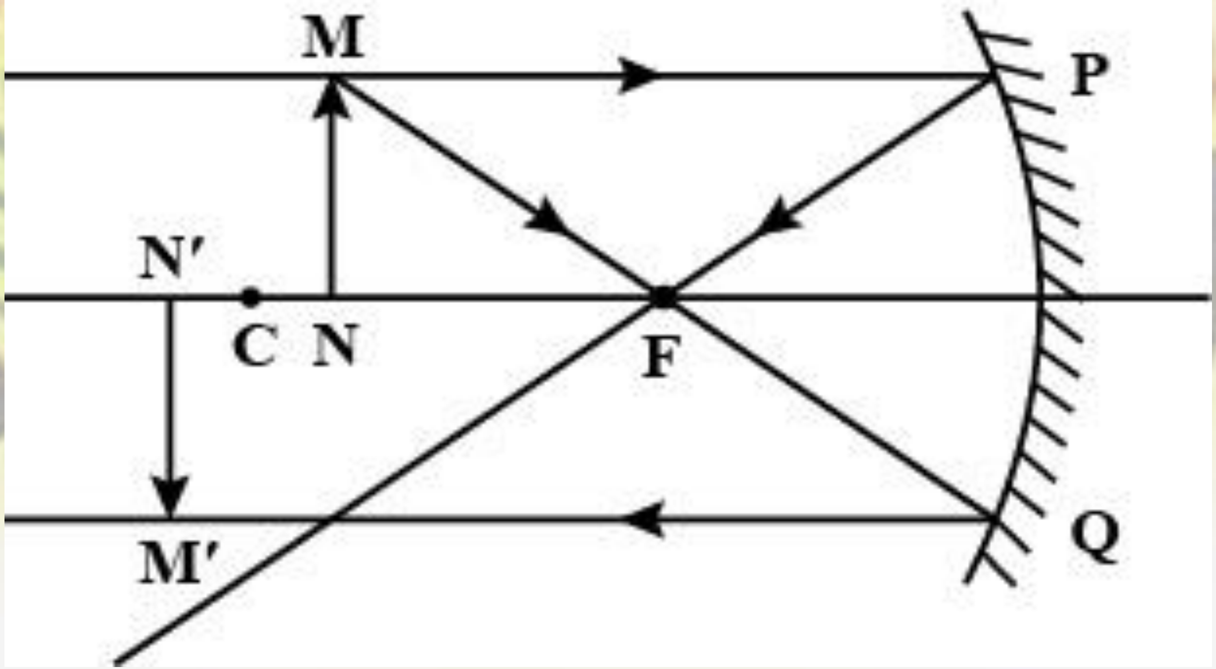
- When object is placed between infinity and C, the image is formed between focus F and centre of curvature C, and the image formed is diminished, real and inverted.



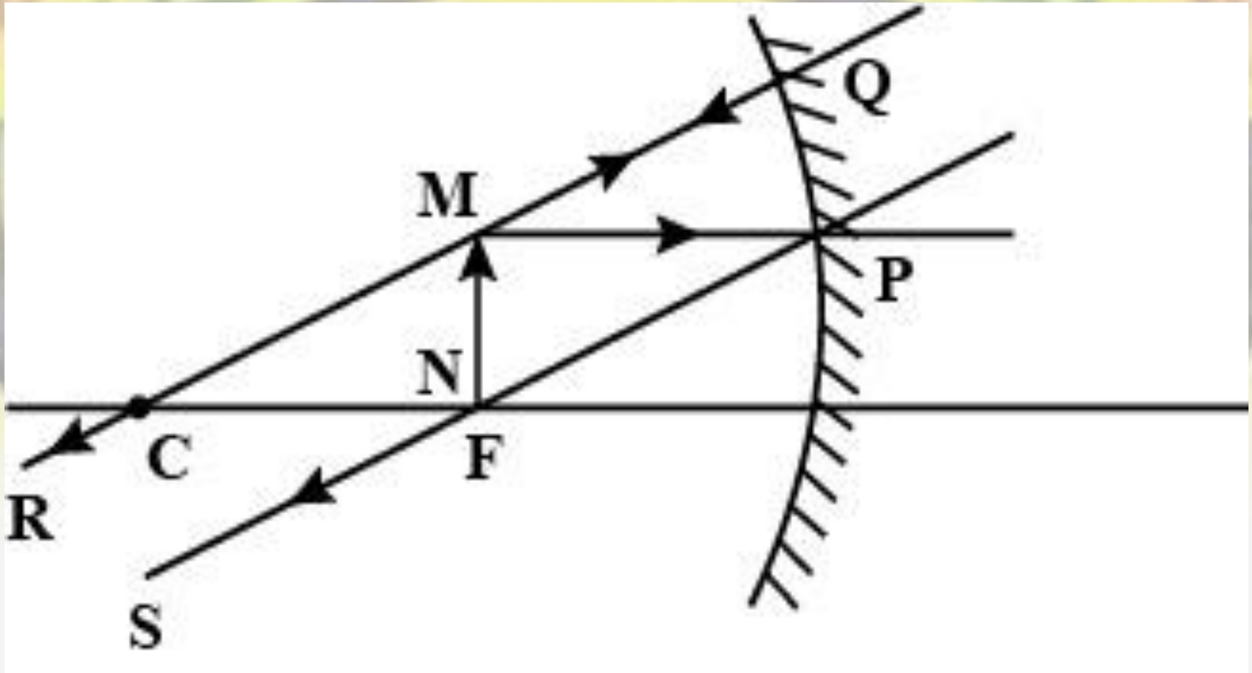
- When object is placed at the centre of curvature C, then the image is also formed at C, and the image is of the same size, real and inverted.



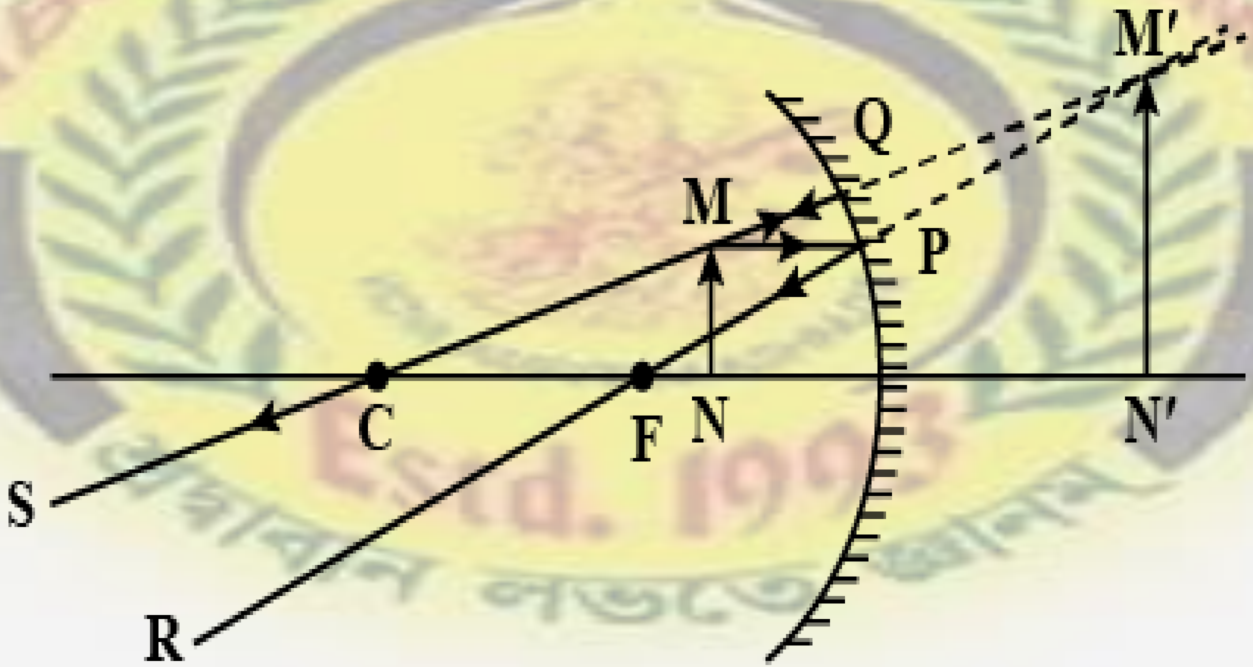
- When the object is placed between C and F, then the image is formed beyond C, and the image formed is enlarged, real and inverted.



- When the object is at F, then the image is formed at infinity, and the image formed is highly enlarged, real and inverted.



- When the image is between P and F, then the image is formed behind the mirror, and it is enlarged and virtual and erect.



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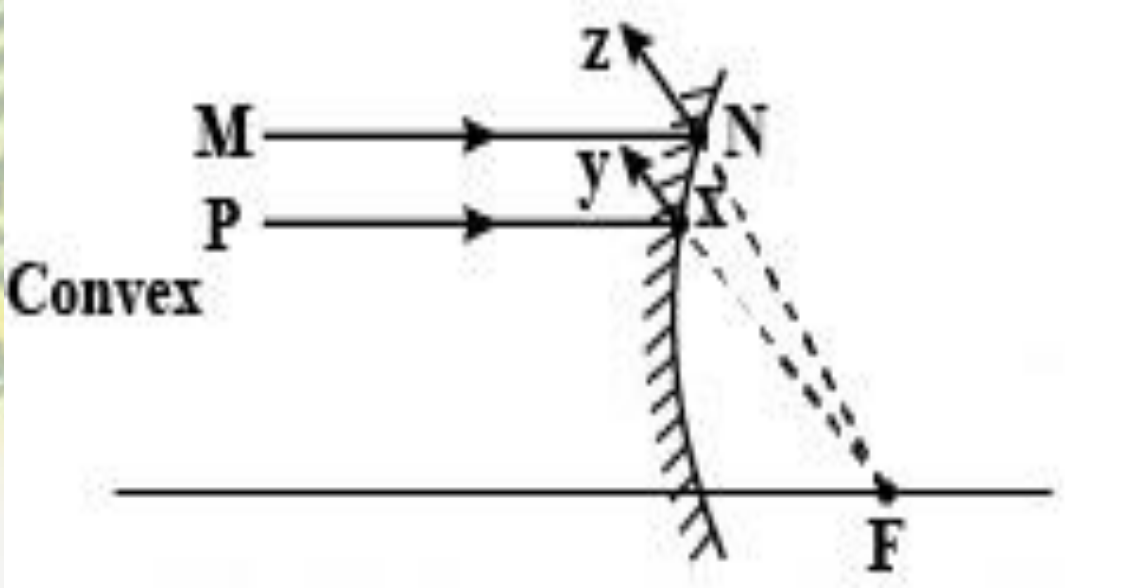
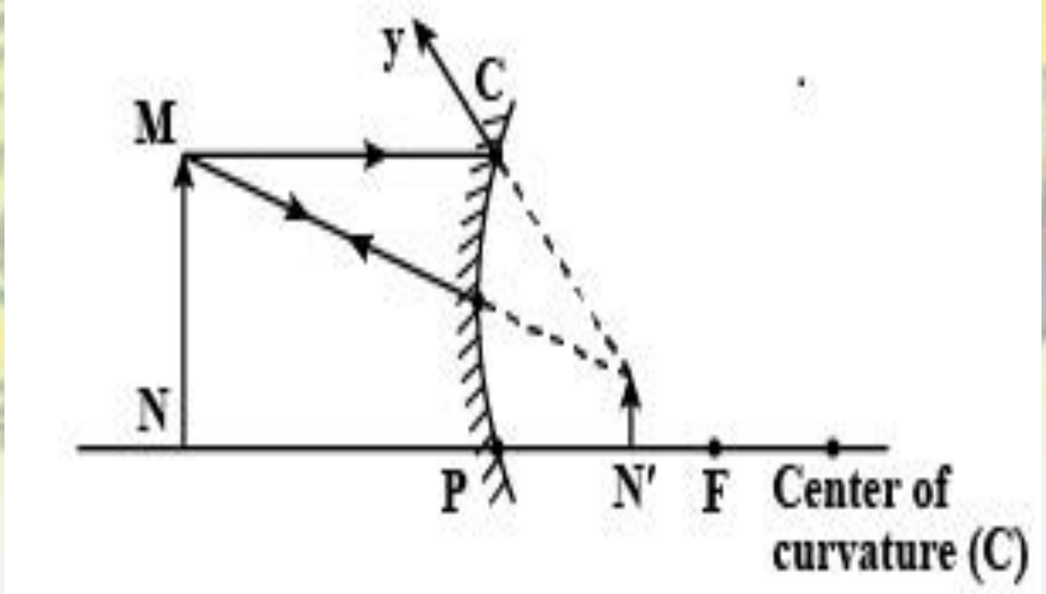
Representation of image formation by convex mirror using ray diagram

- When object is placed at infinity, then the image is formed at the focus, behind the mirror, and the image is highly diminished, point sized, real and inverted.



- When the object is placed between infinity and the pole of mirror, then the image is formed between P and F, behind the mirror, and the image is diminished, virtual and erect.



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Tabular representation of image formed by Concave and Convex mirror

Lens Type	Position of Real Object	Position of Image	Nature of Image	Size of Image
Concave	At infinity	At focus F	Real Inverted	Highly Diminished, point sized
Concave	Beyond C	Between F and C	Real Inverted	Diminished
Concave	At C	At C	Real Inverted	Same size
Concave	Between C and F	Beyond C	Real Inverted	Enlarged
Concave	At F	At infinity	Real Inverted	Highly enlarged
Concave	Between P and F	Behind the mirror	Virtual erect	Enlarged
Convex	At infinity	At focus F, behind mirror	Virtual erect	Highly Diminished, point sized
Convex	Between infinity and pole P	Between P and F, behind the mirror	Virtual erect	Diminished

Mirror formula

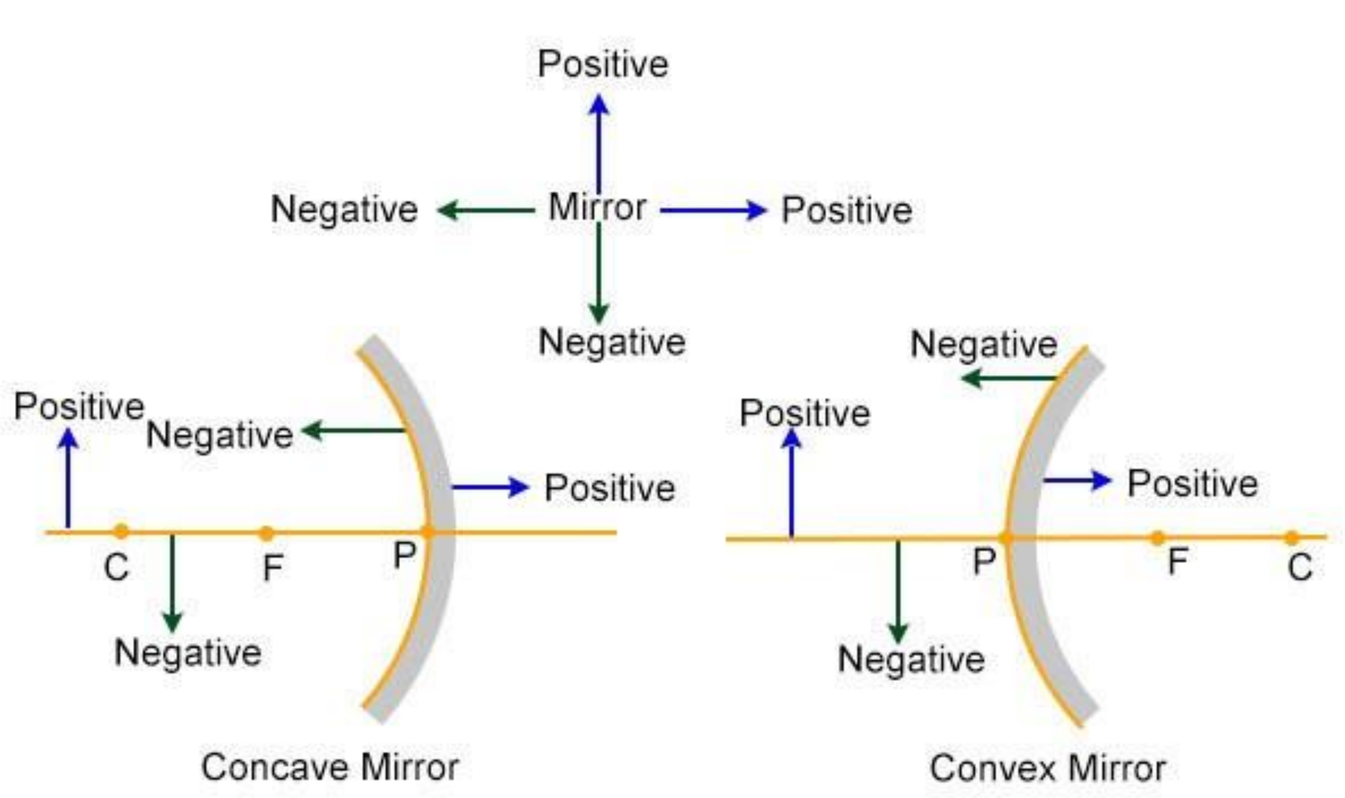
- Mirror formula is applicable for both concave and convex mirror -

$$1/v + 1/u = 1/f$$

where:

- f is the focal length of the mirror.
- v is the image distance (distance of the image from the mirror).
- u is the object distance (distance of the object from the mirror).

Sign conventions for mirror formula



Magnification formula for mirrors

- The relative extent to which the image of an object is magnified with respect to the object size, also expressed as the ratio of the height of the image (h') to the height of the object (h).
- The magnification m is also related to the object distance (u) and image distance (v).

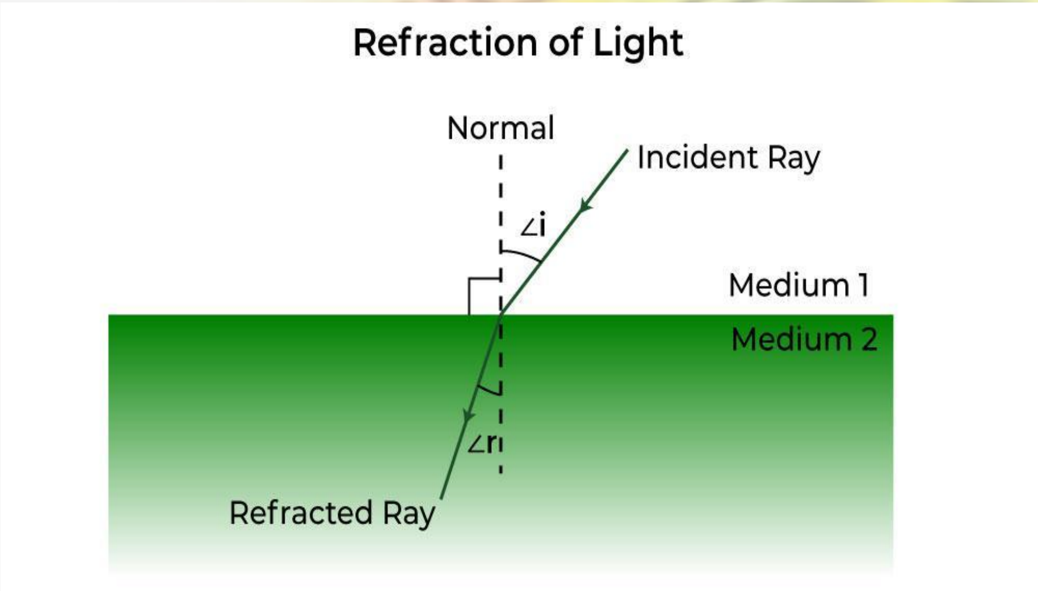
$$\text{Magnification } (m) = h'/h = -v/u$$

Note: The negative sign in the formula indicates the inversion (upright or inverted) of the image.

Refraction of Light

- A phenomenon where light waves change direction as they pass from one transparent medium to another, resulting in a change in the speed of light, such that the change in speed causes the light to bend.

- The basic principles of refraction can be summarized as :
  - **Bending Toward the Normal:** When light passes from a lesser dense medium to a highly dense medium, it slows down and bends toward the normal.
  - **Bending Away from the Normal:** Conversely, when light passes from a highly dense medium to a lesser dense medium, it speeds up and bends away from the normal.


Refraction of Light
Normal
Incident Ray
∠i
Medium 1
Medium 2
∠r
Refracted Ray

Laws of Refraction

- The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane.
- 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 for the given pair of media. This law is also known as Snell's law of refraction. (This is true for angle $0 < i < 90^{o}$)

$$\sin i / \sin r = n \text{ (constant)}$$

here, i = angle of incidence

r = angle of refraction

Refractive index

- It is a measure of how much a substance can bend or refract light.
- Defined as the ratio of the speed of light in a vacuum to the speed of light in the material.

$$n_m = \text{speed of light in air or vacuum/ speed of light in the medium} = c/v$$

where:

- n_m is the refractive index of the medium,
- c is the speed of light in a vacuum or air (approx $3 \times 10^8\ ms^{-1}$),
- v is the speed of light in the material.

Let, v_1 be the speed of light in medium 1 and v_2 be the speed of light in medium 2. Then, refractive index of medium 2 w.r.t refractive index of medium 1 is given as :

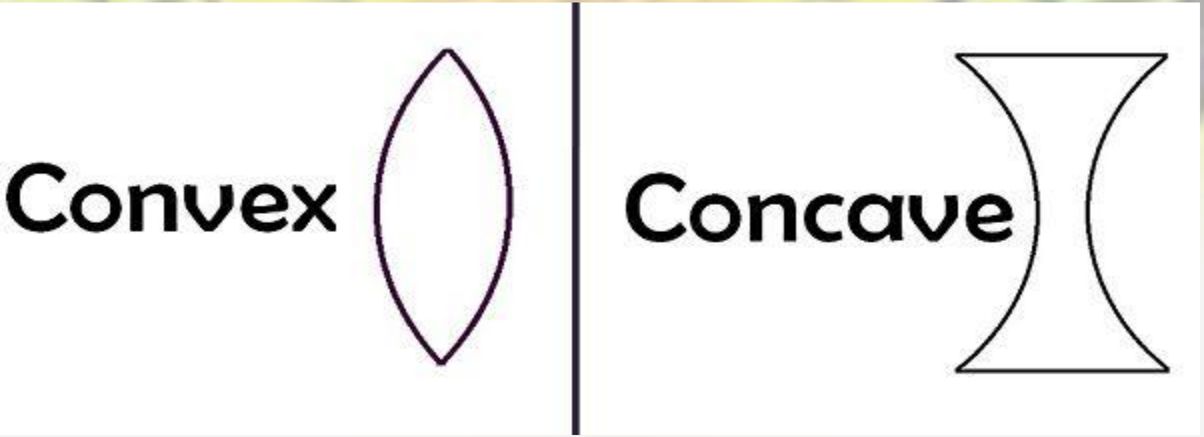
$$n_{21} = v_1/v_2$$

Also, the refractive index of medium 1 w.r.t refractive index of medium 2 is given as :

$$n_{12} = v_2/v_1$$

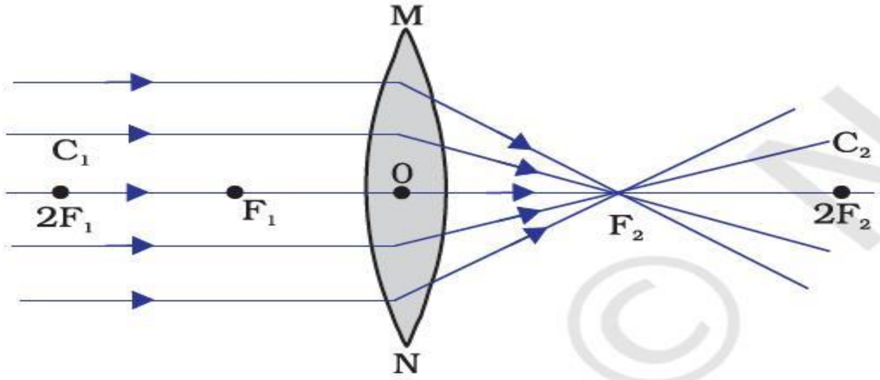
Spherical lenses

- Concave lens - also known as a diverging lens because it causes parallel rays of light to spread out or diverge after passing through it, characterized by its curved inward surfaces on both sides.
- Convex lens - Also known as a converging lens because they cause parallel rays of light to converge or come together after passing through the lens, characterized by its curved outward surfaces on both sides.

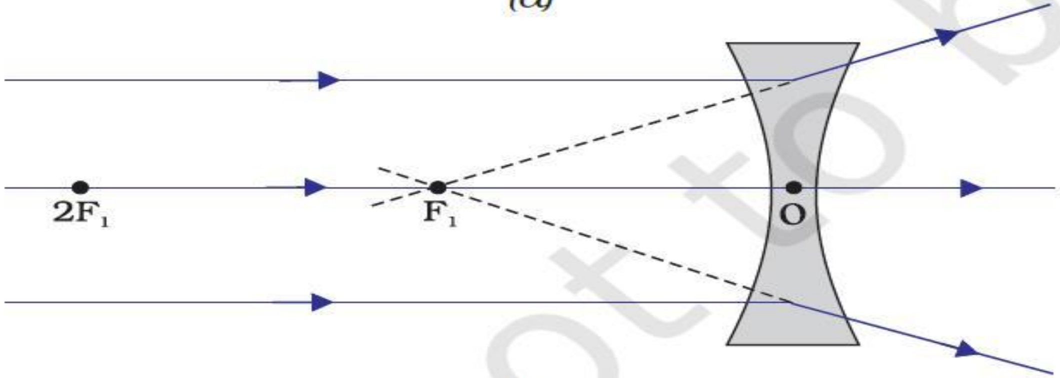


Lenses have two focus, why??

- The existence of two focal points is a result of the way lenses bend and refract light.
- Both convex and concave lenses can have a real focus, where actual light converges, and a virtual focus, where light appears to diverge or converge when extended backward.
- Refraction can occur from both the refracting surface of lens.



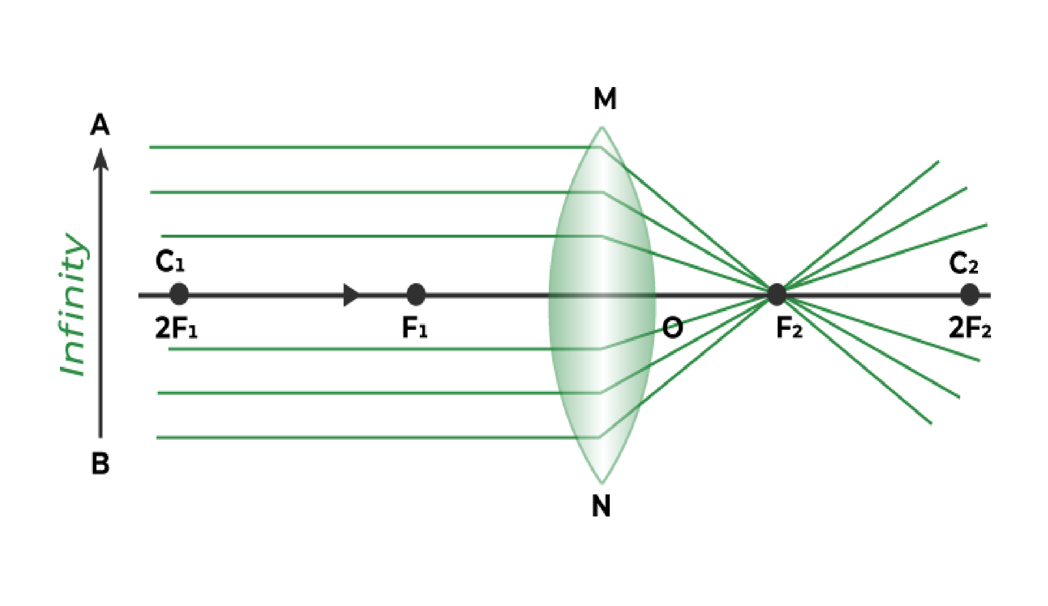
(a)



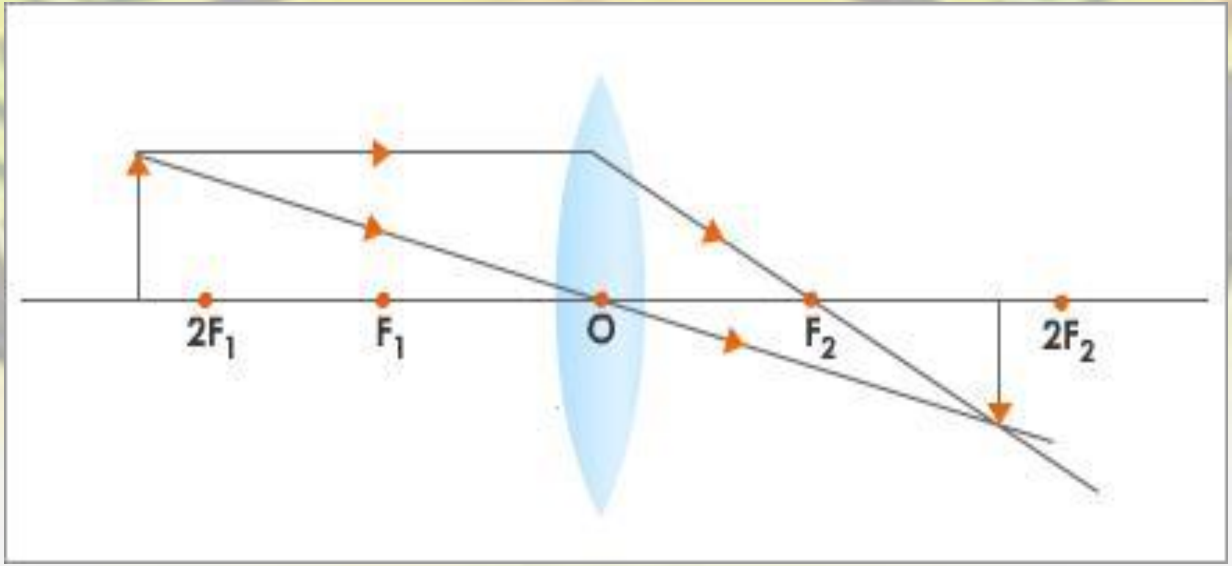
(b)

Image formation by Convex lens

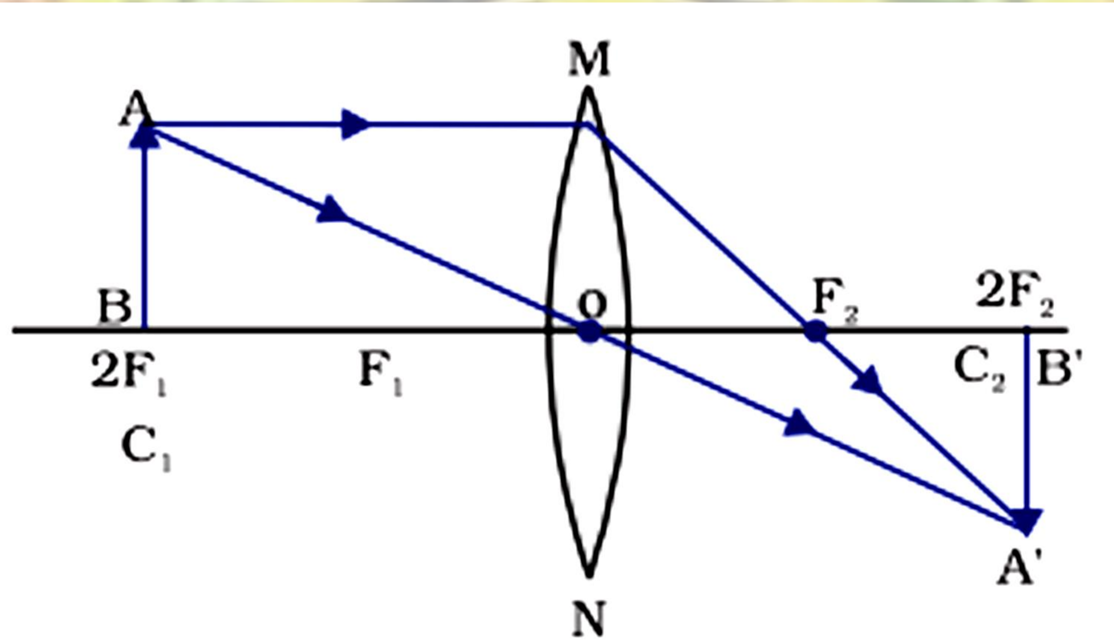
- When object is placed at infinity, the image is formed at focus F_2, and the image formed is highly diminished, point sized, real and inverted.



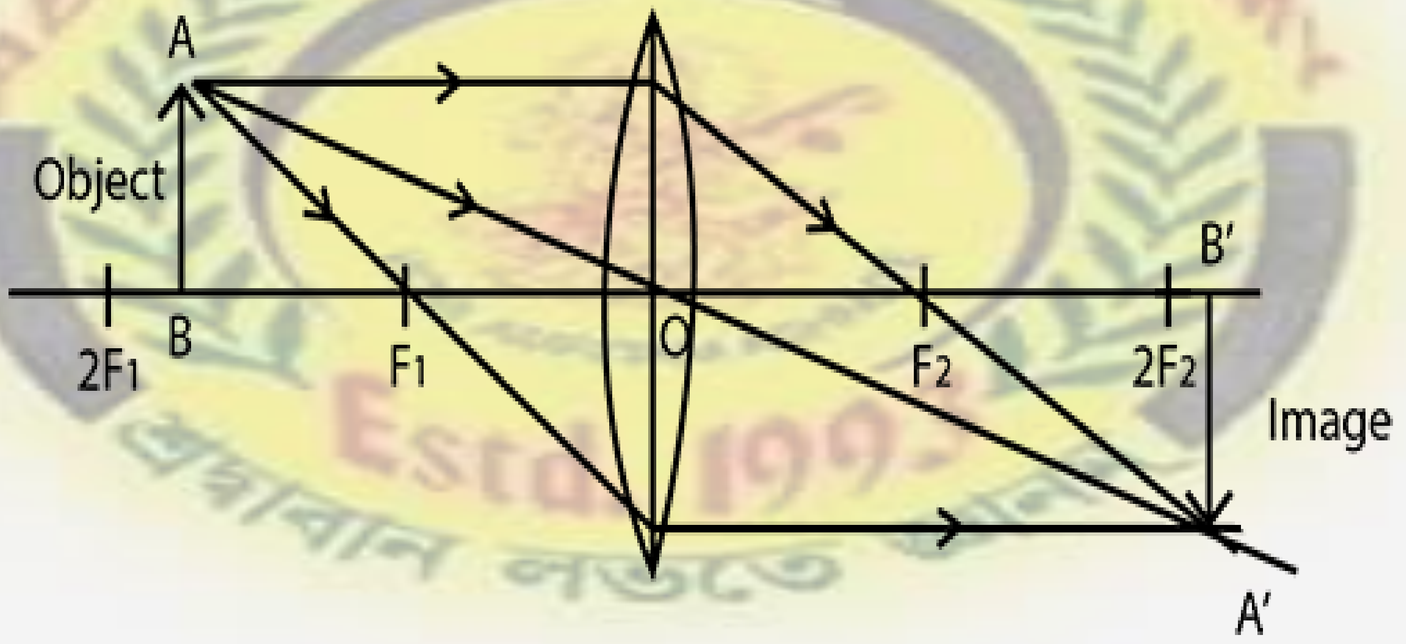
- When the image is placed beyond $2F_1$ or at the centre of curvature C, then the image is formed between F_2 and $2F_2$, and the image is diminished, real and inverted.



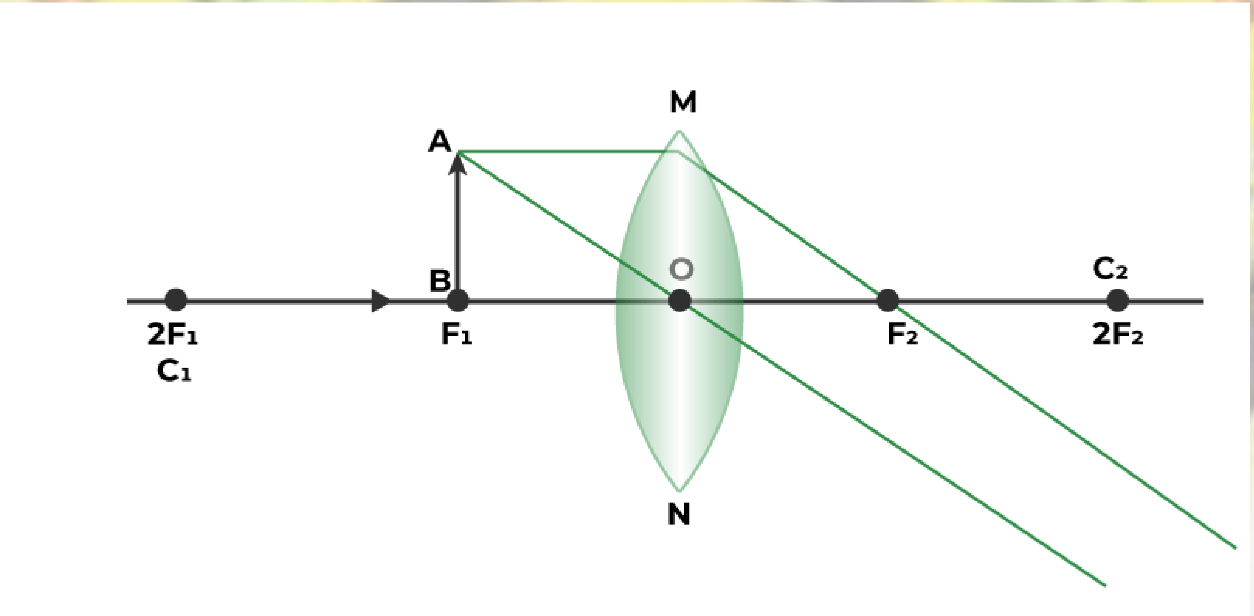
- When the image is placed at $2F_1$, then the image is formed at $2F_2$, and the image formed is of same size as the object, real and inverted



- When the object is placed between F_1 and $2F_1$, the image is formed beyond $2F_2$ and it is enlarged, real and inverted.



- When the object is placed at focus F_1, the image is formed at infinity, and it is infinitely large, real and inverted.



- When the object is placed between F_1 and the optical centre O, the image is formed on the same side of the lens as the object and it is enlarged, virtual and erect.

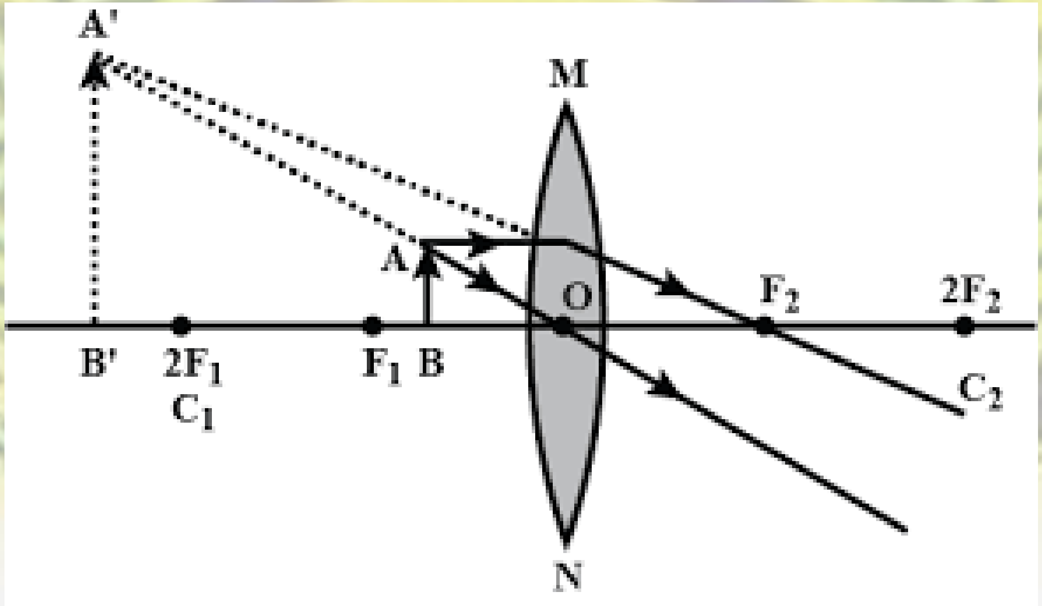
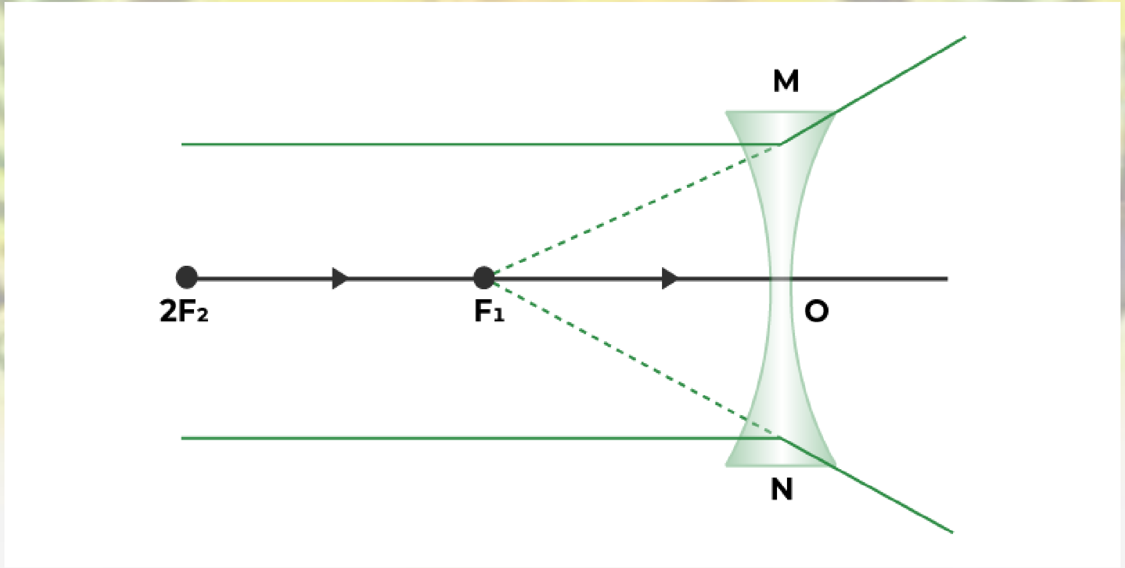
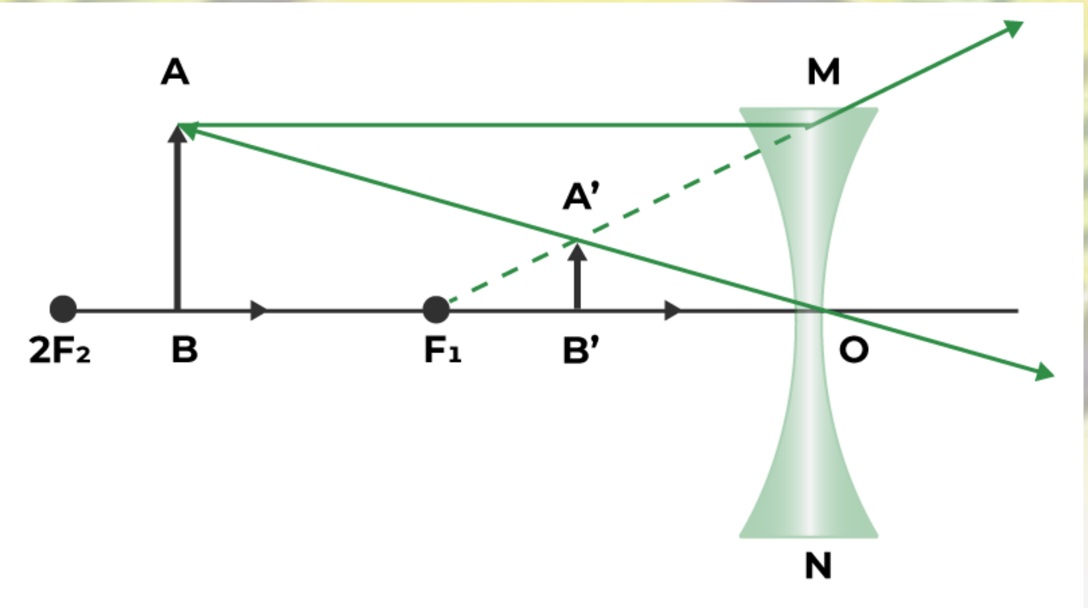


Image formation by Concave lens

- When the object is placed at infinity, the image is formed at focus F_1 and the image is highly diminished, point sized, virtual and erect.



- When the image is placed between infinity and the optical centre O, the image is formed between focus F_1 and the optical centre O and the image is diminished and virtual and erect.



Nature of lens	Position of object	Position of image	Size of image	Nature of image
Convex	At infinity	At F_2	Highly diminished	Real and inverted
Convex	Beyond $2F_1$	Between F_2 and $2F_2$	Diminished	Real and inverted
Convex	At $2F_1$	At $2F_2$	Same size	Real and inverted
Convex	Between F_1 and $2F_1$	Beyond $2F_2$	Enlarged	Real and inverted
Convex	At F_1	At infinity	Infinitely large	Real and inverted
Convex	Between F_1 and O	Same side of the lens as the object	Enlarged	Virtual and erect
Concave	At infinity	At focus F_1	Highly diminished	Virtual and erect
Concave	Between infinity and O	Between F_1 and O	Diminished	Virtual and erect

Lens formula

- This formula gives the relationship between objectdistance (u), image-distance (v) and the focal length (f) –

$$1/v - 1/u = 1/f$$

Where:

- *f* is the focal length of the lens,
- *v* is the image distance (distance of the image from the lens),
- *u* is the object distance (distance of the object from the lens).

Note: the lens formula will also follow the same sign convention which was earlier studied for the mirrors.

Magnification formula for lens

- Magnification produced by a lens, similar to that for spherical mirrors, is defined as the ratio of the height of the image (h’) and the height of the object (h).
- Denoted by ‘m’, it is also defined as the ratio of the image distance (v) to the object distance (u).

$$\text{magnification } (m) = h'/h = v/u$$

Power of lens

- It is a measure of its ability to converge or diverge light and is defined as the reciprocal of its focal length.

$$P = 1/f$$

where:

  - *P* is the power of the lens,
  - *f* is the focal length of the lens.

- The unit of power is the diopter (D), and it is equal to the reciprocal of the focal length measured in meters. $1D = 1m^{-1}$
- Also the power of a lens is independent of the size or shape of the lens and depends only on its focal length.
- Power of a convex lens is positive and that of a concave lens is negative.

- A convex mirror used for rear-view on an automobile has a radius of curvature of 3.00 m. If a bus is located at 5.00 m from this mirror, find the position, nature and size of the image.
- An object, 4.0 cm in size, is placed at 25.0 cm in front of a concave mirror of focal length 15.0 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Find the nature and the size of the image.
- A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens? Also, find the magnification produced by the lens.
- A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens? Also, find the magnification produced by the lens.

- A doctor has prescribed a corrective lens of power +1.5 D. Find the focal length of the lens. Is the prescribed lens diverging or converging?
- Find the focal length of a lens of power – 2.0 D. What type of lens is this?
- The magnification produced by a plane mirror is +1. What does this mean?
- One-half of a convex lens is covered with a black paper. Will this lens produce a complete image of the object?
- Which of the following lenses would you prefer to use while reading small letters found in a dictionary?
    - A convex lens of focal length 50 cm.
    - A concave lens of focal length 50 cm.
    - A convex lens of focal length 5 cm.
    - A concave lens of focal length 5 cm.