CHAPTER 9

RAY OPTICS AND OPTICAL INSTRUMENTS

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REFLECTION OF LIGHT

- When light is incident on a surface, it partially reflected back, partly absorbed by the surface and remaining is transmitted through the surface.
- Mirrors are used to reflect light efficiently.

Ray of Light

- The path along which a light wave travels is called ray of light.

Beam of Light

- A bundle of ray of light is called beam of light.

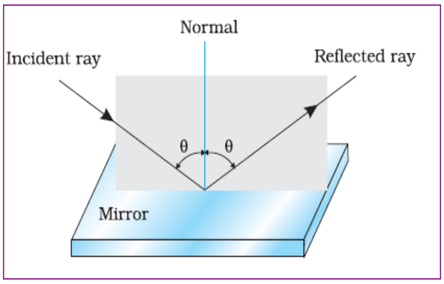
Angle of incidence

- The angle between the incident ray and the normal is the angle of incidence.

Angle of reflection

- The angle between the reflected ray and the normal is the angle of reflection

Reflection of light by plane mirrors



Laws of reflection

- The angle of reflection equals the angle of incidence.

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

Characteristics of image formed by plane mirrors

- The image is as far as behind the mirror, as the object is in front of it.
- Size of the image is same as that of object.
- Image formed is virtual – cannot be produced on screen.
- The image is erect.
- The image is laterally inverted.

Spherical Mirrors

- The portion of a reflecting surface, which forms a part of a sphere, is called a spherical mirror.
- **Concave mirror** – reflecting surface towards the centre of the sphere
- **Convex mirror –** reflecting surface away from the centre of the sphere.

Some definitions

Centre of curvature (C)

- The centre of the sphere of which the mirror forms a part.

Radius of curvature (R)

- The radius of the sphere of which the mirror forms a part.

Pole

- The geometric centre of a spherical mirror is called its pole.

Principal Axis

- The line joining the pole and centre of curvature.

Aperture

- The diameter of the mirror.

Principal Focus

- The point at which, a narrow beam of light incident on the mirror parallel to its principal axis , after reflection from the mirror , meets or appears to come from.

Focal length

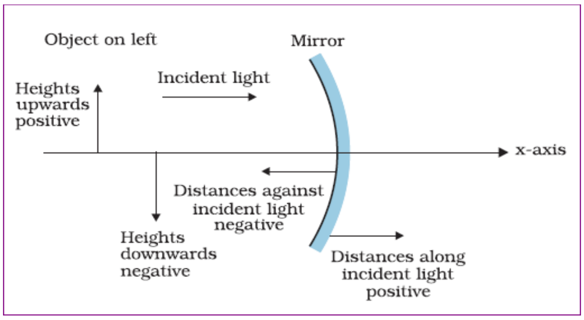
- The distance between pole and principal focus.

Spherical aberration

- The inability of a spherical mirror of large aperture to focus the marginal rays and central rays at a single point is called spherical aberration.

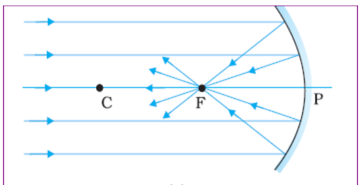
Cartesian Sign Convention

- According to this convention, all distances are measured from the pole of the mirror or the optical centre of the lens.
- The distances measured in the same direction as the incident light are taken as positive and those measured in the direction opposite to the direction of incident light are taken as negative .
- The heights measured upwards with respect to x-axis and normal to the principal axis (x-axis) of the mirror/ lens are taken as positive).
- The heights measured downwards are taken as negative.



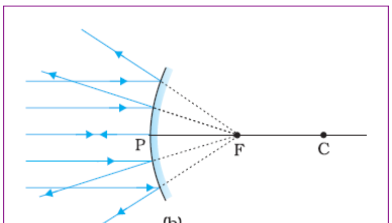
Reflection of light by spherical mirrors

Concave mirror



(a)

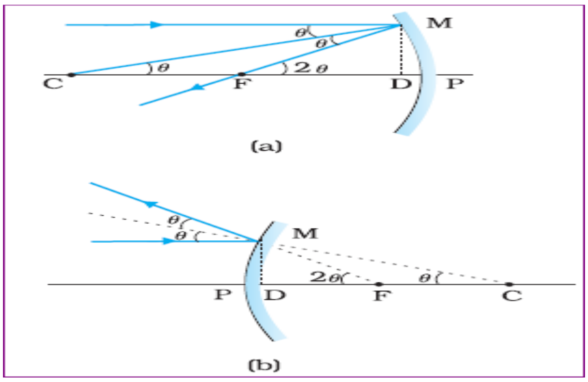
Covex Mirror



(b)

Relation between focal length and radius of curvature of a spherical mirror

- Consider a ray parallel to the principal axis striking the mirror at M.



- Thus from the diagram

$\angle MCP = \theta$ and $\angle MFP = 2\theta$

Now,

$$\tan\theta = \frac{MD}{CD} \text{ and } \tan 2\theta = \frac{MD}{FD}$$

- For small θ, tan θ ≈ θ, tan 2θ ≈ 2θ.

$$\frac{MD}{FD} = 2\frac{MD}{CD}$$

$$\text{or, } FD = \frac{CD}{2}$$

- For small θ, the point D is very close to the point P.
- Therefore, FD = *f and CD = R.*

$$f = R/2$$

Some conventions to draw a ray diagram

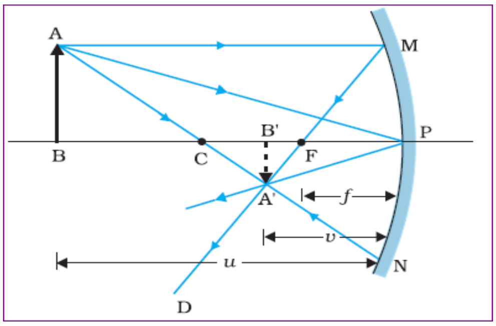
- The ray from the point which is parallel to the principal axis. The reflected ray goes through the focus of the mirror.
- The ray passing through the centre of curvature of a concave mirror or appearing to pass through it for a convex mirror. The reflected ray simply retraces the path.
- The ray passing through (or directed towards) the focus of the concave mirror or appearing to pass through (or directed towards) the focus of a convex mirror. The reflected ray is parallel to the principal axis.

- The ray incident at any angle at the pole. The reflected ray follows laws of reflection.

The mirror equation

- The relation connecting the object distance (*u*), *image distance (v) and the focal length (f) is the mirror equation.*

Derivation



- In the diagram the two right-angled triangles A'B'F and MPF are similar.
- Therefore,

$$\frac{B'A'}{PM} = \frac{B'F}{FP}$$

$$\text{or } \frac{B'A'}{BA} = \frac{B'F}{FP} \quad (\because PM = AB)$$

- Since ∠ APB = ∠ A'PB', the right angled triangles A'B'P and ABP are also similar.
- Therefore,

$$\frac{B'A'}{BA} = \frac{B'P}{BP}$$

- Comparing Equations :

$$\frac{B'F}{FP} = \frac{B'P - FP}{FP} = \frac{B'P}{BP}$$

- Using sign conventions

$$B'P = -v,\ FP = -f,\ BP = -u$$

- We get

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

$$\text{or } \frac{v-f}{f} = \frac{v}{u}$$

- Therefore the mirror equation is given by

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

- The same equation can be derived for a convex mirror too.

Linear Magnification

- Linear magnification (m) is the ratio of the height of the image (h') to the height of the object (h).

$$m = \frac{h'}{h}$$

- In triangles A'B'P and ABP, we have,

$$\frac{B'A'}{BA} = \frac{B'P}{BP}$$

- With the sign convention, this becomes

$$\frac{-h'}{h} = \frac{-v}{-u}$$

so that

$$m = \frac{h'}{h} = -\frac{v}{u}$$

- Therefore the linear magnification is given by

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

- The expression for magnification is same for concave and convex mirror.

Significance of magnification 'm'

- When 'm' is positive, the image is erect (virtual)
- When 'm' is negative, the image is inverted (real)
- For enlarged image, m>1
- For diminished image, m<1

Uses of spherical mirrors

Concave mirrors

- Used as reflectors of table lamps to direct light in a given area.

- Concave mirrors of large aperture are used in reflecting type astronomical telescopes.
- Shaving mirrors are made slightly concave to get erect enlarged image of the face.

Convex mirrors

- They are used in automobiles as rear view mirrors because of the two reasons:
- A convex mirror always produces an erect image.
- The image is diminished in size, so that it gives a wide field of view.

Nature of the image formed by a Concave mirror

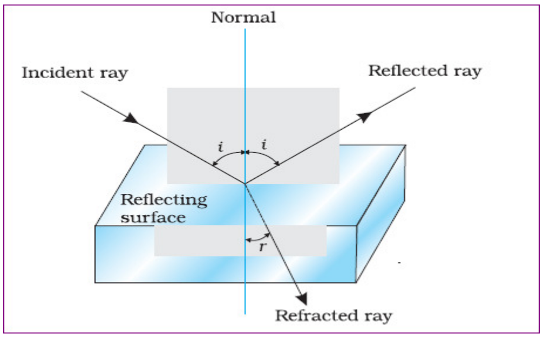
Object position	Image position	Size of image	Nature of image
At infinity	Focus (F)	Point sized	Real
Beyond C	Between F and C	Small	Real and inverted
At C	At C	Same as that of the object	Real and inverted
Between C and F	Behind C	Enlarged	Real and inverted
At F	At infinity	Highly enlarged	Real and inverted
Between F and P	Behind mirror	Enlarged	Virtual and erect

Nature of the image formed by a Convex mirror

- A convex mirror always forms a virtual and diminished image irrespective of the position of the object

REFRACTION OF LIGHT

- The phenomenon of change in path of light as it goes from one medium to another is called ***refraction.***



Laws of Refraction

- The incident ray, the refracted ray and the normal to the interface at the point of incidence, all lie in the same plane.

Snell's law:-

- The ratio of the sine of the angle of incidence to the sine of angle of refraction is constant.
- Now

$$\frac{\sin i}{\sin r} = n_{21}$$

- Where **n_{21}** *is a constant, called the **refractive index** of the second medium* with respect to the first medium.

$$n_{21} = \frac{n_2}{n_1}$$

- Where n_1- absolute refractive index of the first medium and n_2 – absolute refractive index of the second medium.

Refractive index

- The refractive index of a medium depends on
  - Nature of the pair of medium
  - Wavelength of light
- Refractive index is independent of the angle of incidence**.**
- A medium having **larger value of refractive index** is called **optically denser** medium.
- A medium having **smaller value of refractive index** is called **optically rarer** medium.
- Also

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

- Where $n_{12} = \frac{n_1}{n_2}$
- If *n_{32} is the refractive* index of medium 3 with respect to medium 2 then

$$n_{32} = n_{31} \times n_{12}$$

- Where n_{31} is the refractive index of medium 3 with respect to medium 1.

Absolute refractive index

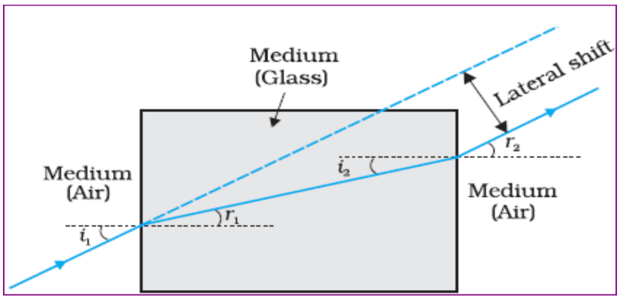
- The ratio of velocity of light in vacuum to the velocity of light in a medium is called absolute refractive index.

$$n = \frac{c}{v}$$

- Where C - velocity of light in vacuum, v- velocity of light in the medium.
- When **light enters from a rarer medium to denser medium,** the refracted ray **bends towards the normal**.
- When **light enters from a denser medium** to rarer medium, the refracted ray **bends away from the normal**.

$n_{air} = 1$	$n_{glass} = 1.5$
$n_{water} = 1.33$	$n_{diamond} = 2.42$

Refraction through a glass slab - Lateral shift

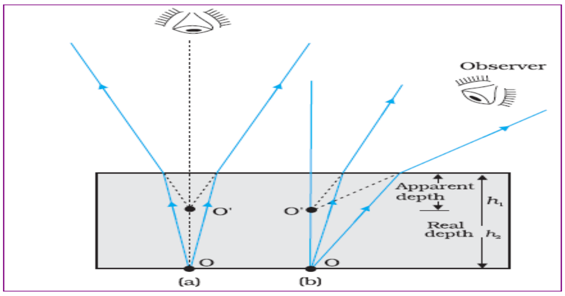


- For a rectangular slab, refraction takes place at two interfaces (air-glass and glass-air).
- When a light ray enters a glass slab it undergoes lateral displacement/ shift with respect to the incident ray.
- The perpendicular distance between the incident ray and the emergent ray, when the light is incident obliquely on a parallel sided refracting slab is called **lateral shift.**

Applications of refraction

Apparent depth

- If an object in a denser medium is viewed from a rarer medium the image appears to be raised towards the surface.
- The bottom of a tank filled with water appears to be raised due to refraction.

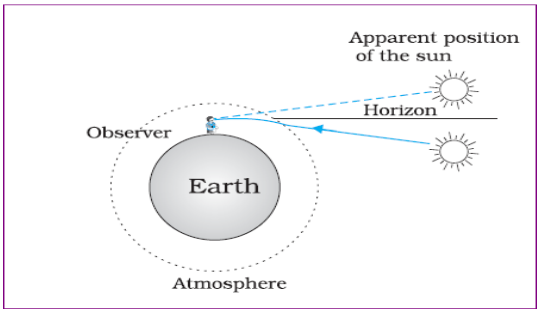


- For viewing near the normal direction

$$\text{Apparent Depth} = \frac{\text{Real Depth}}{\text{Refractive Index}}$$

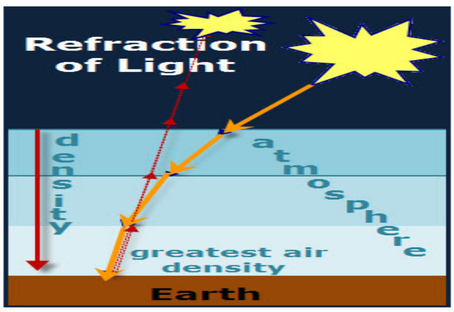
Apparent position of sun

- The sun is visible a little before the actual sunrise and until a little after the actual sunset due to refraction of light through the atmosphere.
- Time difference between actual sunset and apparent sunset is about 2 minutes.



- As we go up, the density of air in the atmosphere continuously decreases, and thus the light coming from the sun undergoes refraction.
- Thus we see the sun at an apparent position raised above the horizon.
- This is the reason for early sunrise and delayed sunset.

Twinkling of stars

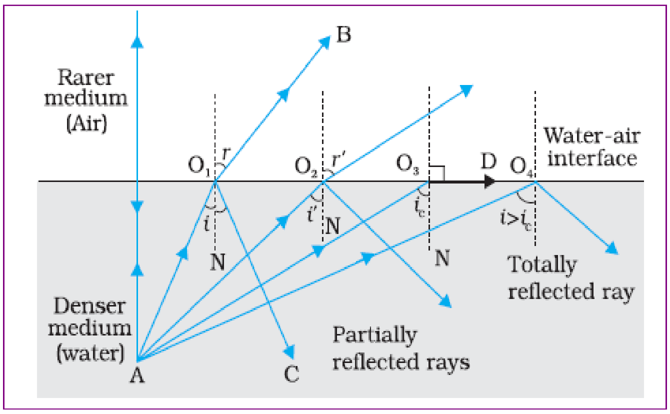


- The light rays coming from the sun undergo refraction and hence the star is viewed at the apparent position.
- As the density of air in the atmosphere continuously changes, the apparent position also changes continuously.
- Thus the star appears to be twinkling.

TOTAL INTERNAL REFLECTION (T I R)

- When light travels from a denser medium to a rarer medium, if the angle of incidence is greater than the critical angle it gets totally reflected in to the same medium. This phenomenon is called **total internal reflection.**

Explanation



- When light travels from an optically denser medium to a rarer medium at the interface, it is partly reflected back into the same medium and partly refracted to the second medium. This reflection is called the ***internal reflection***.
- When a ray of light enters from a denser medium to a rarer medium, it bends away from the normal.
- As the angle of incidence increases, the angle of refraction also increases.
- For a particular angle of incidence the angle of refraction becomes 90^0.
- If the angle of incidence is further increased the ray gets totally reflected into the same medium.
- This phenomenon is called total internal reflection.

Conditions for total internal reflection

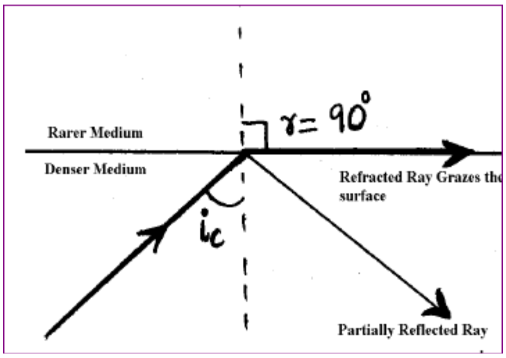
- The light ray should travel from denser medium to rarer medium.
- The angle of incidence should be greater than the critical angle.

Critical Angle

- It is the angle of incidence in the denser medium for which the angle of refraction becomes 90^0.

Substance medium	Refractive index	Critical angle
Water	1.33	48.75°
Crown glass	1.52	41.14°
Dense flint glass	1.62	37.31°
Diamond	2.42	24.41°

Relation connecting refractive index and critical angle



- By Snell's law

$$\frac{\sin i}{\sin r} = \frac{n_1}{n_2}$$

- Here the ray goes from denser to rarer medium
- When **$i = i_c$, $r = 90^0$, thus**

$$\frac{\sin i_c}{\sin 90} = \frac{n_1}{n_2}$$

$$\sin i_c = \frac{n_1}{n_2}$$

$$\frac{1}{\sin i_c} = \frac{n_2}{n_1}$$

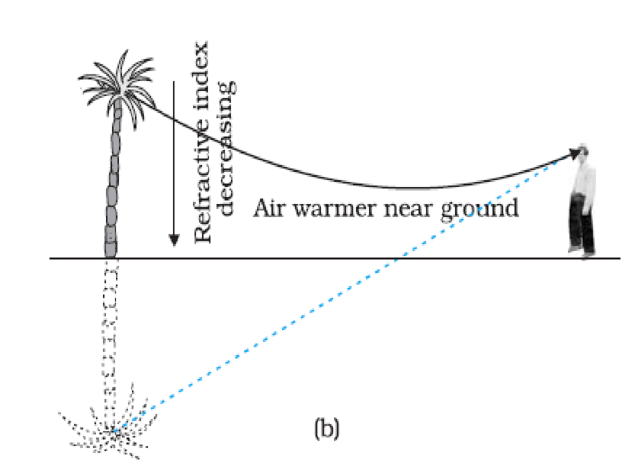
- If the rarer medium is air, $n_1 = 1$, and let $n_2 = n$, then

$$n = \frac{1}{\sin i_c}$$

Applications of Total Internal Reflection

Mirage

- Mirage is due to total internal reflection.



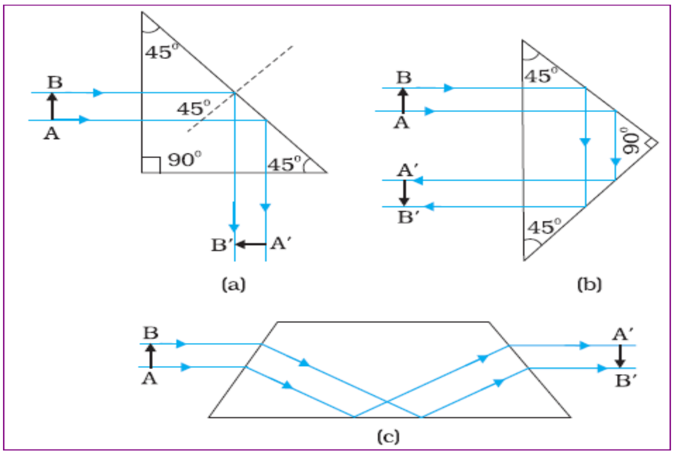
- In hot sunny days the layer of air in contact with sand in a desert (or tar road), becomes hot and rarer.
- The upper layers are comparatively cooler and denser.
- Therefore the ray of light coming down from a distant object like a tree is travelling from a denser medium to a rarer medium and it suffers total internal reflection.
- Thus for an observer the image of a distant object is seen inverted.
- This makes the illusion that the tree is standing near a pool of water. This phenomenon is called mirage.
- During a hot summer day, a distant patch of road appears to be wet due to mirage.

Brilliance of Diamond

- Brilliance of diamond is due to total internal reflection.
- The critical angle for diamond-air interface (≅ 24.4°) is very small, therefore once light enters a diamond; undergo total internal reflection inside it.
- By cutting the diamond suitably, multiple total internal reflections can be made to occur.

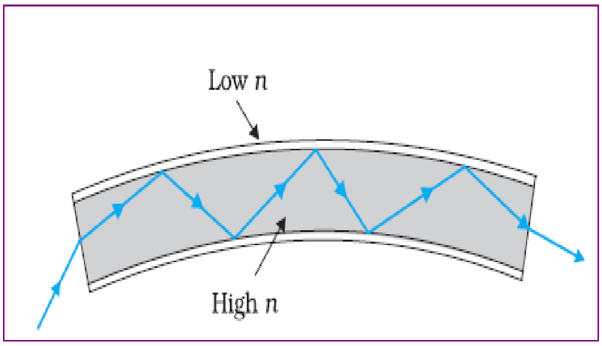
Total reflecting prisms

- Total reflecting prisms are designed to bent light or to invert images without changing their size, based on total internal reflection.



- Total reflecting prisms are used in periscopes.

Optical fibres



- Optical fibre consists of a **core** and **cladding**.
- The refractive index of the material of the core is higher than that of the cladding.
- When a signal in the form of light is directed at one end of the fibre at a suitable angle, it undergoes repeated total internal reflections along the length of the fibre and finally comes out at the other end.
- Since light undergoes total internal reflection at each stage, there is no appreciable loss in the intensity of the light signal.
- Even if the fibre is bent, light can easily travel along its length.

Uses of Optical fibres

- Optical fibres are used as a light pipe for visual examination of internal organs.
- Optical fibres are used to carry electrical signals which are converted to light.

REFRACTION AT SPHERICAL SURFACES

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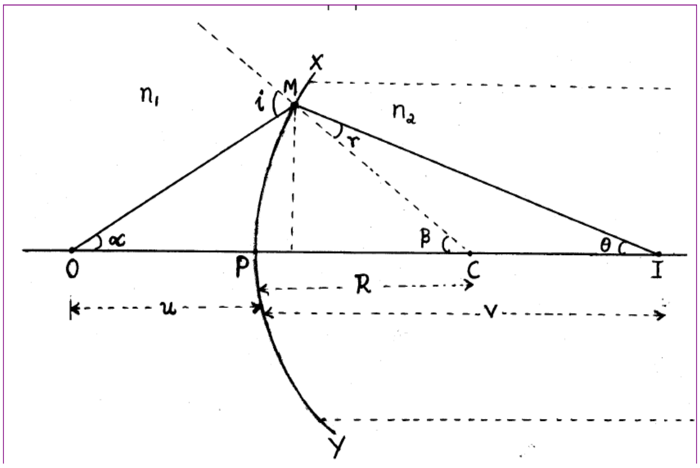
Expression for refraction at a convex surface



- For small angles , tan θ ≈ θ, thus
- From triangle OMP ,

$$\tan\alpha \approx \alpha = \frac{PM}{PO}$$

- From triangle PCM,

$$\tan\beta \approx \beta = \frac{PM}{PC}$$

- From triangle PMI,

$$\tan\theta \approx \theta = \frac{PM}{PI}$$

- From triangle OMC,
  Exterior angle = sum of interior angles
- Thus

$$i = \alpha + \beta = \frac{PM}{PO} + \frac{PM}{PC} \quad ....(1)$$

- From triangle IMC

$$\beta = r + \theta \Rightarrow r = \beta - \theta = \frac{PM}{PC} - \frac{PM}{PI} \quad ....(2)$$

- By Snell's law

$$\frac{\sin i}{\sin r} = \frac{n_2}{n_1}$$

- If I and r are small,

$$\frac{i}{r} = \frac{n_2}{n_1}$$

$$n_1 i = n_2 r$$

- Substituting for I and r,

$$n_1\left(\frac{PM}{PO} + \frac{PM}{PC}\right) = n_2\left(\frac{PM}{PC} - \frac{PM}{PI}\right)$$

- Or

$$n_1\frac{PM}{PO} + n_1\frac{PM}{PC} = n_2\frac{PM}{PC} - n_2\frac{PM}{PI}$$

- Thus

$$\frac{n_1}{PO} + \frac{n_1}{PC} = \frac{n_2}{PC} - \frac{n_2}{PI}$$

- Therefore

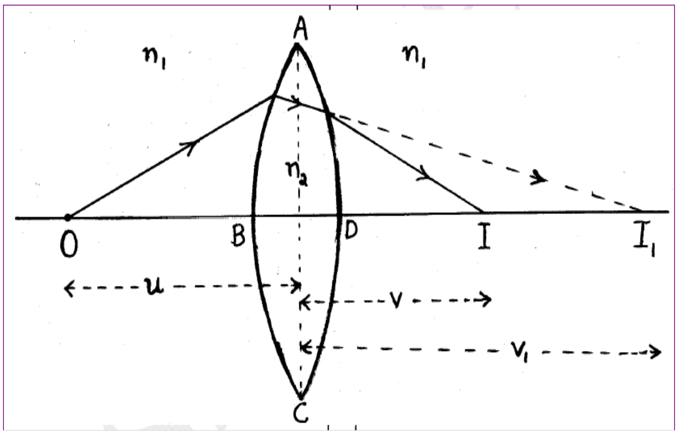
$$\frac{n_1}{PO} + \frac{n_2}{PI} = \frac{n_2 - n_1}{PC} \quad ....(3)$$

- By Cartesian sign convention
  PO = -u , PI = v , PC =R
- Thus equation(3) becomes

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

- This is the **equation of refraction at convex surface.**

Refraction by a lens - Lens maker's formula



- The image formation has two steps:

- The first refracting surface forms the image I_1 of the object O.
- The image formed by the first refracting surface acts as the virtual object for the second refracting surface and the final image is formed at I.
- We have the curved surface formula

$$\frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R}$$

For refraction at the surface ABC

- Light ray travels from n_1 to n_2 and O is the object and I_1 is the image.
- And

$$v \rightarrow v_1, R \rightarrow R_1$$

- Here R_1 **is** the radius of curvature of ABC.
- Thus

$$\frac{n_2}{v_1} - \frac{n_1}{u} = \frac{n_2 - n_1}{R_1} \ldots\ldots\ldots\ldots (1)$$

For refraction at the surface ADC

- Light ray travels from n_2 to n_1.
- Here I_1 is the object and I is the image and

$$n_1 \leftrightarrow n_2, u \rightarrow v_1, v \rightarrow v, R_1 \rightarrow R_2$$

- Here R_2 **is** the radius of curvature of ADC

$$\therefore \frac{n_1}{v} - \frac{n_2}{v_1} = \frac{n_1 - n_2}{R_2} \ldots\ldots\ldots (2)$$

$$\frac{n_1}{v} - \frac{n_2}{v_1} = \frac{-(n_2 - n_1)}{R_2} \ldots\ldots\ldots (3)$$

- Adding equation 1 and 2, we get

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

- Dividing by n_1

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

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

$$\frac{1}{v} - \frac{1}{u} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \ldots\ldots (4)$$

- If the object is at infinity, the image is formed at the principal focus.
- Thus if **u=∞, v=f,** equation 4 becomes

$$\frac{1}{f} - \frac{1}{\infty} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

- Thus the **lens maker's formula** is given by

$$\therefore \frac{1}{f} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right] \ldots\ldots\ldots\ldots (5)$$

Thin lens formula

- We have from eqn 4,

$$\frac{1}{v} - \frac{1}{u} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

- And the lens maker's formula

$$\therefore \frac{1}{f} = (n_{21} - 1)\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$

- If the first medium is air n_1 = 1 and ,let n_2=n, then

$$n_{21} = \frac{n_2}{n_1} = n$$

- Thus

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

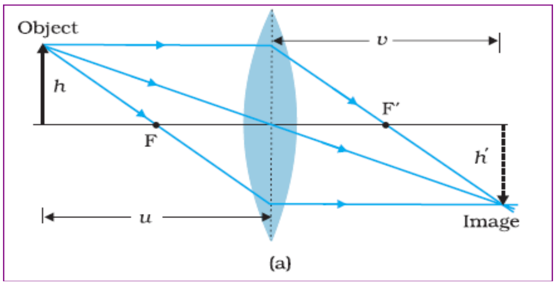
- Therefore

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

- This equation is the **thin lens formula**.
- The formula is valid for both convex as well as concave lenses and for both real and virtual images.

Linear magnification of a lens

- Magnification (*m) produced by a lens is defined,* as the ratio of the size of the image to that of the object.



$$m = \frac{h'}{h} = \frac{v}{u}$$

- The value of m is negative for real images and positive for virtual images.

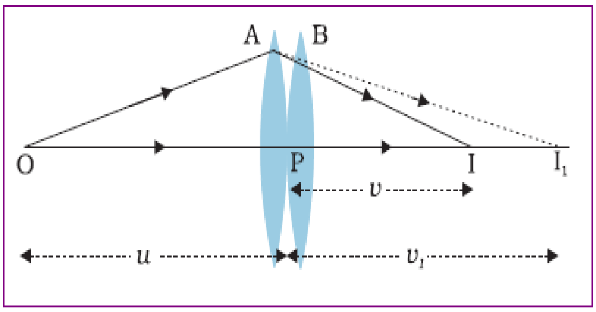
Power of a lens

- Power of a lens is the reciprocal of focal length expressed in metre.
- Power of a lens is a measure of the convergence or divergence, which a lens introduces in the light falling on it.

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

- The SI unit for power of a lens is dioptre (D).
- Power of a lens is positive for a converging lens and negative for a diverging lens.

Combination of thin lenses in contact



- For the first lens, object is at O and image is at I_1.

$$u \to u,\ v \to v_1,\ f \to f_1$$

- Thus

$$\frac{1}{v_1} - \frac{1}{u} = \frac{1}{f_1}$$

- For the second lens object is I_1 and image is at I.

$$u \to v_1,\ v \to v,\ f \to f_2$$

- Therefore

$$\frac{1}{v} - \frac{1}{v_1} = \frac{1}{f_2}$$

- Adding Equations

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2}$$

- If the two lens-system is regarded as equivalent to a single lens of focal length *f, we have*

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

- Therefore

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

- If several thin lenses of focal length f_1, f_2, f_3,*... are in contact, the effective* focal length of their combination is given by

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

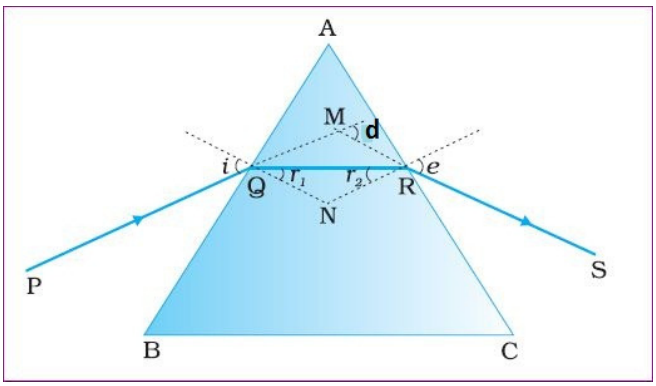
- Thus the power is given by

$$P = P_1 + P_2 + P_3 + \dots$$

- The total magnification

$$m = m_1\, m_2\, m_3\ \dots$$

REFRACTION THROUGH A PRISM



Angle of deviation, (d)

- The angle between the emergent ray RS and the direction of the incident ray PQ is called the *angle of deviation, δ.*

Angle of minimum deviation (D)

- The angle of deviation for which *the* refracted ray inside the prism becomes parallel to its base is called angle of minimum deviation.

Prism Formula (Eqn. for refractive index)

- In the quadrilateral AQNR, two of the angles (at the vertices Q and R) are right angles.
- Therefore, the sum of the other angles of the quadrilateral is 180^0.

$$\angle A + \angle QNR = 180^\circ$$

- From the triangle QNR

$$r_1 + r_2 + \angle QNR = 180^\circ$$

- Comparing these two equations

$$r_1 + r_2 = A$$

- We know ,exterior angle = sum of interior angles, thus

$$\mathbf{d = (i - r_1) + (e - r_2)}$$

- That is

$$\mathbf{d = (i + e - A)}$$

- Thus, the angle of deviation depends on the angle of incidence.
- At the minimum deviation, **d=D, i=e, r_1=r_2,** therefore

$$2r = A \text{ or } r = \frac{A}{2}$$

$$D = 2i - A, \text{ or } i = (A + D)/2$$

- Thus using Snell's law, the refractive index of the prism is given by

$$n_{21} = \frac{\sin\frac{(A+D)}{2}}{\sin\frac{A}{2}}$$

Prism formula for a small angled prism

- For a small angled prism

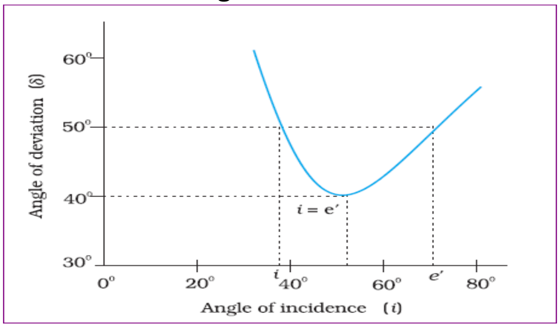
$$n_{21} = \frac{\frac{(A+D)}{2}}{\frac{A}{2}}$$

- Therefore

$$D = (n_{21} - 1)A$$

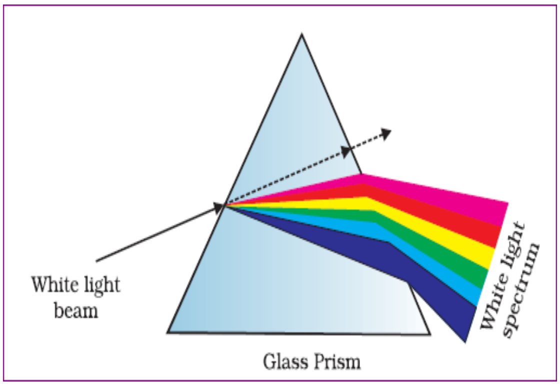
i-d curve

- It is the plot between the angle of deviation and angle of incidence.



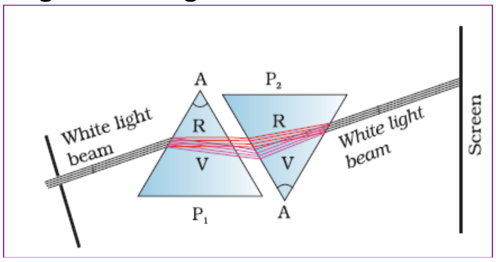
DISPERSION BY A PRISM

- The phenomenon of splitting of light into its component colours is known as *dispersion.*
- *The pattern of colour components* of light is called the spectrum of light.



- Thick lenses could be assumed as made of many prisms, therefore, thick lenses show ***chromatic aberration*** *due to* dispersion of light.
- When white light is passed through a prism, it splits into its seven component colors (**VIBGYOR).**
- If we place a second prism in an inverted position, close to the first prism, the

second prism recombines the colors and we get white light.



Cause of dispersion

- Dispersion takes place because the refractive index of medium for different wavelengths (colors) is different.

Dispersive medium

- The medium in which the different colours of light travel with different velocities is called a dispersive medium.
- Eg :- Glass

Non-Dispersive medium

- The medium in which all colours travel with the same speed is called non-dispersive medium.
  Eg:- vacuum

Chromatic abberation

- The inability of a lens to focus all wavelength to a single point is called chromatic aberration.

SOME NATURAL PHENOMENA DUE TO SUNLIGHT

The rainbow

- This is a phenomenon due to combined effect of dispersion, refraction and reflection of sunlight by spherical water droplets of rain.

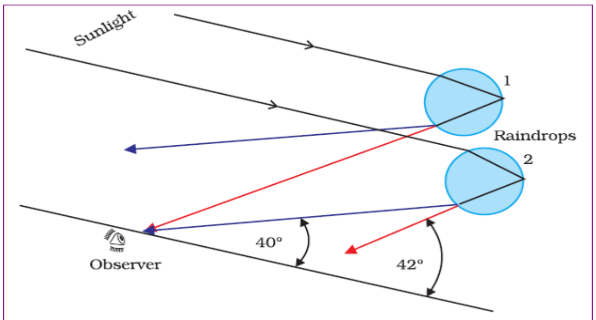
Condition for a person to see rainbow

- The conditions for observing a rainbow are that the sun should be shining in one part of the sky, while it is raining in the opposite part of the sky.
- An observer can therefore see a rainbow only when his back is towards the sun.

Formation of rainbow

Primary rainbow

- A primary rainbow is a result of three step processes: **refraction, total internal reflection** and again **refraction.**

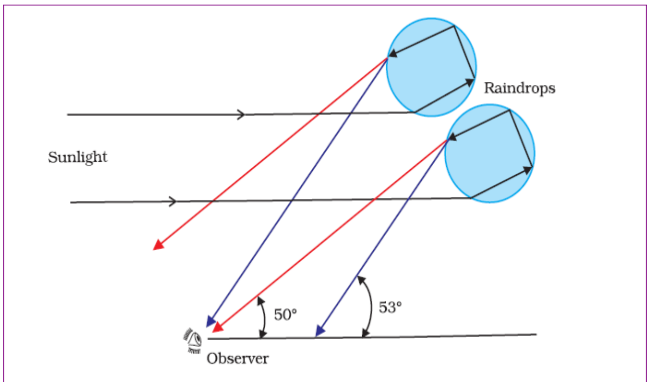


(b)

- In a primary rainbow the violet light emerges from raindrops at an angle of 40^0 relative to the incoming sunlight and red light emerges at an angle of 42^0.
- Thus the observer sees a rainbow with **red colour on the top** and **violet on the bottom.**

Secondary rainbow

- A secondary rainbow is a result of four-step process: **refraction, total internal reflection,** again **total internal reflection** and **refraction**.



(c)

- In a secondary rainbow the violet light emerges from the raindrops at an angle of 53^0 relative to the incoming sunlight and red light emerges at an angle of 50^0.
- Thus an observer sees a secondary rainbow with violet colour on the top and red on the bottom.
- Secondary rainbow is fainter than primary rainbow.

Scattering of light

- The irregular and partial reflection of light at the dust particles and air molecules in the atmosphere is called scattering.

Rayleigh's scattering law

- According to Rayleigh's scattering law the intensity of the scattered light is inversely proportional to forth power of wave length.

$$I_s \alpha \frac{1}{\lambda^4}$$

- Rayleigh's law is applicable only if the size of the scatterer is less than the wavelength of the light.

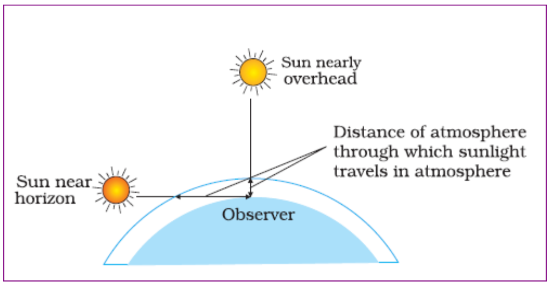
Blue color of the sky

- When sun light comes through the atmosphere it undergoes scattering at the dust particles and air molecules.
- Thus the low wavelength region (bluish region) is more scattered.
- Since our eyes are more sensitive to blue than violet, sky appears blue.

White clouds

- The particles of cloud are comparatively bigger in size.
- Therefore, all colors of sunlight are almost equally scattered. Thus clouds appear white.

Color of setting or rising sun



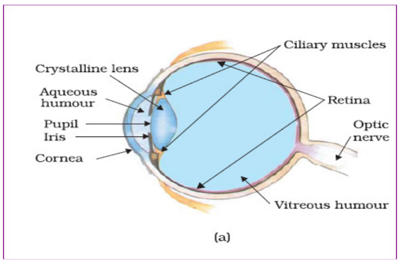
- During sunrise and sunset light has to travel more distance through the atmosphere.
- Thus most part of low wavelength region is scattered away and the least scattered longer wavelength region (reddish region) reaches our eye. Therefore the sun appears red.

Blue color of the sea

- It is due to the scattering of sunlight at the water molecules and dust particles.
- By Rayleigh's scattering law, low wavelength region (blue region) is more scattered. Therefore, sea appears blue

OPTICAL INSTRUMENTS

The eye



- Light enters the eye through a curved front surface, the **cornea**. It passes through the **pupil** which is the central hole in the **iris**.
- The size of the pupil can change under control of muscles. The light is further focused by the eye lens on the retina.
- The retina contains rods and cones which sense light intensity and colour, respectively, and transmit electrical signals via the optic nerve to the brain which finally processes this information.
- The shape (curvature) and therefore the focal length of the lens can be modified by the **ciliary muscles.**

Accommodation

- The curvature and hence the focal length of the eye lens can be adjusted by the ciliary muscles. This ability of the eye is called accommodation.

Near point (least distance of distinct vision)

- The closest distance for which the lens can focus light on the retina is called least distance of distinct vision or near point.
- For normal eye it is about **25cm**.it is denoted by **D.**
- This distance increases with age, because of the decreasing effectiveness of the ciliary muscle and the loss of flexibility of the lens.

Presbyopia

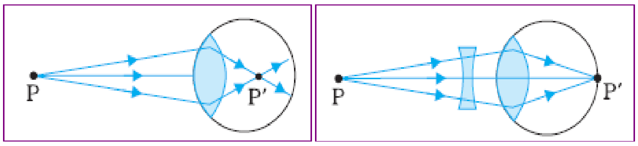
- The near point may be as close as about 7 to 8 cm in a child ten years of age, and may increase to as much as 200 cm at 60 years of age.
- Thus, if an elderly person tries to read a book at about 25 cm from the eye, the

image appears blurred. This condition (defect of the eye) is called *presbyopia.*

- It is corrected by using a converging lens for reading.

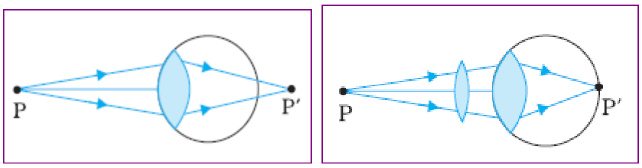
Nearsightedness or **myopia**

- In certain eyes, the light from a distant object arriving at the eye lens may get converged at a point in front of the retina.
- This type of defect is called near-sightedness or myopia.
- This defect can be compensated by using a **concave lens**



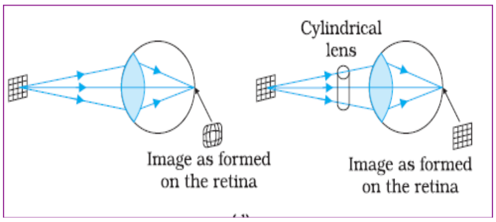
Far sightedness (long sight) or hypermetropia

- In certain eyes, the light from a near object is focused at a point behind the retina. This defect is called farsightedness or hypermetropia.
- This defect can be corrected by using **convex lens**.



Astigmatism

- Astigmatism occurs when the cornea is not spherical in shape.
- This can be corrected using cylindrical lens.



The microscope

- Microscope is used to get magnified images of near objects.

Simple microscope

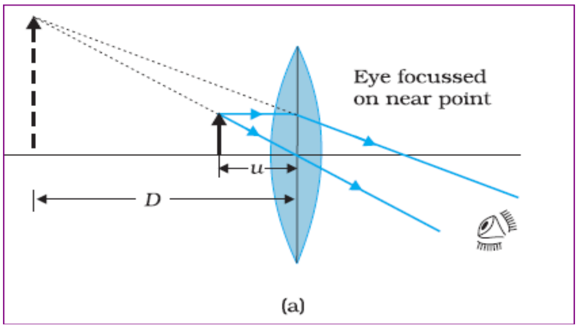
- Convex lens of small focal length is used as a simple microscope.
- If the object is at the focus, the image is at infinity.
- If the object is brought closer, then the image is formed at a distance closer than infinity.
- The position of the object can be adjusted so that the image is formed at the least distance of distinct vision.

Linear magnification

Image formed at the near point D

- The linear magnification *m, for the image* formed at the near point *D, by a simple microscope is,*

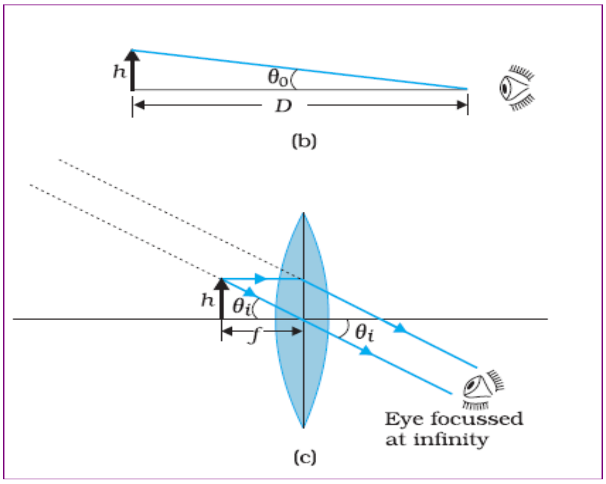
$$m = \frac{v}{u} = v\left(\frac{1}{v} - \frac{1}{f}\right) = \left(1 - \frac{v}{f}\right)$$



- Now according to our sign convention, *v is* negative, and is equal in magnitude to *D.*
- *Thus,* the magnification is

$$m = \left(1 + \frac{D}{f}\right)$$

When the image is at infinity



- If the image is formed at infinity,

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

Nature of the image

- The image is erect, magnified and virtual.

Limitation of simple microscope

- A simple microscope has a limited maximum magnification (≤ 9)

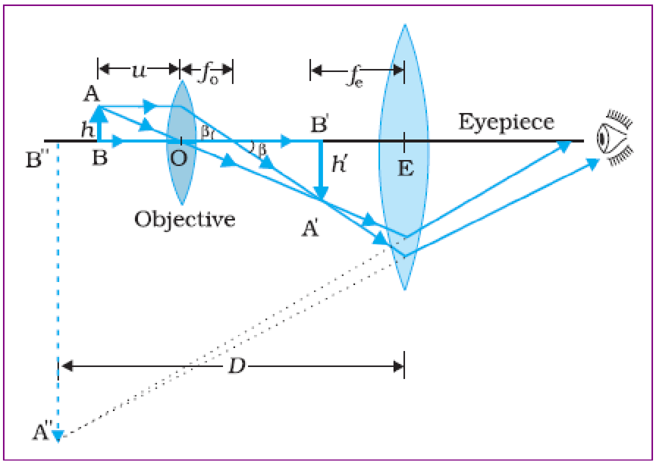
Compound microscope

- Compound microscope consists of two convex lenses objective and eye piece.
- The **focal length and aperture of objective** is **less than those of eye piece**.

Working

- When an object is placed beyond the focal length of the objective, a magnified, real and inverted image is formed beyond the '2f' of the objective on the other side.
- The distance between the lenses is adjusted so that this image falls within the focal length of the eye piece.
- Now the eyepiece acts as a simple microscope and the final image is formed at the least distance of distinct vision.

Ray diagram



Nature of the final image

- The final image is inverted with respect to the original object.

Linear magnification

When the image is at near point

- The total magnification of the combination of objective and eye piece is given by

$$m = m_o m_e$$

- Where m_O- magnification of objective m_e-magnification of eye piece.
- We have

$$m_o = \frac{v_o}{u_o}$$

$$m_e = \left(1 + \frac{D}{f_e}\right)$$

- Therefore

$$m = \frac{v_o}{u_o}(1 + \frac{D}{f_e})$$

- Since the object is p laced very n ear to the focus of the objective,

$$u_0 \approx f_0 \text{ and } v_0 \approx L, \text{the length of the tube}$$

- Therefore

$$m = (\frac{L}{f_o})(1 + \frac{D}{f_e})$$

Image formed at infinity

- If the final image is formed at infinity, then

$$m = m_o m_e = \left(\frac{L}{f_o}\right)\left(\frac{D}{f_e}\right)$$

$$m = (\frac{L}{f_o})(\frac{D}{f_e})$$

Resolving power of a microscope

- Resolving power of a microscope is defined as the reciprocal of minimum separation between two point objects which can be distinctly seen by it.

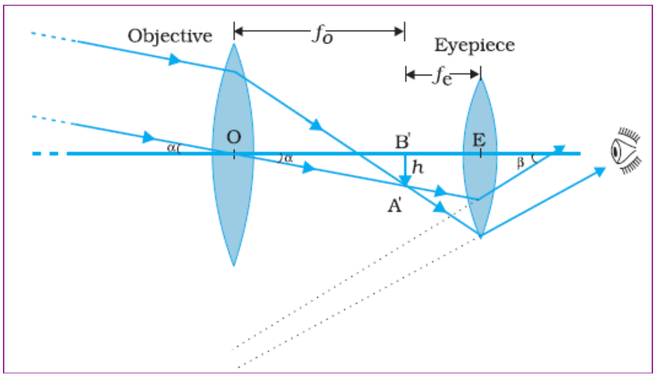
$$R.P. = \frac{1}{d_{min}} = \frac{2n\sin\beta}{1.22\lambda}$$

- Where **λ,** is the wavelength of the light used, **n** is the refractive index of the transparent medium between the object and the objective of the microscope, and **β** is half of the angle subtended by the diameter of the objective lens at the focus of the microscope.
- The quantity **n sin β** is called the **numerical aperture**.

Telescope

- The telescope is used to provide angular magnification of distant objects.
- The objective has a large focal length and a much larger aperture than the eyepiece.

A refracting telescope



- Refracting telescopes can be used both for terrestrial and astronomical observations.
- Light from a distant object enters the objective and a real and inverted image is formed at its focus (F_o).
- The eyepiece magnifies this image producing a final inverted image with respect to the object.

Magnification(m)

- The magnifying power 'm' is the ratio of the angle 'β' subtended by the final image at eye to the angle 'α' subtended by the object at the lens or eye.

$$m = \frac{\beta}{\alpha}$$

- But we have

$$\beta \approx \tan\beta = \frac{h}{f_e} \text{ and } \alpha \approx \tan\alpha = \frac{h}{f_0}$$

- Therefore

$$m = \frac{h/f_e}{h/f_0} = \frac{f_0}{f_e}$$

- That is

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

Nature of final image

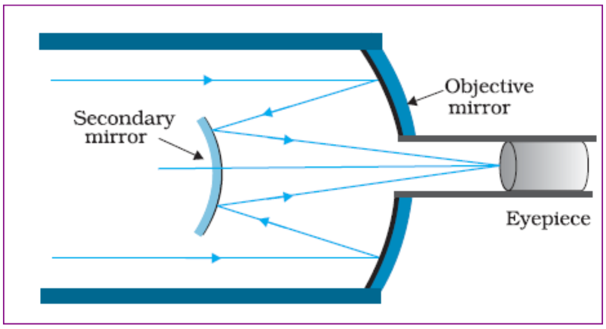
- The final image is enlarged, inverted and virtual with respect to the object.

Disadvantages of refracting telescope

- In refracting telescopes, to get better resolving power objective lens of large aperture is needed.
- Big lenses are very heavy and therefore, difficult to support by their edges.
- It is difficult and expensive to make such large sized lenses.
- Chromatic aberration is a main defect in a lens.

Reflecting telescopes

- In reflecting type telescopes, a concave mirror is used as objective instead of convex lens.
- The light from the object is reflected by the concave mirror to the secondary mirror, which again reflects the light into the eyepiece.
- This type of reflecting telescope is known as **cassegrain telescope.**



The advantages of a reflecting type telescope

- There is no chromatic aberration in a mirror.
- If a parabolic mirror is chosen as the objective, spherical aberration can be removed.
- Mechanical support is much less of a problem since a mirror weighs less.

Resolving power of a Telescope

- The resolving power of a telescope is defined as the reciprocal of smallest angular separation between two distant objects whose images are distinctly separated by the telescope.

$$R.P. = \frac{1}{\Delta\theta} = \frac{d}{1.22\lambda}$$

- Where d is the diameter of telescope objective and λ is the wavelength of light used.
- Δθ is called the limit of resolution of the telescope.

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