The two parts of optics on the basis of behaviour of light
Optics

Geometric or ray optics   Wave optics
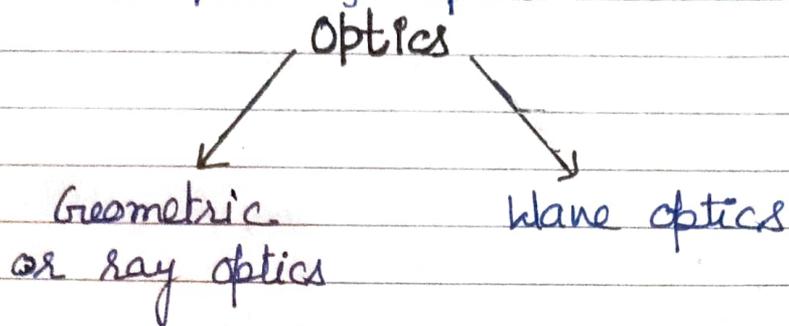
Ray Optics :   (*For the objects of large dimensions)

1. Electromagnetic radiation belonging to wavelength of about 400 nm to 750 nm is called light.

2. The speed of light is finite and measurable. In vacuum speed of light
$$c = 3 \times 10^8 \, m/s$$

3. Also $c = \dfrac{1}{\sqrt{\mu_0 \epsilon_0}}$

where $\mu_0 \rightarrow$ permeability of the free space.
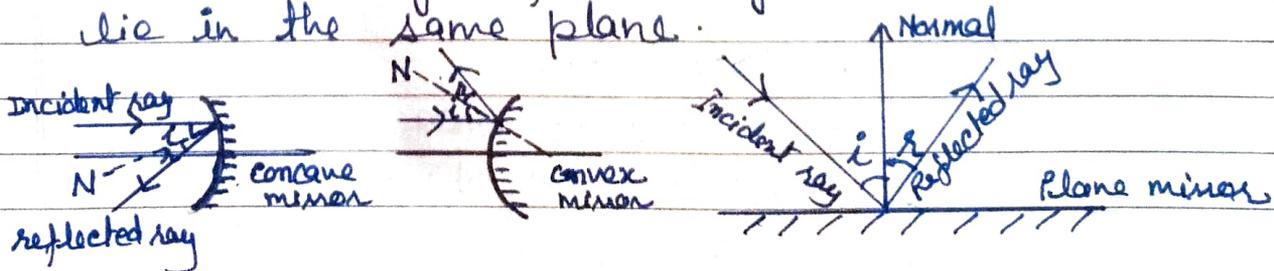$\epsilon_0 \rightarrow$ permittivity of free space.

4. Reflection of light — by plane mirrors.
— by spherical mirrors

Bouncing back of light from a smooth surface is called the reflection of light.
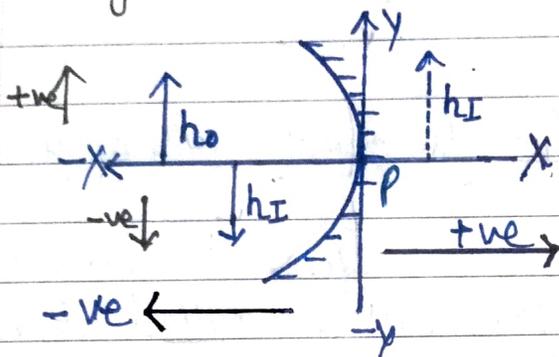
Laws of Reflection:

(I) $\angle i = \angle r$

(II) Incident ray, reflected ray and normal all three lie in the same plane.

Subject: Page No.

5. Reflection of light by spherical Mirrors
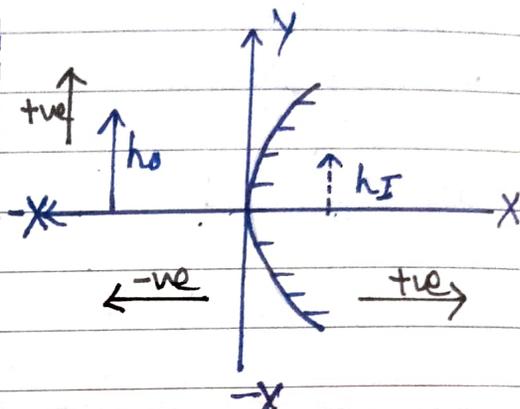
Mirrors — Concave mirror,
Mirrors — Convex mirror

Sign convention:

For Concave Mirror
$u \to -ve$, $f \to -ve$
$v \to -ve$ for real image
$\to +ve$ for virtual image
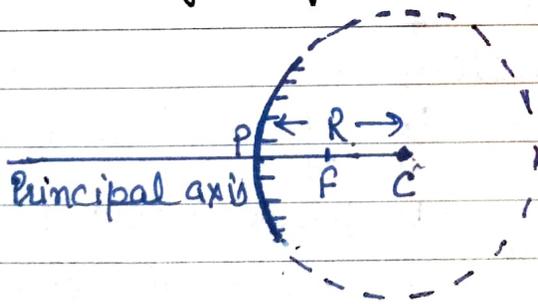
For convex mirror
$u \to -ve$, $v \to +ve$
$f \to +ve$

6. Focal length of spherical Mirror

$c \to$ Centre of curvature
$R \to$ Radius of curvature
$f \to$ focus
$PF = f \to$ Focal length
$PC = R$

Focal length $f = \dfrac{R}{2}$

7. The Mirror Equation:

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

{* This formula is valid for both the types of mirrors.}

here,

$f \to$ focal length
$v \to$ distance of image
$u \to$ distance of object

8. Linear Magnification

$$m = \frac{h_I}{h_o} = \frac{-v}{u}$$

If $m = -ve$ (R and I)
$m = +ve$ (V and E)

Ratio of height of image to the height of object is called linear magnification.

9. If lower half of a mirror is covered with an opaque material there will be image of whole object as before but intensity of the image will be low.

10. If an object moves with constant speed towards a convex mirror from infinity to focus, the image will move slower in the beginning and then faster.

The speed of image, $V_i = \left(\frac{-f}{f+u}\right)^2 V_o$
(at any instant)

here V_o is speed of object.

11. Refraction:

Bending of light when it passes from one medium to another is called refraction.

Laws of Refraction:

(1) The incident ray, refracted ray and normal, all lie in the same plane.

(11) $\frac{\sin i}{\sin r} = n_{21}$ or $_1n_2 = const$ [Snell's law]

where n_{21} is the refractive index of second medium with respect to the first medium.
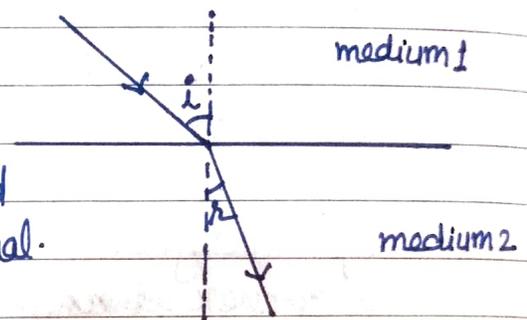
Refractive Index :

The ratio of speed of light in vacuum to the speed of light in a medium is called refractive index of that medium.

$$R.I \quad n = \frac{c}{v}$$

12. If medium 2 is denser, refracted ray bends towards the normal.

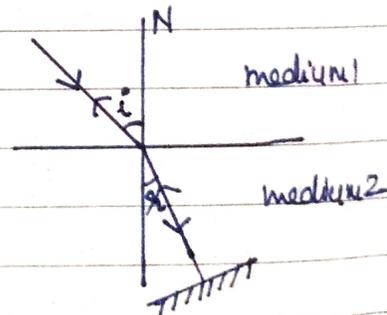i.e for $n_{21} > 1$, $r < i$

medium 1

medium 2

13. If medium 2 is rarer, refracted ray moves away from the normal.

i.e for $n_{21} < 1$, $r > i$

14. Optical density is not similar to mass densit always. For example mass density of turpentine is less than water but optical density is higher.

15. For two medium

$$n_{12} = \frac{1}{n_{21}} \Rightarrow n_{12} \times n_{21} = 1$$

N

medium 1

medium 2

For three mediums

$$n_{12} \times n_{23} \times n_{31} = 1$$
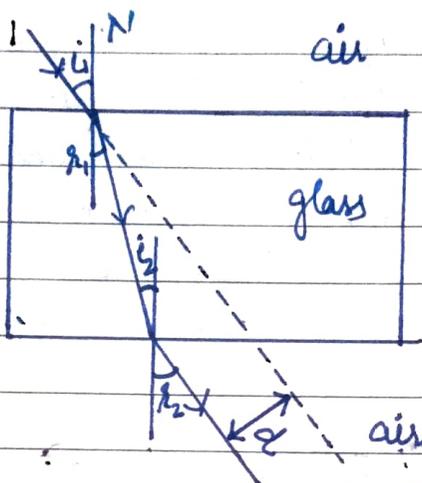
This is known as principle of reversibility.

We can prove as

$L.H.S = n_{12} \times n_{23} \times n_{31}$

$= \frac{n_1}{n_2} \times \frac{n_2}{n_3} \times \frac{n_3}{n_1} = 1 = R.H.S$

16. Leteral Shift:

d → leteral shift/displacement

here
$$r_2 = i_1$$

i.e the emergent ray is parallel to the incident ray
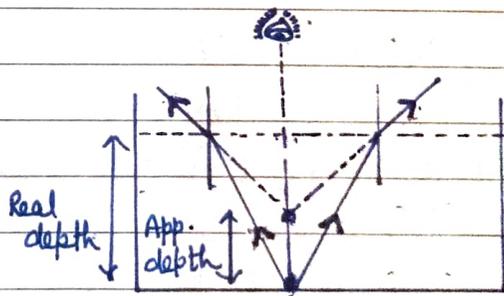There is no deviation, but there is a leteral shift d.

Leteral shift $d = \dfrac{t \sin(i - r)}{\cos r} = t \sec r \sin(i - r)$

where 't' is the thickness of glass slab, and $l_1 = i$, $r_1 = r$.

17. Relation between Real depth and Apparent depth:

Refractive index
of the medium $= \dfrac{\text{Real depth}}{\text{App. depth}}$

or $n_{21} = \dfrac{\text{Real depth}}{\text{Apparent depth}}$

18. Refraction of light through the atmosphere:
* Advanced sunrise and delayed sunset (of 2 minutes)
The refractive index of air with respect to vacuum
is 1.00029. Therefore there is an apparent shift in
the direction of sun by about half a degree and about
2 minutes.

* The oval shape of sun at sunset and sunrise. At sunset and sunrise the sun is near horizon. The ray of light from the upper part and the lower part of sun bend unequally on travelling through earth atmosphere. That's why sun appears oval or flattened at sunset and sunrise.
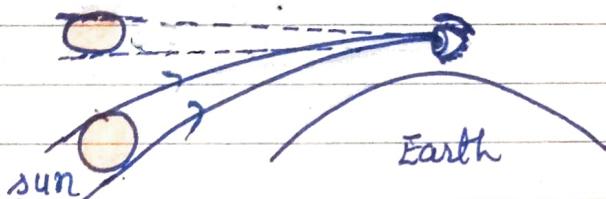
20. $$\frac{\sin i}{\sin r} = {}_1n_2 = \frac{n_2}{n_1} = \frac{V_1}{V_2}$$

21. If light travels air to any medium, then $V_1 = C$ and $V_2 = V$.

    i.e. $n = \frac{c}{V}$

22. Whether it is a wave or particle or anything else, whenever two mediums and two velocities are involved one must follow snell's law to take the shortest time. i.e.
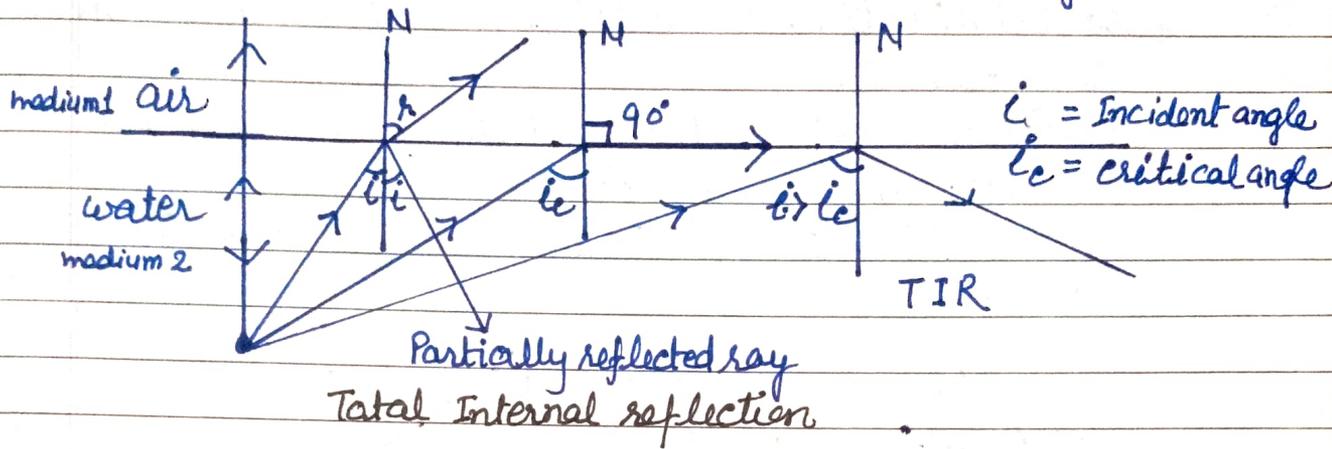
    $$\frac{\sin i}{\sin r} = \frac{V_1}{V_2}$$

23. Total Internal Reflection:
    When light travels denser to rarer medium and angle of incidence is bigger than critical angle, the light is totally reflected. This is called total internal reflection.
    (No refraction takes place)

24. Critical Angle: The angle of Incidence in denser medium for which angle of refraction in rarer medium becomes 90° is called critical angle.

medium1 air

water
medium 2

N   N   N

90°

i = Incident angle
i_c = critical angle

i_c $i > i_c$

TIR

Partially reflected ray
Total Internal reflection.

25 If light travels medium 2 (water) to medium 1 (air) than.

$$_1n_2 = \frac{1}{\sin i_c} = \frac{1}{\sin c} \Rightarrow \boxed{\sin c = \frac{n_1}{n_2} = \frac{n_R}{n_D}}$$
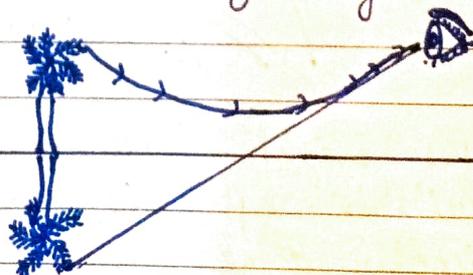
where c is the critical angle.

26. Critical angle for diamond is least ($= 24.41°$) as its refractive index is most.

27. Total Internal Reflection in nature and Its Applications
(1) Mirage It is an optical illusion in which a person in hot desert sees the inverted image of tall objects in the pool of water. This phenomenon is called mirage.
It is also experienced on a highways in hot sunny day.

(II) **Diamond:** The critical angle for diamond is very small ($=24.4°$), therefore the multiple TIR occur inside the diamond which makes it sparkle so brilliantly. By cutting the diamond its brilliance is increased.

(III) **Prism!** Prism designed to bend light by $90°$ or $180°$ make use of TIR.

Such prism invert image without changing the size.

AB = A'B'

here $i_c < 45°$

AB = A'B'
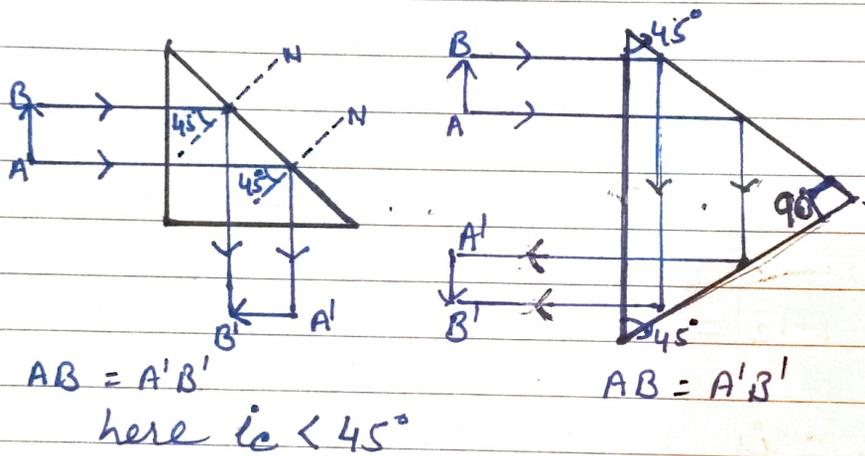
(IV) **Optical Fibres:** Optical fibres are fabricated with high quality composite glass/quartz fibres and extensively used for transmitting audio and video signal through long distances.

It works on the principle of TIR.
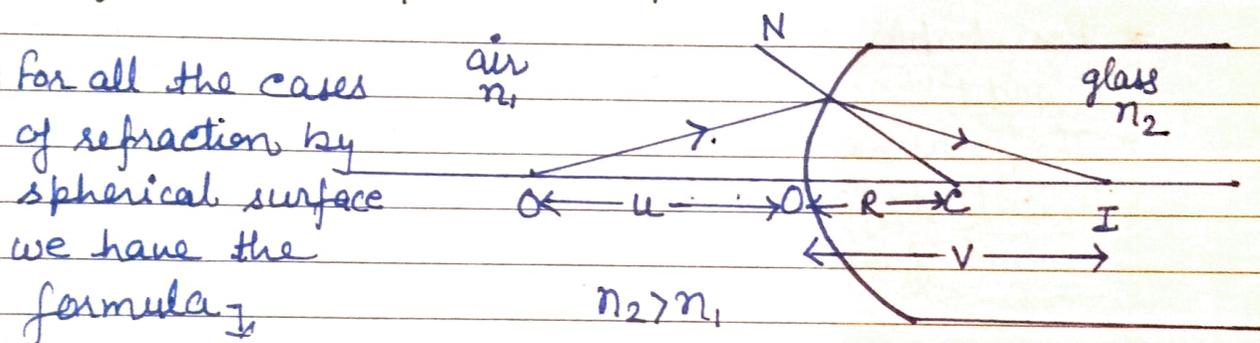

$n_2 > n_1$

core   cladding
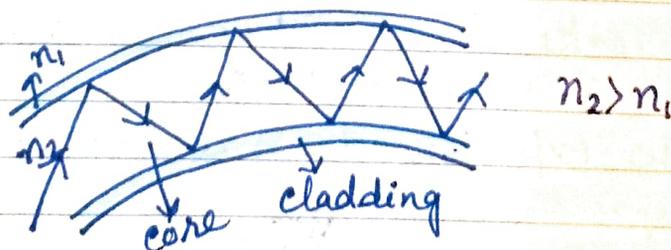
When light signal directed at one end of fibre at suitable angle, it undergoes repeated TIR and finally comes out at the other end with very

less loss of intensity of light.
It can be used to act as an optical pipe.

Uses:- • In telecommunications
         • In medicals to examin internal organs of the body.
         • In decorative lamp
         • Silica glass fibres transmitted signals more than 95%
of the light over a fibre length of 1 km.

28. Refraction at Spherical Surface

for all the cases
of refraction by
spherical surface
we have the
formula ↴

$$\frac{n_2}{V} - \frac{n_1}{u} = \frac{(n_2 - n_1)}{R}$$

This formula is valid for concave surface as well
as convex surface.

29 Refraction by lens:-
Lens formula -

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

Lens Maker's Formula:

$$\frac{1}{f} = (n_2 - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

* Lens Maker's formula is used to design lenses of desired focal length using surfaces of suitable radii of curvature.
* formula is valid for both the lenses.
* We also find lens formula by Lens Maker's formula i.e.

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

which is also valid for both the lenses - convex and concave for both type of images - 'real and inverted' and 'virtual and erect'.
* For double convex and concave lens the two foci F and F' are at equidistance from the optical centre.
* The focus on the side of (original) source of light is called first focus where the other is called second focal point.

30. Magnification by lenses

$$m = \frac{h_I}{h_o} = \frac{v}{u}$$

m is +ve for virtual and erect image.
m is -ve for real and inverted image

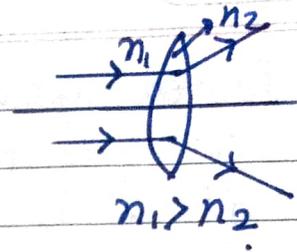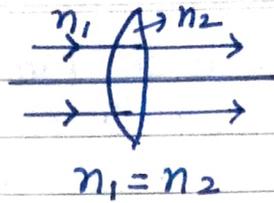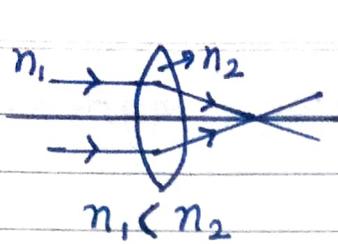31. Change in focal length of a lens on changing medium :-

When lens of refractive index n_2 is dipped into a medium of refractive index n_1, then
(i) If $n_1 < n_2$, Nature of lens does not change.
(ii) If $n_1 = n_2$, Lens disappears.
(iii) If $n_1 > n_2$, Lens changes its nature - convex lens behaves as concave lens and concave lens as convex lens.

$n_1 < n_2$ $n_1 = n_2$ $n_1 > n_2$

$n_1 < n_2$ $n_1 = n_2$ $n_1 > n_2$
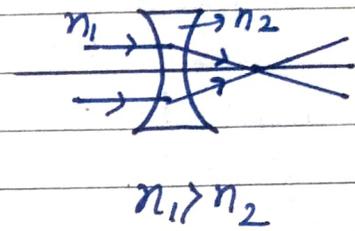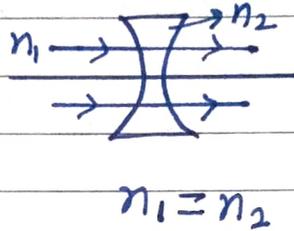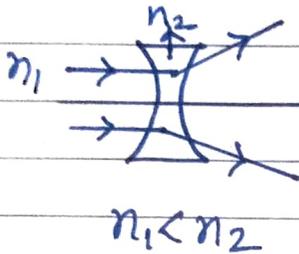
Change in nature of lens and also change in focal length of lens can be verified by lens maker's formula -

$$\frac{1}{f} = (n_2-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

32 Power of a Lens :-

In fig -

$$\delta = \frac{h}{f}$$
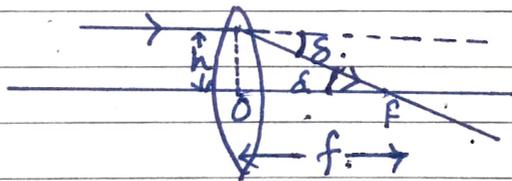
If $h = 1$ and δ is small

$$\delta = \frac{1}{f}$$

i.e $P = \frac{1}{f}$

The reciprocal of focal length (in metre) of a lens is called its power.

SI unit - dioptre (D)

$$1 D = 1 m^{-1}$$

* Power of a lens of 1m focal length is 1 D.
* If f is +ve, P is +ve
* If f is -ve, P is -ve.

33. Combination of Focal Length:-

If two thin lenses of focal length f_1 and f_2 are kept in contact, the effective focal length is given by -

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

for several lenses

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + ---$$

In terms of power

$$P = P_1 + P_2 + P_3 + ---$$

* Effective power is the algebraic sum of individual powers. i.e. P is +ve for convex lens and -ve for concave lens.

* Combination of lenses helps to obtain diverging or converging lenses of desired magnification and to enhance the sharpness of the image.

* Magnification of the combination of the lenses-

$$m = m_1 m_2 m_3 ----$$

It is in multiplication because image formed by first lens is act as an object for the second lens.

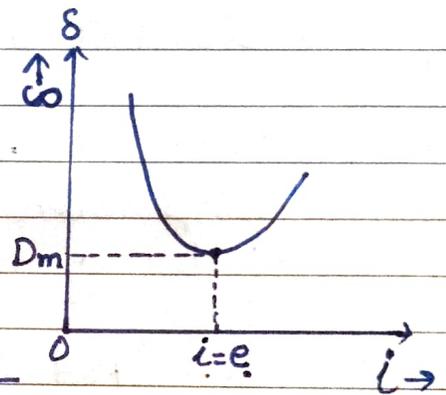* Uses - In cameras, microscopes, telescope, etc.

34. Refraction through a Prism:-
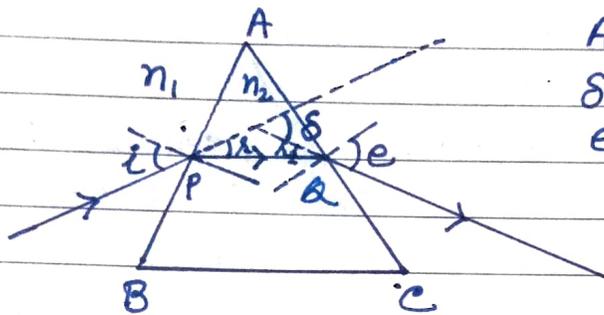
$A \rightarrow$ Prism angle.
$\delta \rightarrow$ Angle of deviation
$e \rightarrow$ Angle of emergence

Here $\delta = i + e - A$
when $\delta = Dm$, then
$i = e$ and $r_1 = r_2$
i.e $PQ \parallel BC$
and $n_{21} = \dfrac{Sin\left[\dfrac{A + Dm}{2}\right]}{Sin \dfrac{A}{2}}$
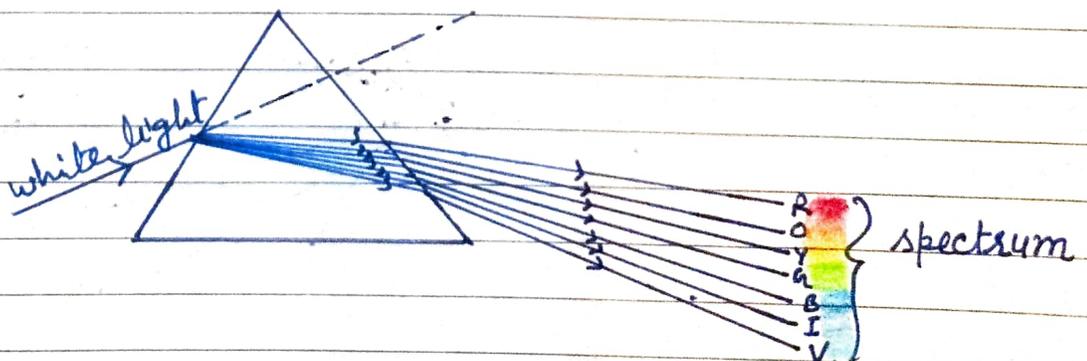
For thin prism
$$Dm = (n_{21} - 1) A \qquad [\because \text{for small angle } sin\theta \approx \theta]$$
It implies that thin prisms do not deviate much light.

35. Dispersion by a Prism:-
The phenomenon of splitting of light into its component colours is known as dispersion.
The coloured band of splitting light is called spectrum

spectrum

* Prism does not creat colours, it just split the white light into its components (of 7 colours)

* A ray of light does not exist. Actual ray is a beam of many rays of light.

* In the visible spectrum red colour has highest wavelength (~ 700 nm) while violet colour has shortest wavelength (~ 400 nm)

36. Cause of Dispersion:-
Dispersion takes place because the refractive index of medium for different wavelength is different.
e.g. Red light bends least and violet bends most.
(Remember $\mu \propto \frac{1}{\lambda}$) μ or $n \rightarrow$ Refractive index
i.e. Red light travels faster than violet light in glass medium. ($V \propto \lambda$)

* Due to the dispersion of light thick lenses show chromatic aberration.

** Remember in vacuum of speed of light is independent of wavelength and hence all colours travels with same speed.

$\because \delta_v > \delta_R$
$\therefore V_R > V_v$ $V \rightarrow$ velocity
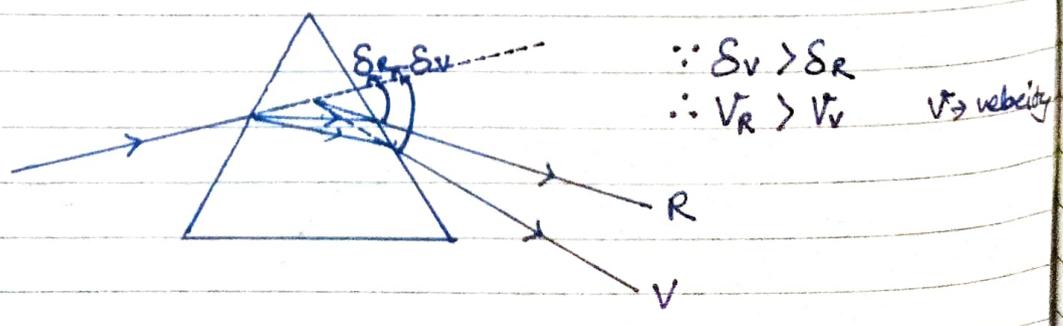
$$** \quad \frac{\sin i}{\sin r} = \frac{n_2}{n_1} = \frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2} = \frac{f_1}{f_2}$$

optical Instruments

The instruments which uses reflecting and refracting properties of mirror, lenses and prism are called optical intruments.
e.g. Periscope, kaleidoscope, binoculars, telescopes microscopes etc.

1 Simple Microscopes (Magnifying glass):

* It is a converging lens of small focal length.
* When object is place b/w focus 'F' and optical centre 'O', the image formed by convex lens is erect magnified and virtual.

AB = Object height
A'B' = Image height
OA = -u
OA' = -v = -D
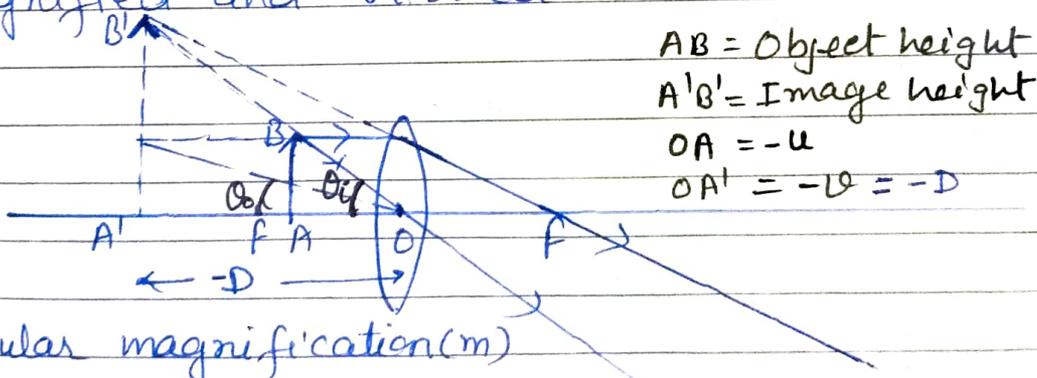
Angular magnification (m)

$$m = \frac{\tan \theta_i}{\tan \theta_o} = \frac{AB/OA}{AB/OA'} \quad \Rightarrow \quad m = \frac{\theta_i}{\theta_o} = \frac{OA'}{OA} \quad \left[\begin{array}{l} \because \tan \theta \approx \theta \\ \text{for small} \\ \text{angles} \end{array} \right]$$

or

$$m = \frac{OA'}{OA} = \frac{-D}{-u} = \frac{D}{u}$$

by $\frac{1}{f} = \frac{1}{v} - \frac{1}{u} \Rightarrow \frac{1}{f} = \frac{1}{+v} - \frac{1}{-u} \Rightarrow \frac{1}{u} = \frac{1}{f} + \frac{1}{v}$

then

$$m = D \left[\frac{1}{v} + \frac{1}{f} \right]$$

$$m = D\left[\frac{1}{v} + \frac{1}{f}\right]$$

Case I - If image is formed at near point (D)
i.e $v = D$

then

$$m = 1 + \frac{D}{f}$$

Case II - If image is formed at infinity (far point) i.e, $v = \infty$, then

In normal adjustment $m = \frac{D}{f}$ $\left[\because \frac{1}{\infty} = 0\right]$

* Generally m provided by simple microscope is not more than 9. $\boxed{m \leq 9}$

Compound Microscope

In compound microscope two convex lenses are used to increase the magnifying power. One lens is objective lens, which forms real and inverted magnified image.
Image formed by objective lens acts as an object for second lens (Eyepiece) and formed virtual and erect magnifying image like simple microscope.

actual object

objective

Image formed at 'D'

final image
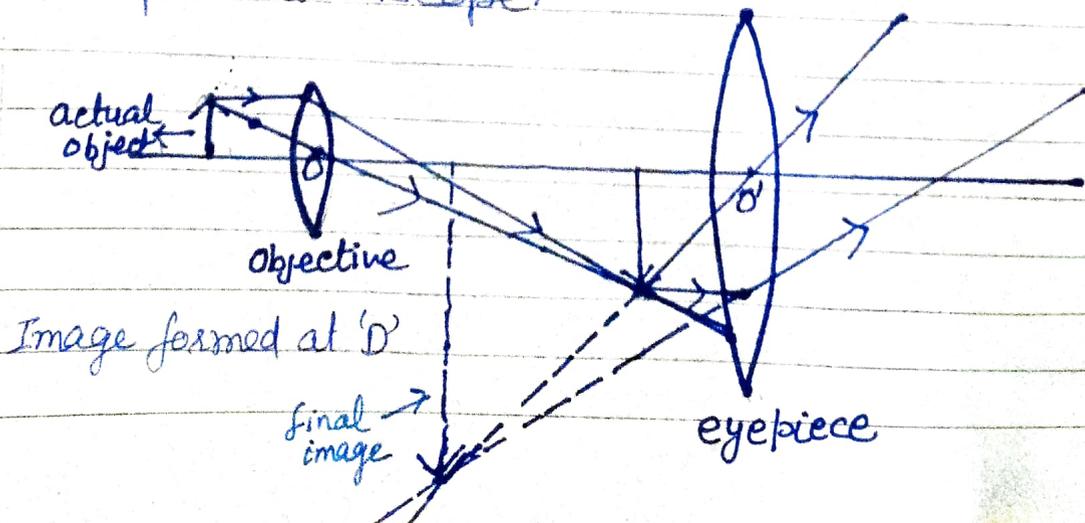
eyepiece

$$\text{magnification } m = m_o m_e$$

where,

$m_o \rightarrow$ magnification by objective lens

and $m_e \rightarrow$ magnification by eyepiece lens

here $m_o = \dfrac{v_o}{u_o}$

and $m_e = \dfrac{\theta_i}{\theta_o} = D\left[\dfrac{1}{v_e} + \dfrac{1}{f_e}\right]$ [for simple microsco- -pe

then

$$m = m_o m_e$$

$$m = \dfrac{v_o}{u_o} \cdot D\left[\dfrac{1}{v_e} + \dfrac{1}{f_e}\right]$$

* Length of microscope = Distance b/w objective
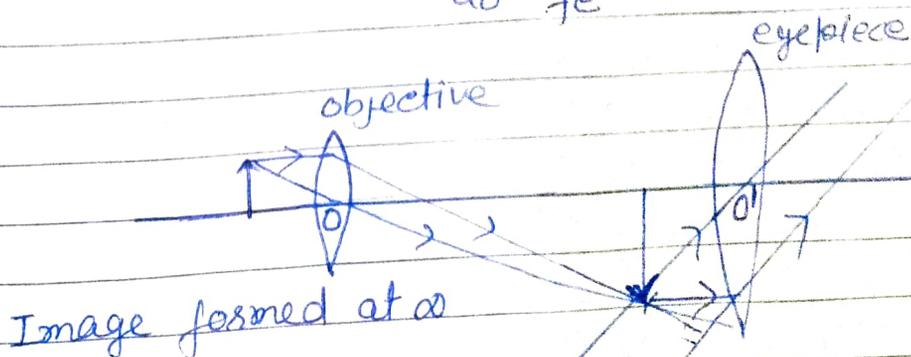$$\text{and eyepiece}$$
$$= v_0 + u_e$$

* Case I - If image is formed at near point (at D)
then, $v = D$
$$m = \dfrac{v_o}{u_o}\left[1 + \dfrac{D}{f_e}\right]$$

* Case II
If image is formed at ∞ (far point)
then, $v_e = \infty$ (Normal Adjustment)
$$m = \dfrac{v_o}{u_o} \cdot \dfrac{D}{f_e}$$

objective   eyepiece
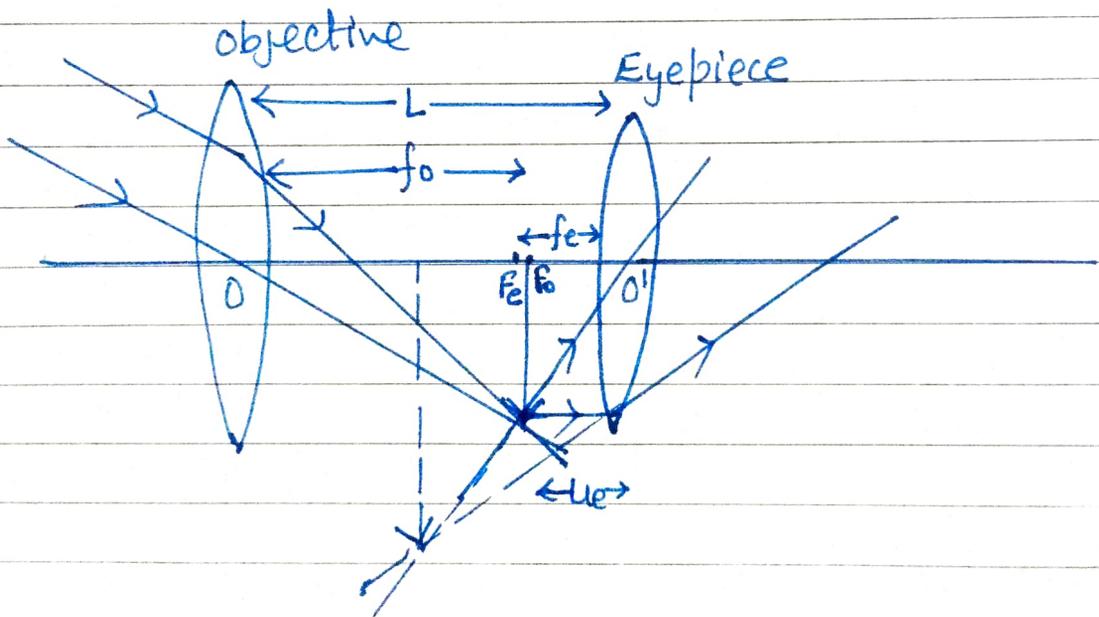
Image formed at ∞

Astronomical Telescope

It is used to provide angular magnification to distant objects.

It consists two convex lenses - Objective and eyepiece.

* Objective has larger and focal length and aperture.

* Light from distant object enters objective and a real image is formed at focus of objective. Eyepiece than magnifies its image producing a final inverted image.

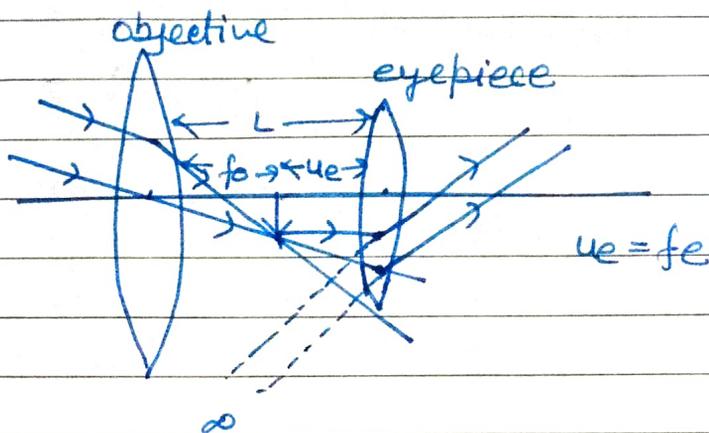Case I - Final image is formed at near point (at D)

$$m = \frac{-f_o}{f_e}\left[1 + \frac{f_e}{D}\right]$$

* Length of telescope $= f_o + u_e = L$

Case II - If final image is formed at far point (at ∞)
for image to be at ∞, $u_e = f_e$

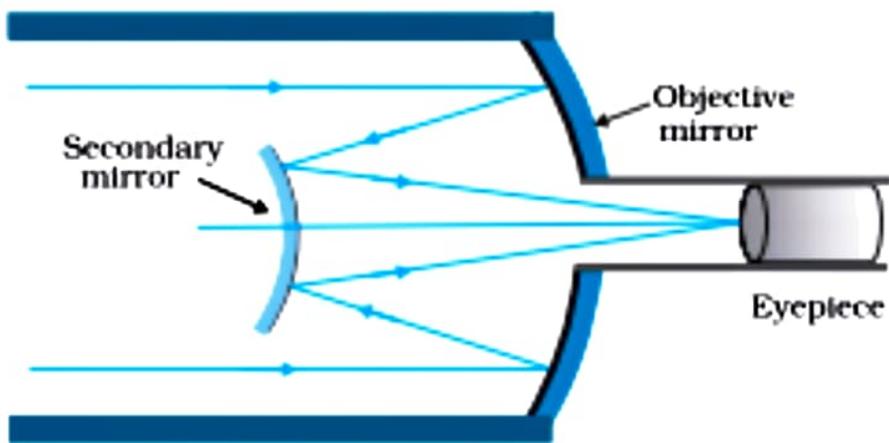$$m = -\frac{f_o}{f_e}$$ [Normal adjustment]

$$L = f_o + f_e$$ [L → length of telescope]

$u_e = f_e$

* Compound microscope is used to observe minute nearby objects whereas the telescope is used to observe distant objects.

* In compound microscope focal length of objective is lesser than that of eyepiece but in telescope objective has larger focal length than eyepiece.

* The objective of a telescope have large focal length and large aperture to increase the M.P and to collect large amount of light respectively.

Reflecting type Telescope (Cassegrian 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).

In normal adjustment, magnifying power

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

Advantages of Reflecting type telescope

1. There is no chromatic aberration as the objective is a mirror.

2. Spherical aberration is reduced using mirror objective in the form of a parabolic.

3. The image is brighter compared to that in a refracting type telescope.

4. Mirror requires grinding and polishing of only one side.

5. High resolution is achieved by using a mirror of large aperture.

6. A mirror weights much less than a lens of equivalent optical quality.