Introduction

This is a learning as well as an exam preparation video.

At the end of the video are practice assignments for you to attempt.

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Chapter 9: Ray Optics And Optical Instruments

Chapter 9: Ray Optics and Optical Instruments

Ray Optics or Geometrical Optics:

In this optics, the light is considered as a ray which travels in a straight line. It states that for each and every object, there is an image.

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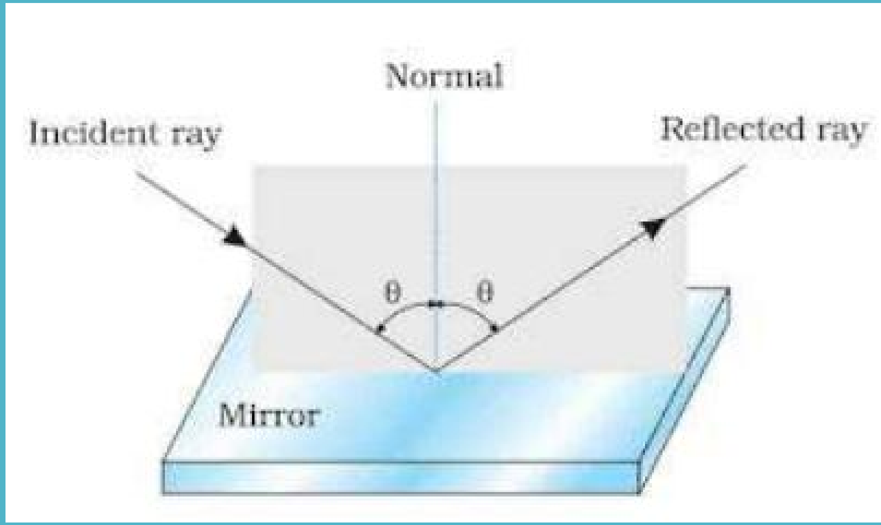
Reflection of Light:

The phenomenon in which a light ray is sent back into the same medium from which it is coming, on interaction with a boundary, is called reflection. The boundary can be a rigid surface or just an interface between two media.



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Law of reflection:

The angle of reflection equals the angle of incidence $\angle i = \angle r$.

The incident ray reflected ray and the normal to the reflecting surface at the point of incidence lie in the same plane.

Formation of Image by the Plane Mirror:

The formation of image of a point object O by a plane mirror is represented in figure.

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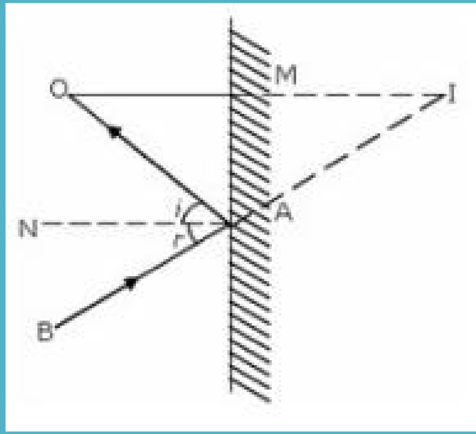
Law of reflection:



The image formed I has the following characteristics:

- The size of image is equal to the size of object.
- The object distance = Image distance i.e., OM = MI.
- The image is virtual and erect.
- When a mirror is rotated through a certain angle, the reflected ray is rotated through twice this angle.

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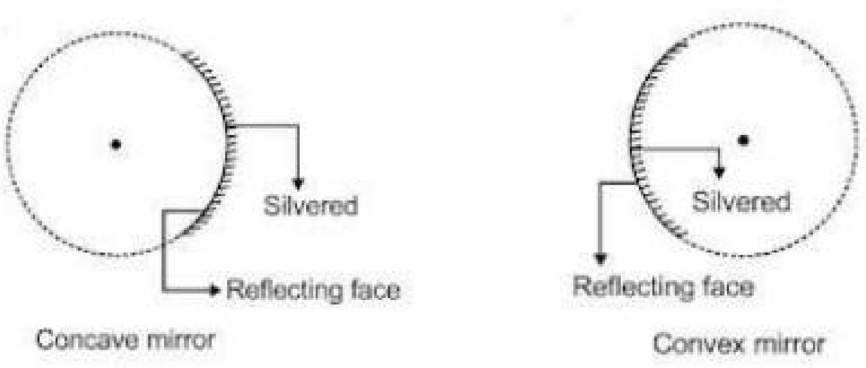
Spherical Mirrors:

A spherical mirror is a part of sphere. If one of the surfaces is silvered, the other surface acts as the reflecting surface. When convex face is silvered, and the reflecting surface is concave, the mirror is called a concave mirror. When its concave face is silvered and convex face is the reflecting face, the mirror is called a convex mirror.



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Spherical Mirrors:

- Centre of curvature: Centre of curvature is the center of sphere of which, the mirror is a part.
- Radius of curvature: Radius of curvature is the radius of sphere of which, the mirror is a part.
- Pole of mirror: Pole is the geometric center of the mirror.
- Principal axis: Principal axis is the line passing through the pole and center of curvature.
- Normal: Any line joining the mirror to its center of curvature is normal.

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Spherical Mirrors:

Reflection of Light from Spherical Mirror:

1. A spherical mirror is a part cut from a hollow sphere.
2. They are generally constructed from glass.
3. The reflection at spherical mirror also takes place in accordance with the laws of reflection.

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Refraction of light:

Refraction is the bending of a wave when it passes from one medium to another. The bending is caused due to the differences in density between the two substances.

“Refraction is the change in the direction of a wave passing from one medium to another.”

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Laws of Refraction:

Two laws of refraction are given as below:

The incident ray, refracted ray and the normal to the refracting surface at the point of incidence lie in the same plane.

The ratio of the sine of the angle of incidence to the sine of the angle of refraction is constant for the two-given media. This constant is denoted by n and is called the relative refractive index.

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Laws of Refraction:

$$n = \frac{\sin i}{\sin r} \text{ (snell's law)}$$

where, n is refractive index of the second medium when first medium is air.

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Sign Convention:

Following sign conventions are the new cartesian sign convention:

- All distances are measured from the pole of the mirror & the distances measured in the direction of the incident light is taken as positive. In other words, the distances measured toward the right of the origin are positive.
- The distance measured against the direction of the incident light are taken as negative. In other words, the distances measured towards the left of origin are taken as negative.

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Sign Convention:

- The distance measured in the upward direction, perpendicular to the principal axis of the mirror, are taken as positive & the distances measured in the downward direction are taken as negative.

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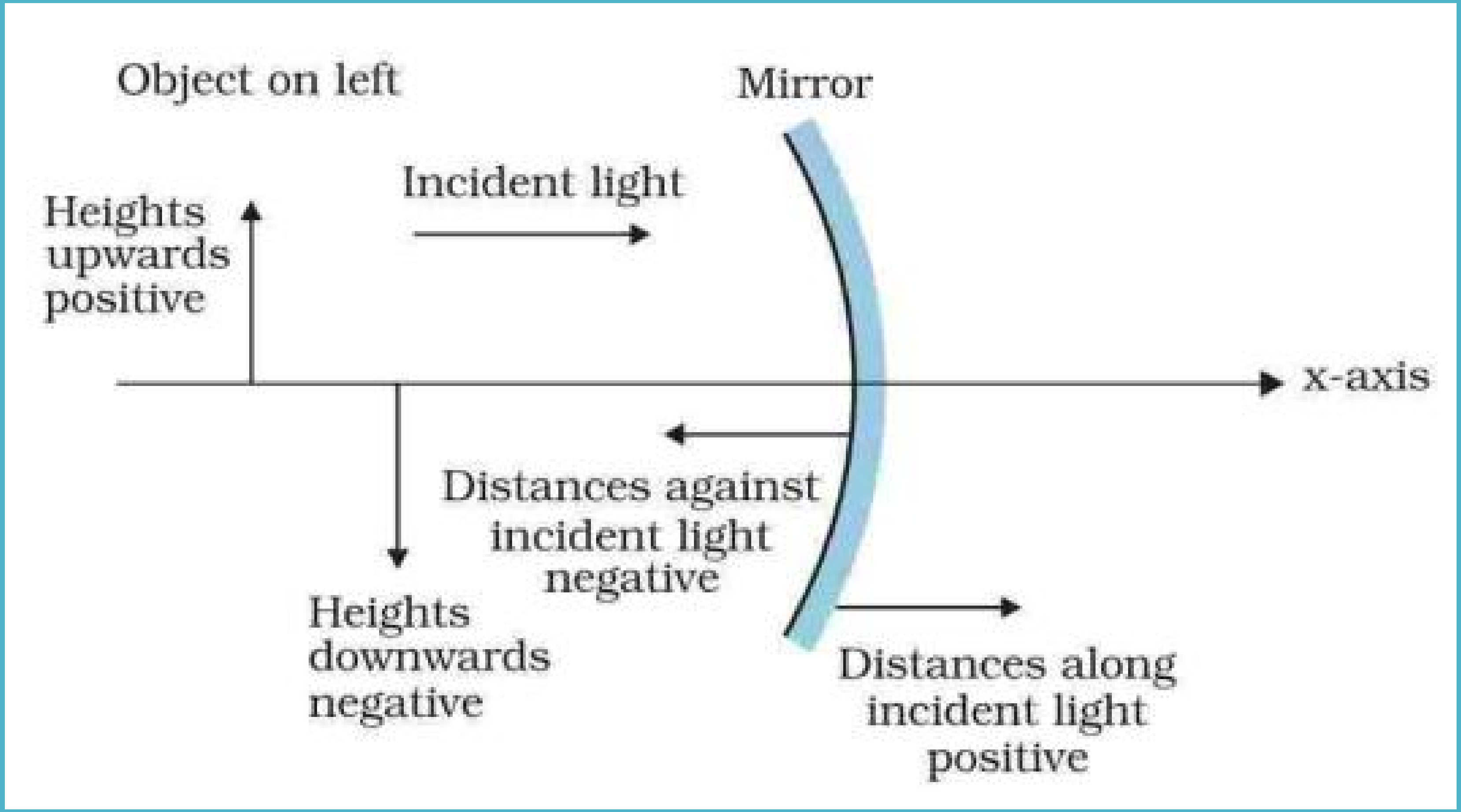
Sign Convention:



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Focal Length of Spherical Mirrors:

When a parallel beam of light is incident on a concave mirror, and a convex mirror. The rays are incident at points close to the pole P of the mirror and make small angles with the principal axis. The reflected rays converge at a point F on the principal axis of a concave mirror. For a convex

mirror, the reflected rays appear to diverge from a point F on its principal axis.

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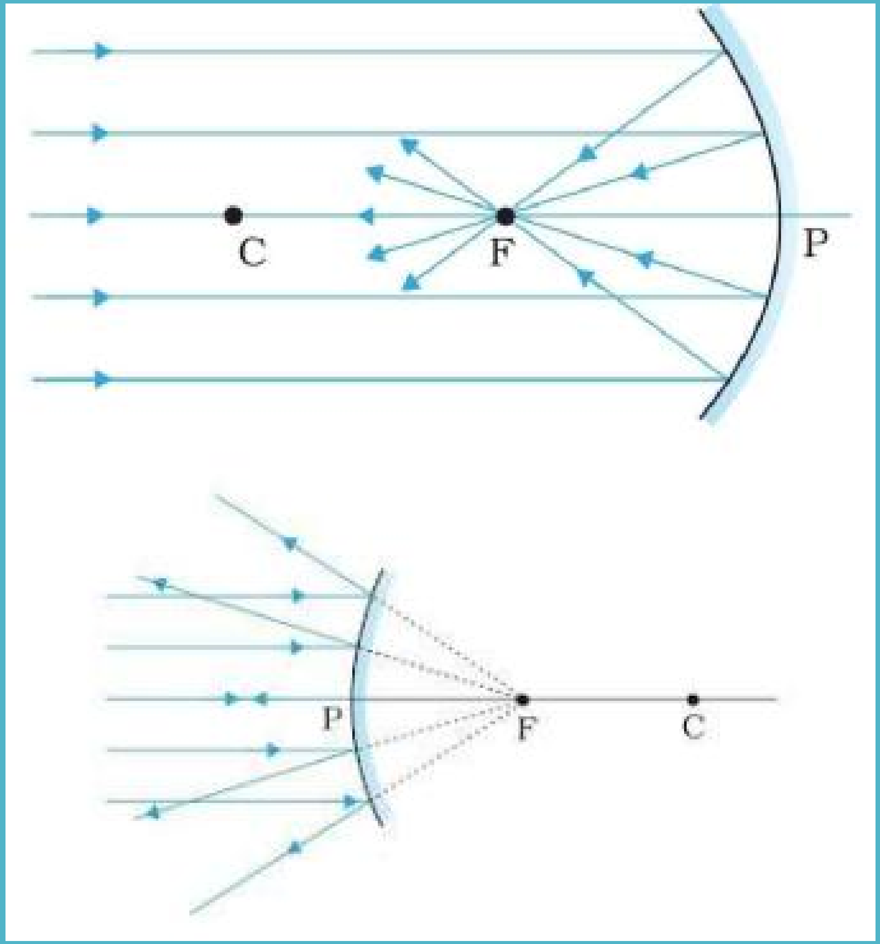
Focal Length of Spherical Mirrors:



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Focal Length of Spherical Mirrors:

The point F is called the principal focus of the mirror. The distance between the focus F and the pole P of the mirror is called the focal length of the mirror, denoted by f.

If, R be the radius of curvature of the mirror then relation between R and f is given by

$$f = \frac{R}{2}$$

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Focal Length of Spherical Mirrors:

Principal Axis of the Mirror:

The straight line joining the pole and the centre of curvature of spherical mirror extended on both sides is called principal axis of the mirror.

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Focal Length of Spherical Mirrors:

Mirror Formula:

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$$

Where u = distance of the object from the pole of mirror

v = distance of the image from the pole of mirror

f = focal length of the mirror

$$f = \frac{R}{2}$$

Where R is the radius of curvature of the mirror.

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Lens:

Lens is a transparent medium bounded by two surfaces of which one or both surfaces are spherical.

Lens Formula:

Lens formula relates the distance of object from the lens with distance of image from the lens. It is given by.

$$\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$$

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Lens:

Where, u = object distance

v = image distance

f = focal length

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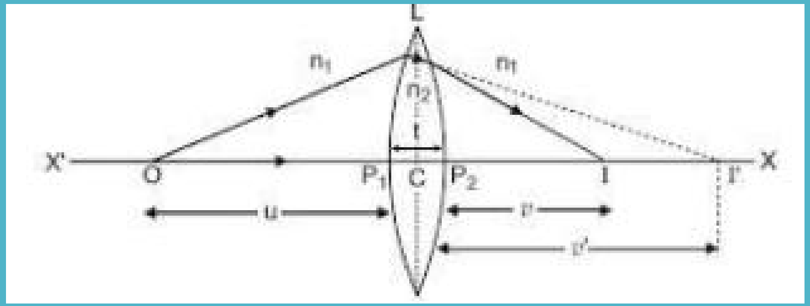
Lens Maker's Formula:

Lens Maker's formula gives the focal length of a lens in terms of the nature of the surfaces by which the lens is bounded and the nature of material of the lens.



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Lens Maker’s Formula:

Let us consider the situation shown in figure. C1 and C2 are the centers of curvature of two spherical surfaces of the thin lens. O is the object and I' is the image due to first refraction. Let radii of curvature be R1 and R2.

For the first refraction at image distance is v1. From the formula for refraction at a curved

surface, we get

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Lens Maker's Formula:

$$\frac{n_2}{v_1} = \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \quad \ldots .(i)$$

Final image position is I, which is also the image due to second refraction. Let this image distance be v. For the second refraction, v1 becomes the object distance. Hence we get,

$$\frac{n_1}{v} = \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2} \quad \ldots .(ii)$$

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Lens Maker's Formula:

$$\frac{n_1}{v} = \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2} \quad \ldots.(ii)$$

Adding (i) and (ii), we get

$$\left(\frac{n_1}{v} - \frac{n_1}{u}\right) = (n_2 - n_1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{v} - \frac{1}{u} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$\frac{1}{v} - \frac{1}{u} = (n - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

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Lens Maker's Formula:

According to the definition of the focal length f

$$\frac{1}{f} = (n-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

This is called the "Lens Maker's formula".

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Lens Maker's Formula:

Power of Lens:

The ability of a lens to converge or diverge the rays of light incident on it is called the power of the lens.

$$P = \frac{1}{f(\text{in m})}$$

SI unit of power lens = dioptre (D) = m-1

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Prism:

prism, in optics, piece of glass or other transparent material cut with precise angles and plane faces, useful for analyzing and reflecting light. An ordinary triangular prism can separate white light into its constituent colors, called a spectrum. Each color, or wavelength, making up the white light is bent, or refracted, a different amount; the shorter wavelengths (those toward the violet end of the spectrum) are bent the most, and the longer wavelengths (those toward the red end of the spectrum) are bent the least. Prisms of this kind are used in certain spectroscopes, instruments for analyzing light and for determining the identity and structure of materials that emit or absorb light.

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Prism:

Dispersion:

When white light is incident on a prism, different colors having different wavelengths suffer different deviations. The phenomenon of splitting of light into its component colors is known as dispersion. The pattern of color components of light (VIBGYOR) is called the spectrum of light. The deviation produced by a thin prism depends on the refractive index.

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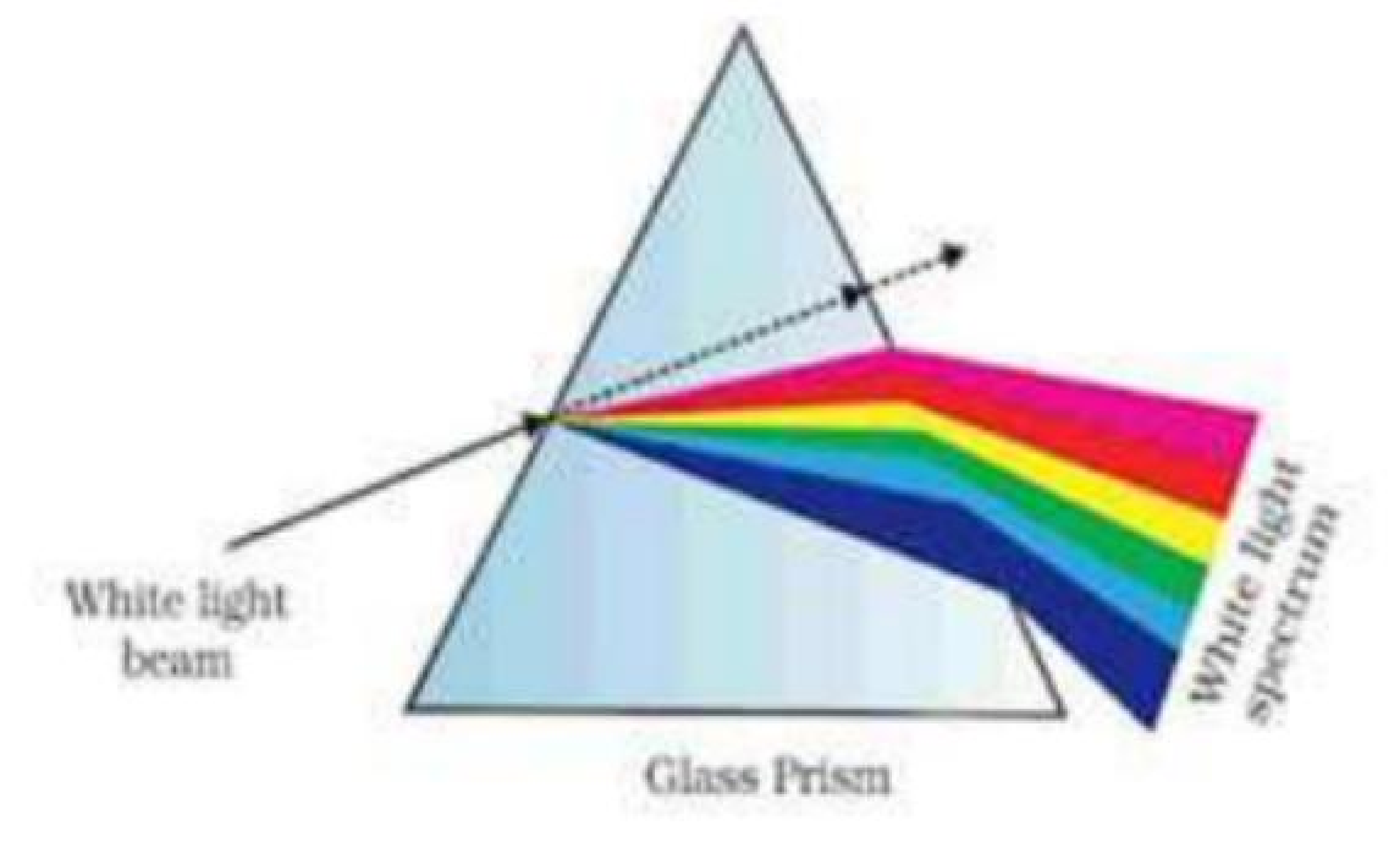
Prism:



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Prism:

Angular Dispersion: Angular dispersion produced by a prism for white light is the difference in

the angles of deviation for two extreme colors i.e., violet and red. It is given by.

$$\theta = \delta_V - \delta_R$$

$$\theta = (n_V - n_R)A$$

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Prism:

Dispersive Power: Dispersive power of a prism is defined as the ratio of angular dispersion to the mean deviation produced by the prism.

$$\omega = \frac{\delta_V - \delta_R}{\delta_Y}$$

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Optical Instruments:

Optical instruments are the devices which help human eye in observing highly magnified images

of tiny objects, for detailed examination and in observing very far objects whether terrestrial or

astronomical.

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Optical Instruments:

The Eye:

Light enters the eye through cornea a curved front surface. It passes through the pupil which is the central hole in the iris. The size of pupil can change under control of muscles. The light is further focused by the eye lens on the retina. The retina is a film of nerve fibers covering the curved black surface of the eye. The retina contains rods and cones which sense light intensity and color respectively and transmit electrical signals via the optic nerve to the brain.

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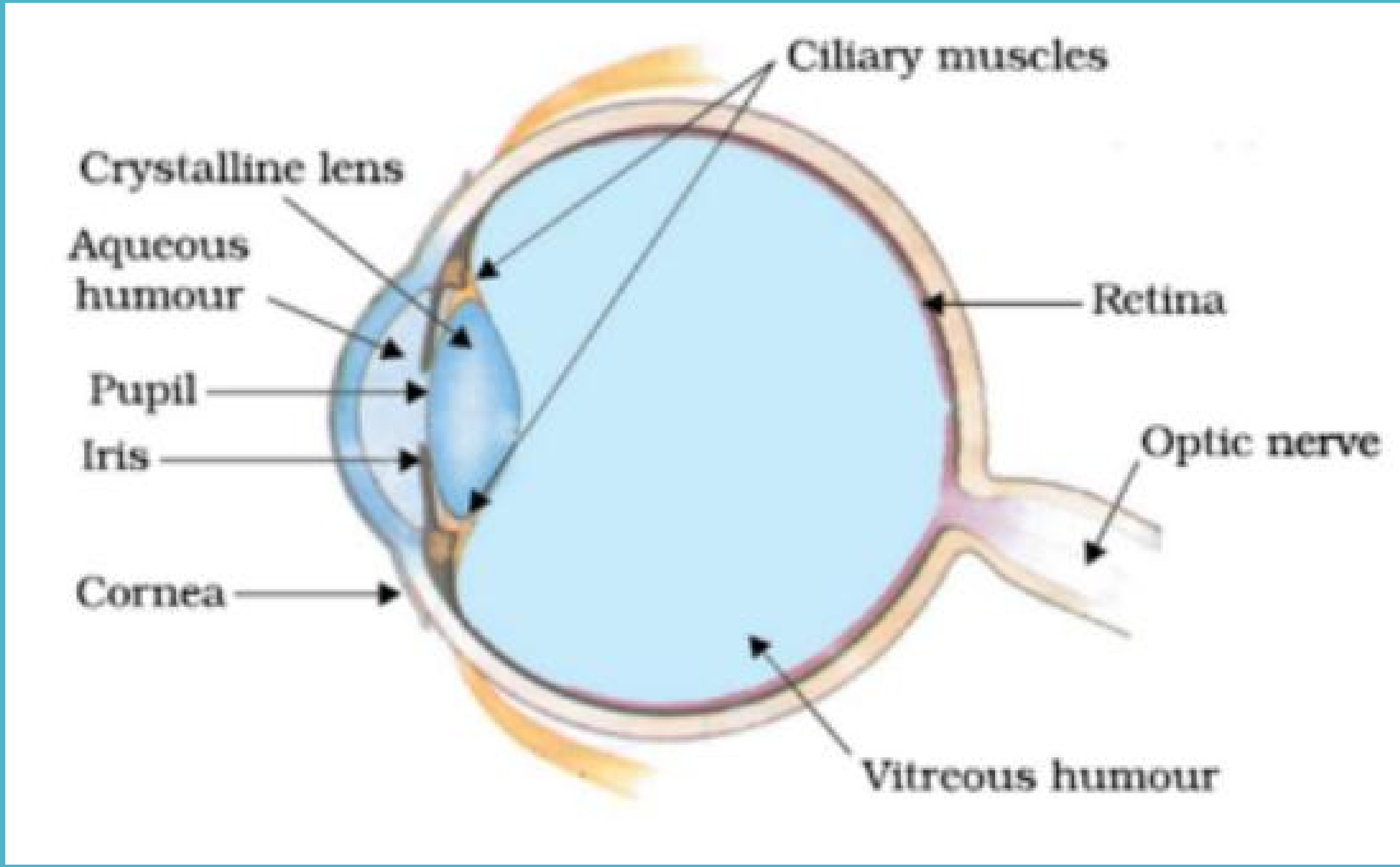
Optical Instruments:



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Optical Instruments:

The shape (curvature) and therefore the focal length of the lens can be modified somewhat by ciliary muscles. So, images are formed at the retina for objects at all distances. This property of the eye is called accommodation.

The closest distance for which the eye lens can focus light on the retina is called the least distance of distinct vision or the near point. The standard value for normal vision is taken as 25cm (Symbol D). If the object is too close to eye; the lens cannot curve enough to focus the image on the retina, and the image is blurred.

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Optical Instruments:

The microscope:

A simple magnifier or microscope is a converging lens of small focal length. The lens nearest the object, called the objective, forms a real, inverted, magnified image of the object. This serves as the object for the second lens, the eyepiece, which functions essentially like a simple microscope or magnifier, producing an enlarged virtual final image.

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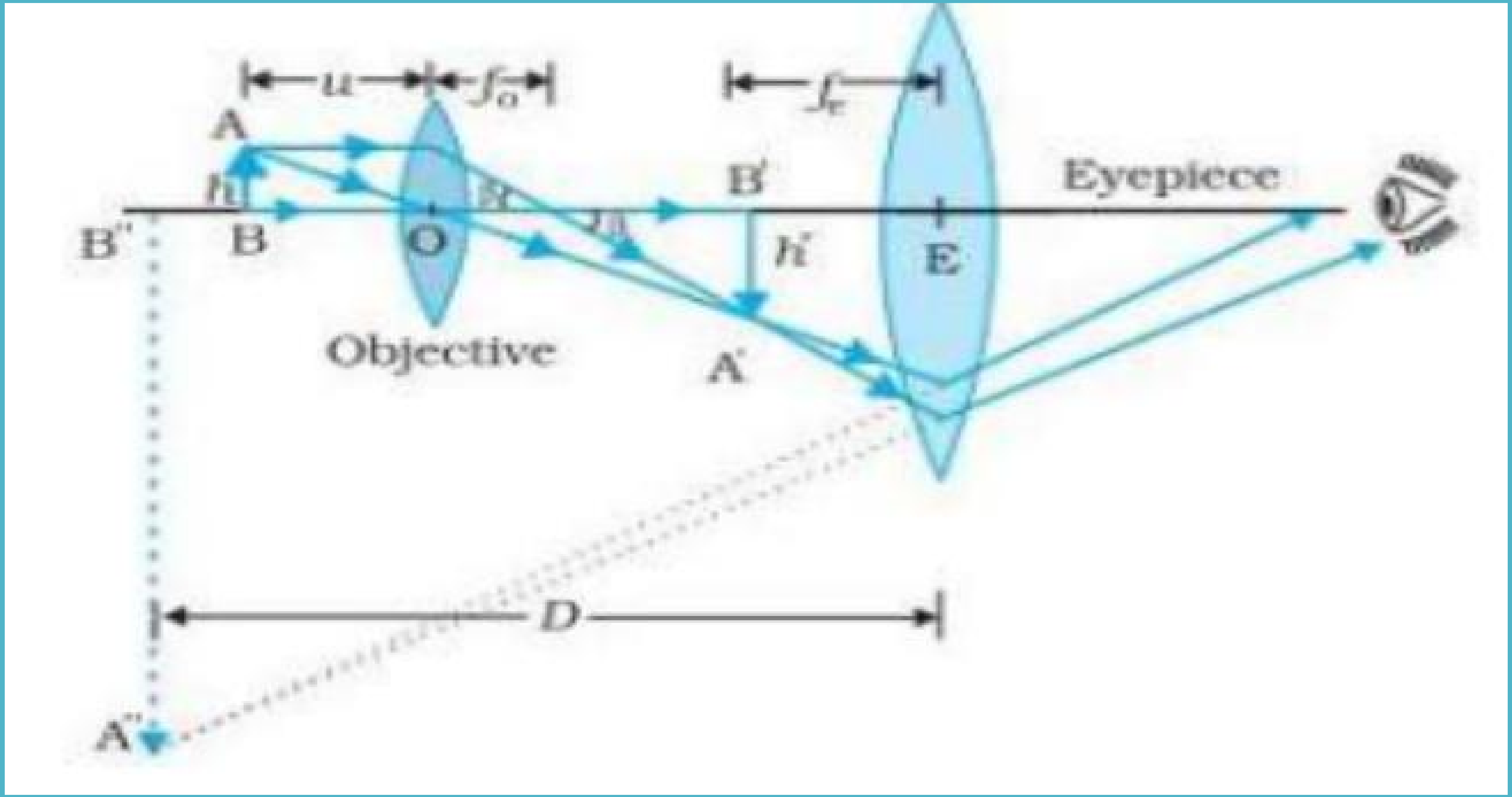
Optical Instruments:



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Optical Instruments:

The first inverted image is thus near (at or within) the focal point of the eyepiece, at a distance appropriate for final image formation at infinity, or a little closer for image formation at the near point. Clearly, the final image is inverted with respect to the original object.

Magnification power is given by

$$m = \frac{v_0}{u_0}\left[\frac{D}{v} + \frac{D}{f_e}\right]$$

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Optical Instruments:

Telescope:

This device is used to observe objects which are far away. However, a telescope has

an objective lens of large aperture and considerable focal length and eye lens that with a small

aperture and focal length.

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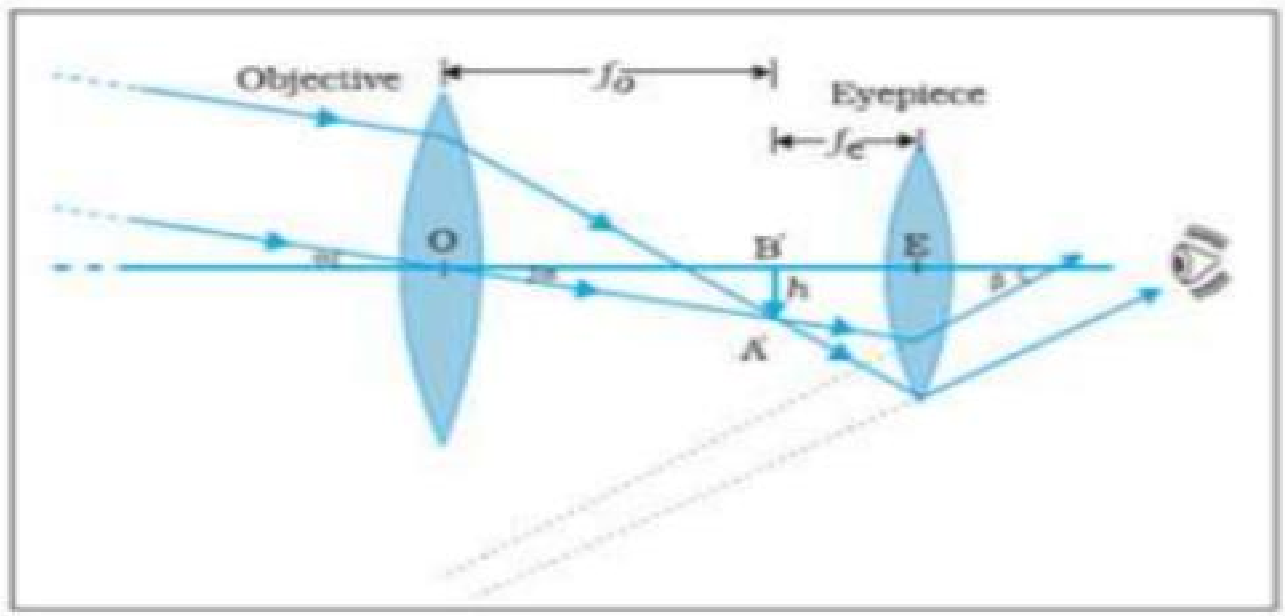
Optical Instruments:



Magnifying power is given by

$$m = -f_0\left[\frac{1}{f_e} + \frac{1}{v}\right]$$

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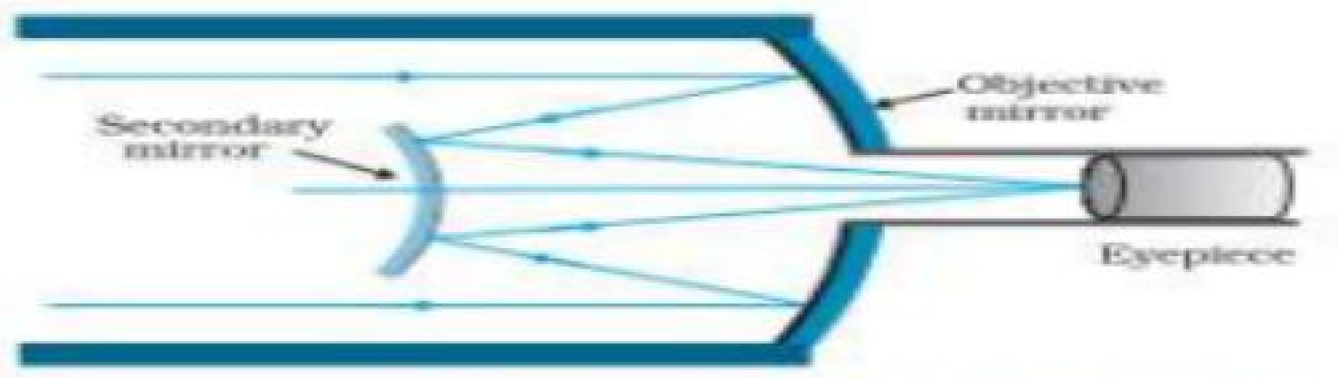
Optical Instruments:

Reflecting Telescope (Cassegrain telescope):

In such telescope, one objective lens is replaced by a concave parabolic mirror of large aperture, which is free from chromatic and spherical aberrations.



Schematic diagram of a reflecting telescope (Cassegrain).

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Optical Instruments:

In normal adjustment, magnifying power

$$m = \frac{f_0}{f_e} = \frac{\frac{R}{2}}{f_e}$$

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Optical Instruments:

Advantages of taking mirror objectives are:

- There is no chromatic aberration in a mirrors.
- If a parabolic reflecting surface is chosen, spherical aberration is also removed.
- Mechanical support is much less of a problem since a mirror weighs much less than a lens of equivalent optical quality and can be supported over.
- Entire back surface not just over rim unlike lens

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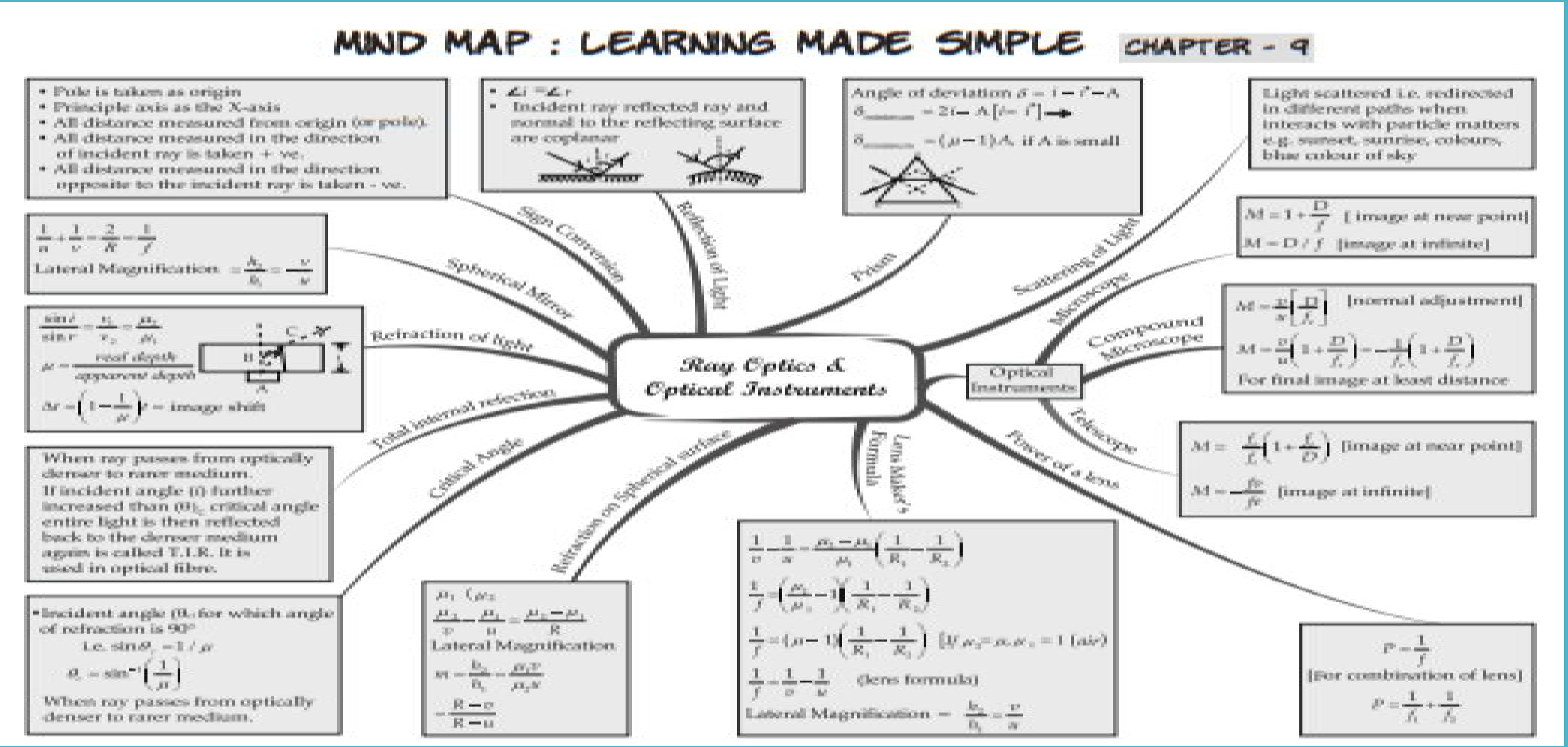

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