Introduction

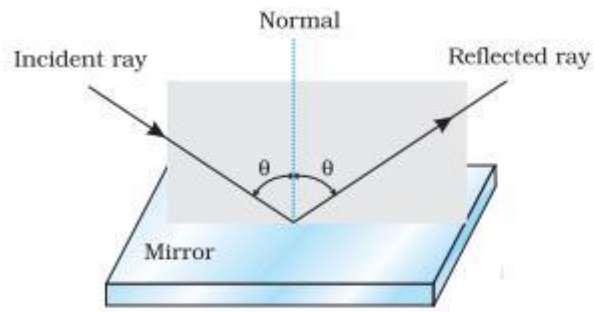
- We will try to learn what is light and also will try to understand some important phenomenon related to light and applications of optics in different optical instruments like microscope, telescope etc.
- How the phenomenon of laws of reflection and refraction play important part in our day to day to life.
- Light helps us to see all the objects around us. The entire phenomenon related to this we try a have a look on them.
- Also try to understand why certain objects enhance properties of light more as compared to others.

- **What is Light**?
  - Light is a form of energy which enables us to see things around us.
  - Light travels in straight path.
  - Speed of light is c =3 x 10^8m/s.
  - Light waves are the most common form of Electromagnetic waves.
  - Ray of light is the path of the light wave travelling from one point to another.
  - Beam of light is bunch of rays of light.

Reflection of light by Spherical Mirrors

- Reflection of light is the bouncing back off a ray of light when it strikes a boundary between different media through which it cannot pass.
- Reflection helps us to see different objects in this world.

- Laws of Reflection :-
  - The angle of reflection is equal to the angle of incidence (angle between incident ray and the normal). <i = <r
  - The incident ray, reflected ray and the normal to the reflecting surface at the point of incidence all lie in the same plane.
- Note: - These laws are valid at each point on any reflecting surface whether plane or curved.



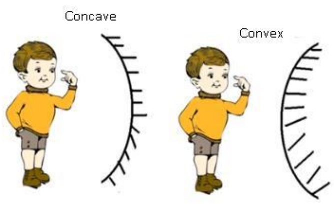
The incident ray, reflected ray and the normal to the reflecting surface lie in the same plane.

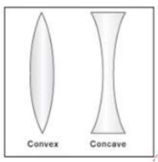
Spherical Mirrors

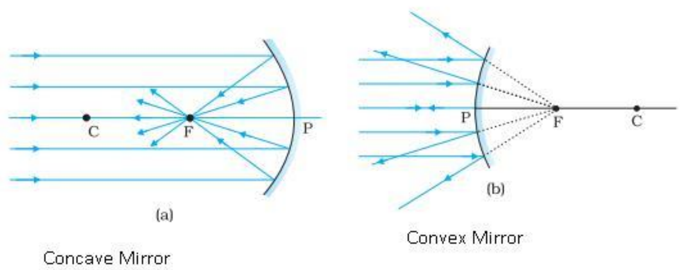
- A spherical mirror is a part of a reflective spherical surface and they are in sphere in shape.
- It is made up of a large number of extremely small plane mirrors.

Spherical Mirrors are of two types:-

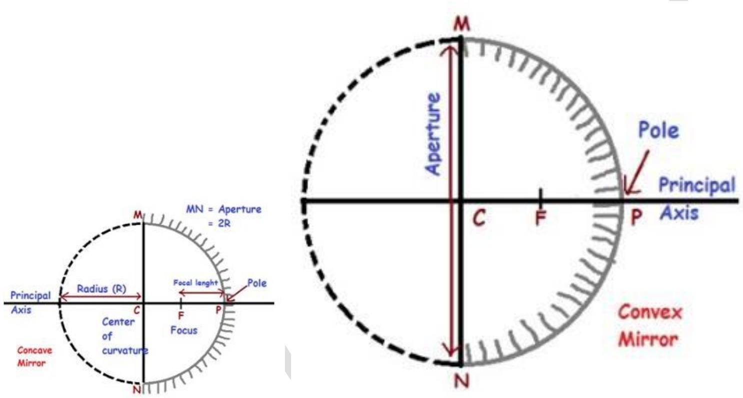
1. Concave Mirror: -
- They are silvered on the inside of sphere.
- It is a converging mirror.
- In a Concave mirror when the rays of light reflect back they meet or converge at a point that is why known as converging mirror.
2. Convex Mirror: -
- They are silvered on the outside of sphere.
- In Convex mirror the rays don't meet at appoint after reflection that is why it is a diverging mirror.







<u>Some terminologies related to Spherical Mirrors</u>:-



Pole:

- The centre of the reflecting surface of a spherical mirror.
- It lies on the surface of the mirror.
- The pole is usually represented by the letter P.

2. Centre of curvature:

- The reflecting surface of a spherical mirror forms a part of a sphere. The sphere's centre is called as centre of curvature.
- It is represented by the letter C.
- The centre of curvature is not a part of the mirror. It lies outside its reflecting surface.
- The centre of curvature of a concave mirror lies in front of it.
- However, it lies behind the mirror in case of a convex mirror.

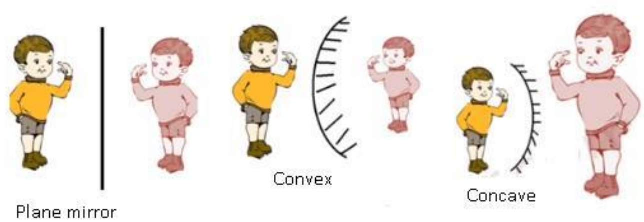
3. Radius of curvature
- The radius of the sphere of which the reflecting surface of a spherical mirror forms a part
- It is represented by the letter R.

4. Principal axis
- A straight line passing through the pole and the centre of curvature of a spherical mirror.
- Principal axis is normal to the mirror at its pole.

5. Principal Focus
- Rays parallel to the principal axis falling on a concave mirror meet/intersect at the point on the principal axis. The point is called principal focus of concave mirror.
- The reflected rays appear to come from a point on the principal axis when rays parallel to the principal axis fall on a convex mirror, that point is called principal focus of convex mirror.
- The principal focus is represented by the letter F.
- The distance between the pole and the principal focus of a spherical mirror is called the focal length. It is represented by the letter f.

6. Aperture
- The diameter of the reflecting surface of spherical mirror is called its aperture.
- Mirrors whose aperture is much smaller than its radius of curvature, we use R=2f.

Image formation by Spherical Mirrors
- The rays of light through centre of curvature retrace its path.
- The ray of light parallel to the principal axis, on reflection, passes through the focus.
- The ray of light through F is reflected parallel to the principal axis.
- There are 2 ways an image is formed: -
  - Real image of an object where reflected rays actually meet, they are inverted and formed on the same side of the object.
  - Virtual image of an object where reflected rays appear to meet. They are always erect and cannot be projected on the screen.
  - They are formed beyond the mirror



<u>Sign Convections</u>:-
Following are the sign convections which are to be followed:
1. The pole (P) of the mirror is taken as the origin. The principal axis of the mirror is taken as the x-axis (X'X) of the coordinate system.

(2) The object is always placed to the left of the mirror. This implies that the light from the object falls on the mirror from the left-hand side.

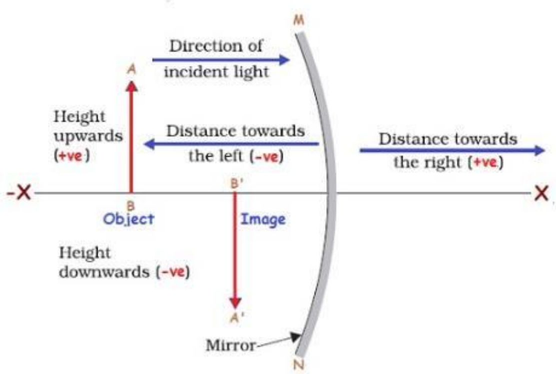
(3) All distances parallel to the principal axis are measured from the pole of the mirror.

(4) All the distances measured to the right of the origin (along + x-axis) are taken as positive while those measured to the left of the origin (along – x-axis) are taken as negative.

(5) Distances measured perpendicular to and above the principal axis (along + y-axis) are taken as positive whereas which are measured along (-y axis) are taken as negative.

(vi) The heights measured upwards with respect to x-axis and normal to the principal axis (x-axis) of the mirror/ lens is taken as positive. The heights measured downwards are taken as negative.

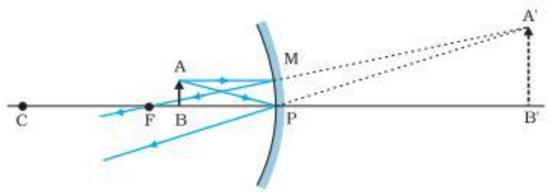
(vii) The radius of curvature and the focal length of a concave mirror are negative and those for a convex are positive.



Mirror Formula

- Concave Mirror
- (1/v) + (1/u) = (1/f)
- Where:-
- The distance of the object from its pole is called the object distance (u).
- The distance of the image from the pole of the mirror is called the image distance (v).
- The distance of the principal focus from the pole is called the focal length (f).
- Mirror equation relates image distance (v) with object distance (u) and focal (f) length
- Consider a concave mirror, an object AB placed in the front of the concave mirror. The image produced is A'B'.
- Consider two right-angled similar triangles A'B'F and MPF.
- Therefore (B'A'/PM) = (B'F/FP)
- Or (B'A'/BA) = (B'F/FP) (because PM= AB) (1)
- Since <APB = <AP'B', the right angles triangles are also similar.
- Therefore, (B'A'/BA) = (B'P'/BP) (2)
- Comparing equations (1) and (2):-
- (B'F/FP) = (B'P –FP)/(FP) = (PB')/(PB) equation (A)
- Considering the sign conventions:
  - Light travels from the object to the mirror MPN. Hence this is taken as the positive direction.
  - The object AB, image A'B' as well as the focus F from the pole P, we have to travel opposite to the direction of incident light.
  - Therefore all are taken as negative.
  - This implies, B'P = -v , FP =-f and BP =-u
  - Therefore equation(A) changes to:
    - (-v –f)/(-f) = (-v/-u)
    - Or (v-f)/(f) =(v/u)

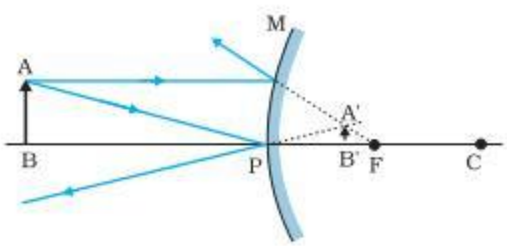
   - => (1/v) +(1/u) = (1/f)
  - This relation is known as the mirror equation.



(Concave mirror)

(b) In case of convex mirror

- Using equation (A) (B'F/FP) = (B'P –FP)/(FP) = (PB')/(PB)
- Image Distance PB' = (+v) as it is measured from the pole and in the direction of the incident ray.
- PF= + f as it is also along the incident ray.
- Object distance PB= (-u) as it is in the direction opposite to the incident ray.
- Substituting the values,
  - (v-f)/(u) = (+v/-u)
  - =>(v/f) – 1 = ((-v/u)
  - Dividing throughout by f,
  - (1/f) – (1/v) =(-1/u)
  - Or (1/f) = (1/v) –(1/u)
- Therefore the mirror equation will be:- (1/f) = (1/v) –(1/u)



Magnification of a Spherical Mirror

- Linear Magnification (m) produced by a spherical mirror gives the relative extent to which the image of an object is magnified with respect to the object size.
- Mathematically,
- m= (height of the image h')/(height of the object h)
- Or, m = (h')/(h)
- If the sign of magnification is negative then the image is real and if it is positive then the image is virtual.
- A real, inverted image is formed by a concave mirror.
- In triangles A'B'P and ABP, we have,
- (-B'A'/BA) =(-B'P)/(BP) (From equation 2)
- Applying sign convention, this becomes
- (– h'/h) = -(-v/- u)
- Therefore, m = (h'/h) = (- v/u)

Concave Mirror

- <u>In case of convex mirror</u>: Virtual and erect image is formed.
- m = (h'/h) = (A'B')/(AB) = (PB')/(PB)
- m= -(v/u)

Convex Mirror

<u>Note</u>: - It is valid for all the cases of reflection by a spherical mirror (concave or convex) whether the image formed is real or virtual.

<u>Problem</u>:

A small candle, 2.5 cm in size is placed at 27 cm in front of a concave mirror of radius of curvature 36 cm. At what distance from the mirror should a screen be placed in order to obtain a sharp image? Describe the nature and size of the image. If the candle is moved closer to the mirror, how would the screen have to be moved?

<u>Answer</u>:

Given:

Size of the candle, h =2.5cm

Image size = h'

Object distance, u = −27 cm

Radius of curvature of the concave mirror, R = −36 cm

Focal length of the concave mirror, f =(R/2) = (-36/2) =-18cm

By mirror formula,

(1/u) + (1/v) = (1/f)

Or (1/v) = (1/f) – (1/u)

= (1/-18) - (1/-27)

= (-3 +2)/ (54)

= (-1/54)

Therefore v = -54cm

Therefore, the screen should be placed 54 cm away from the mirror to obtain a sharp image.

The magnification of the image is given as:

m= (h'/h)

=-(v/u)

Therefore, h' = (-v/u) x h

= - (-54/-27) x 2.5

=-5cm

The (-) ive sign shows the image is real and inverted. If the candle is moved closer to the mirror, the screen has to be moved away from the mirror to obtain the image on the screen.

However when the candle is moved to a distance less than 18cm from the mirror, the image will become virtual image and cannot be obtained on the screen.

Problem:-

Suppose while sitting in a parked car, you notice a jogger approaching towards you in the side view mirror of R = 2 m. If the jogger is running at a speed of 5 m s–1, how fast the image of the jogger appear to move when the jogger is (a) 39 m, (b) 29 m, (c) 19 m, and (d) 9 m away.

Answer:-

From the mirror equation, we get, (1/f) = (1/u) + (1/v)

For convex mirror, since R = 2 m, f = 1 m. Then for u = –39 m,

v = (1/u) + (1/f)

=> v = (fu)/ (u-f)

Therefore putting f= +1m, u =-39m,

v= (39/40) m

Since the jogger moves at a constant speed of 5 m s^{-1}, after 1 s the position of the image v (for u = –39 + 5 = –34m) is (34/35) m.

The shift in the position of image in 1 s is

= (39/40)-(34/35) = (1365 -1360)/ (1400)

= (5/1400) = (1/280) m

Therefore, the average speed of the image when the jogger is between 39 m and 34 m from the mirror, is (1/280) ms^{-1}

Similarly, it can be seen that for u = –29 m, –19 m and –9 m, the speed with which the image appears to move is (1/150) ms^{-1}, (1/60) ms^{-1} and (1/10) ms^{-1} respectively

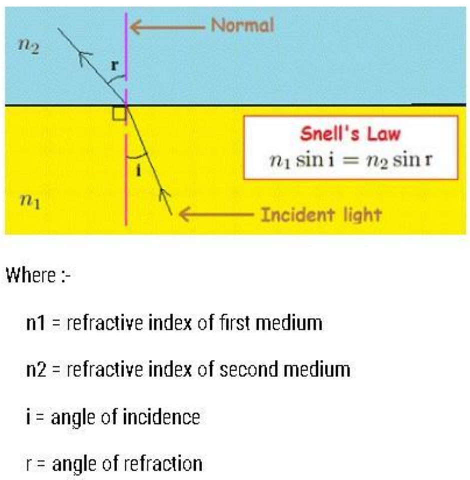
Although the jogger has been moving with a constant speed, the speed of his/her image appears to increase substantially as he/she moves closer to the mirror. This phenomenon can be noticed by any person sitting in a stationary car or a bus. In case of moving vehicles, a similar phenomenon could be observed if the vehicle in the rear is moving closer with a constant speed.

Refraction of Light

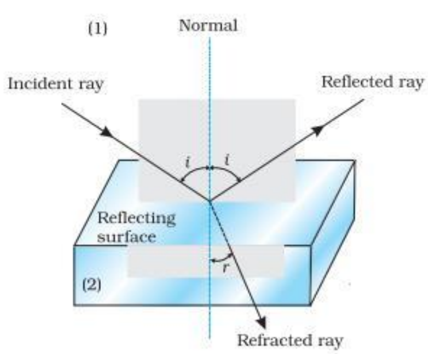
- Light does not travel in the same direction in all media .When a light ray passes obliquely from rarer medium (air) to a denser medium (water, glass) there is a change in its direction of propagation.
- This bending of light at the boundary when it passes from one medium to another is termed as refraction.
- Refraction is due to change in the speed of light as it enters from one transparent medium to another.

- Laws of refraction given by Snell's law:

1. The incident ray, the refracted ray and the normal to the interface at the point of incidence, all lie in the same plane.
2. The ratio of the sine of the angle of incidence to the sine of angle of refraction is constant.
    - The angles of incidence (i) and refraction (r) are the angles that the incident and its refracted ray make with the normal, respectively.
        - n_{21} = (sin i)/(sin r)
        - Where n_{21} = is a constant known as refractive index of the second medium with the first.



- **Note**: - The refractive index (n_{21}) depends on the wavelength of light, also characteristic of pair of media.
- It is independent of the angle of incidence.

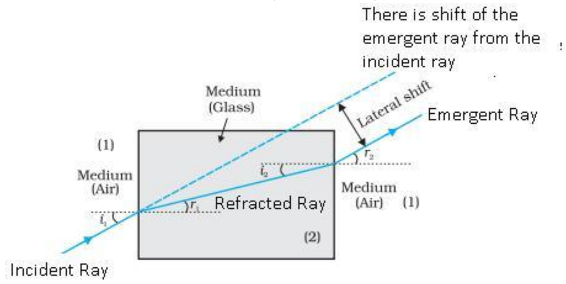


- If n_{21} >1, r<i then the refracted ray bends towards the normal. Medium 2 will be optically denser. So medium 2 is called optically denser medium as compared to medium 1.
- If n_{21} <1, r>i then the refracted ray bends away from the normal. Medium 2 will be optically denser. So medium 2 is called optically rarer medium as compared to medium 1.

1. <u>Refraction through a parallel-side slab</u>

- For a rectangular slab, refraction takes place at two interfaces (air-glass and glass-air).

- From the diagram it is clear that $r_2=i_1$e. emergent ray is parallel to the incident ray, there will be no deviation.
- But there will be lateral shift w.r.t the incident ray.
- Refractive index of medium 3 w.r.t medium 1 $n_{31}=(n_3/n_1)$
- Or $n_{31} = (n_3/n_2) \times (n_2/n_1) = (n_{32} \times n_{21})$
  - Where
  - n_1 = refractive index of medium 1
  - n_2 = refractive index of medium 2
  - n_3 = refractive index of medium 3
- It can be written as: - $(n_{31} \times n_{21})$ where n_{31} is the refractive index of medium 3 w.r.t medium 1.

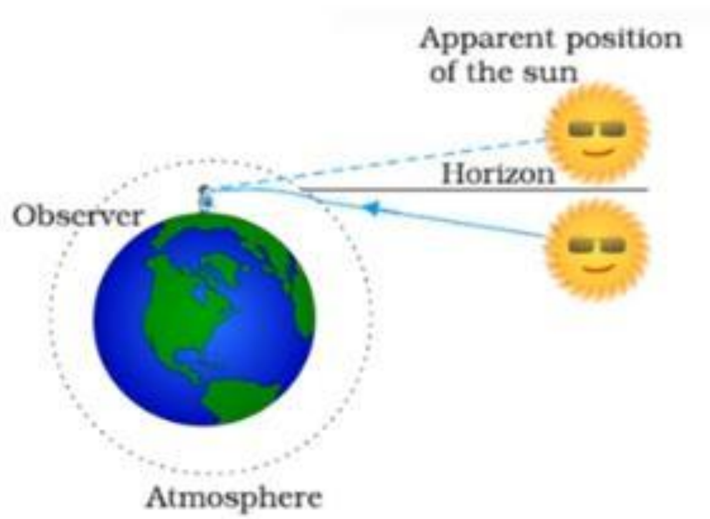


Refraction & Natural phenomena

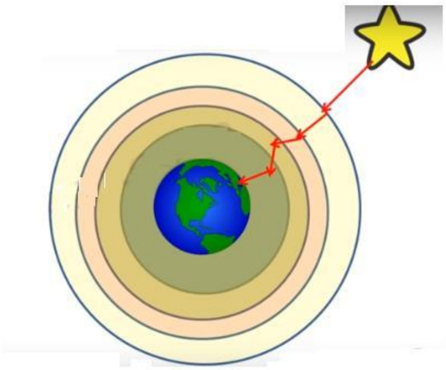
- The refraction of light through the atmosphere is responsible for many interesting phenomena.

1. <u>Advanced Sunrise and Delayed Sunset:-</u>

- For example, 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.
- By actual sunrise we mean the actual crossing of the horizon by the sun.
- The figure shows the actual and apparent positions of the sun with respect to the horizon. The refractive index of air with respect to vacuum is 1.00029.
- Due to this, the apparent shift in the direction of the sun is by about half a degree and the corresponding time difference between actual sunset and apparent sunset is about 2 minutes.
- The apparent flattening (oval shape) of the sun at sunset and sunrise is also due to the same phenomenon.



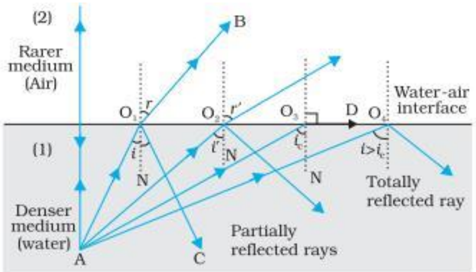
2. Twinkling of Stars:-



- All the stars have light of their own. Stars twinkle because by the time the light reaches our eye, it passes through the various layers of the atmosphere.
- At one point of time star appears to be at one position and at another minute it appears to be at another position.
- So if we see one object at two different places at a very frequent interval of time. Therefore we feel that the star is twinkling.
- This twinkling of star is also the phenomenon of refraction of light.

Total Internal Reflection

- 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.
- In total internal reflection phenomenon there is no refraction and the entire incident ray will get reflected.
- Conditions for Total Internal Reflection are as follows:-
    - Light ray travels from denser to rarer medium.
        - When a ray of light moves from a denser medium to a rarer medium it moves away from the normal. The ray will get refracted at an r (angle of refraction).
        - But if we keep increasing angle of incidence it will further move from normal and the angle of refraction will become less.
        - A condition will come if we keep on increasing the angle of incidence, the angle of refraction will become equal to 90^0 and further increase in angle of incidence there will be no refraction will occur but reflection will take place.
        - This is total internal reflection.
        - The limiting factor beyond what total internal reflection will take place will be :-
            - The angle of incidence should be greater than the angle of incidence for which angle of refraction is 90^0.
        - Angle of incidence should correspond to angle of refraction = 90^0.
        - This angle is known as Critical angle.
        - Angle of incidence should be greater than Critical angle.
    - Total internal Reflection is an optical phenomenon observed when a ray of light travelling from denser to rarer medium strikes the boundary at an angle greater than the critical angle.

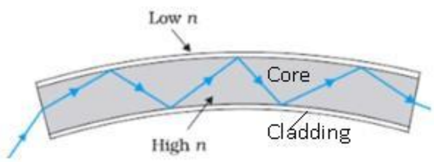


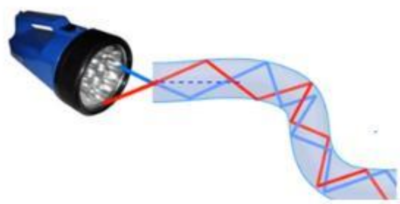
Applications of Total Internal Reflection

- Optical Fibres:-
    - They are used in telecommunication industries.
    - Optical fibres work on the phenomenon of total internal reflection.
    - Characteristics of Optical Fibres:-
        - They are small in size and light in weight.
        - They have greater information carrying capacities than metallic wires.


Working of Optical fibres:

- Optical fibres are fabricated with high quality composite glass/quartz fibres.
- Each fibre consists of a core and cladding. The refractive index of the material of the core is higher than that of the cladding.
- As there is difference in the refractive index of core and denser; core acts as a denser medium and cladding acts as a rarer medium.





- 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.
- Optical fibres are fabricated such that light reflected at one side of inner surface strikes the other at an angle larger than the critical angle.
- Even if the fibre is bent, light can easily travel along its length. Thus, an optical fibre can be used to act as an optical pipe.
- They are made up of plastic.

<u>Glass vs. Plastic Optical Fibres</u>

Plastic Optical fibres	Glass Optical fibres
1.Cheaper	They are not so cheap.
2. Flexible	They are not so flexible.
3. They can withstand more stress.	They cannot withstand more stress.
4. Less efficient transmission.	More efficient transmission over large distances.

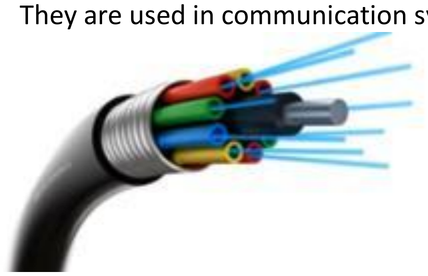
<u>Applications of Optical Fibres</u>

1. Fibre optic endoscopy

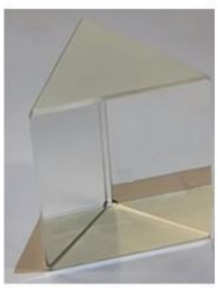
1. Decorative items

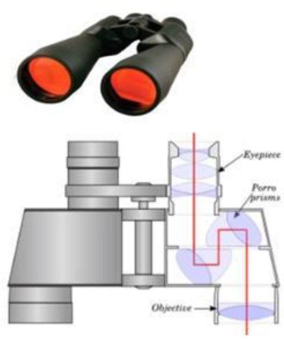
Different plastic strips when electricity is passed theses strips will keep revolving giving different colours.

1. They are used in communication system

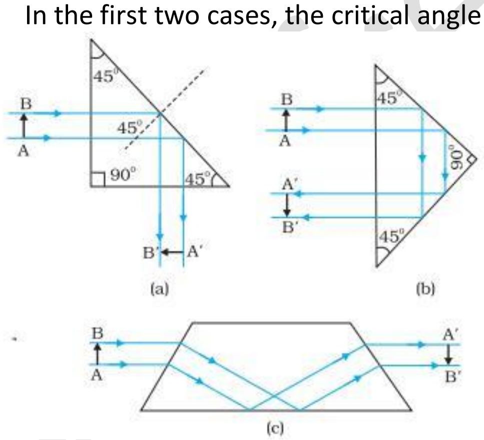


1. Prism





- Prisms make use of total internal reflection which makes it useful in binoculars.
- Prisms designed to bend light by 90º or by 180º make use of total internal reflection.
- Such a prism is also used to invert images without changing their size.
- In the first two cases, the critical angle i_c for the material of the prism must be less than 45º.

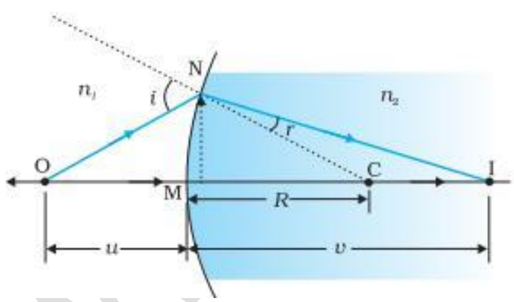


Problem:
A prism is made of glass of unknown refractive index. A parallel beam of light is incident on a face of the prism. The angle of minimum deviation is measured to be 40°. What is the refractive index of the material of the prism? The refracting angle of the prism is 60°. If the prism is placed in water (refractive index 1.33), predict the new angle of minimum deviation of a parallel beam of light.

Answer:
Given:
Angle of minimum deviation, $\delta_m = 40°$
Angle of the prism, A = 60°
Refractive index of water, μ = 1.33
Refractive index of the material of the prism = μ'
The angle of deviation is related to refractive index (μ') as:
$\mu' = (\sin (A + \delta_m)/2)/ (\sin (A/2))$
= (sin (600 + 400))/ (sin (600/2))
= (sin (500))/ (sin (300))
= 1.532
Hence, the refractive index of the material of the prism is 1.532.
Since the prism is placed in water,
Let δ_m '= the new angle of minimum deviation for the same prism.
The refractive index of glass with respect to water is given by the relation:
$\mu_g^w = (\mu')/ (\mu)$
$= (\sin (A + \delta_m ')/ (2)) / (\sin (A/2))$
$(\sin (A + \delta_m ')/ (2)) = (\sin (A/2)) (\mu')/ (\mu)$
$(\sin (A + \delta_m ')/ (2))$ = sin (600) (1.532)/ (1.33)
$(\sin (A + \delta_m ')/ (2))$ = 0.5759
$(A + \delta_m ')/ (2)$ = sin -1(0.5759)
$(A + \delta_m ')/ (2)$ = 35.160
$(600 + \delta_m ')$ = 70.320
Therefore, δ_m '= (70.320 - 600)
δ_m '=10.320
Hence, the new minimum angle of deviation is 10.32°

Refraction at Spherical Surfaces

- Consider refraction at a spherical interface between two transparent media. An infinitesimal part of a spherical surface can be regarded as planar and the same laws of refraction can be applied at every point on the surface.



- The rays are incident from a medium of refractive index n_1, to another of refractive index n_2.
- Assuming the aperture (or the lateral size) of the surface to be small compared to other distances involved, so that small angle approximation can be made.
- Consider NM will be taken to be nearly equal to the length of the perpendicular from the point N on the principal axis.
- Considering small angles,
    - tan<NOM = (MN)/(OM)
    - tan < NCM = (MN/MC)

  - tan<NIM = (MN)/(MI)
  - Now, for ΔNOC, <i is the exterior angle. Therefore, i = ∠NOM + ∠NCM
  - i = (MN/OM)+(MN/MC) (equation (1))
  - Similarly, r = ∠NCM – ∠NIM
  - e., r = (MN/MC) – (MN/MI) (equation (2))
  - Now, by Snell's law n_1 sin i = n_2 sin r or for small angles
  - $n_1 i = n_2 r$
- Substituting i and r from Equation. (1) and (2), we get
- $(n_1/OM) + (n_2/MI) = (n_2 – n_1)/MC)$ Equation (3)
- Here, OM, MI and MC represent magnitudes of distances. Applying the Cartesian sign convention,
- OM = –u, MI = +v, MC = +R
- Substituting these in Eq. (3), we get,
- $(n_2 – v) – (n_1/u) = (n_2 – n_1)/(R)$ Equation (4)
- Equation (4) gives us a relation between object and image distance in terms of refractive index of the medium and the radius of curvature of the curved spherical surface. It holds for any curved spherical surface.

Problem:

A small pin fixed on a table top is viewed from above from a distance of 50cm. By what distance would the pin appear to be raised if it is viewed from the same point through a 15cm thick glass slab held parallel to the table? Refractive index of glass = 1.5. Does the answer depend on the location of the slab?

Answer:

Given:

Actual depth of the pin, d = 15 cm

Apparent depth of the pin = d'

Refractive index of glass, μ = 1.5

Ratio of actual depth to the apparent depth is equal to the refractive index of glass, i.e. μ = (d/d')

Therefore, d' = (d/ μ)

= (15/1.5) =10 cm

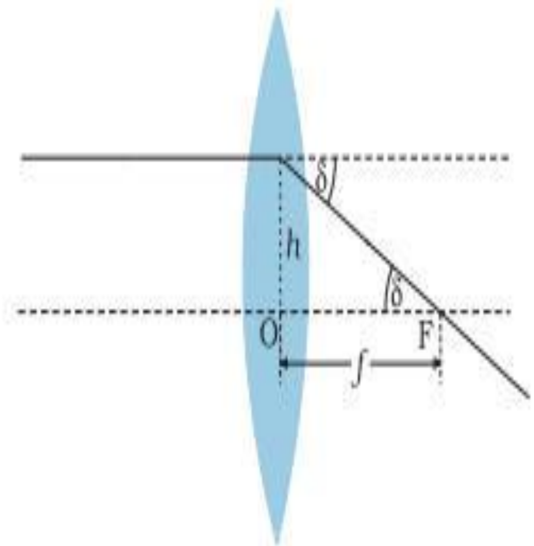
The distance at which the pin appears to be raised = (d' –d)

= (15-10) = 5cm

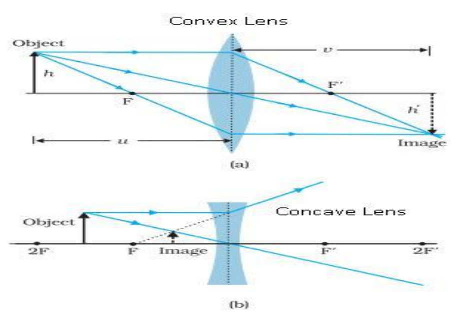
For a small angle of incidence, this distance does not depend upon the location of the slab.

Lens Maker's Formula

- The image formation can be seen in terms of two steps:
- The first refracting surface forms the image I_1 of the object O.
  - The image I_1 acts as a virtual object for the second surface that forms the image at I.
  - Applying equation,
  - $(n_1 /OM) + (n_2/MI) = (n_2 – n_1)/MC)$
  - to the first interface ABC, we get
  - $(n_1/OB) + (n_2/BI_1) = (n_2-n_1)/BC_1)$ (Equation 1)
- A similar procedure applied to the second interface ADC :$(n_2 /DI_1) + (n_1/DI) =(n_2 – n_1)/(DC_2)$ (Equation 2)
  - (In this case medium on the right side of ADC is n_1 while on left is n_2. Also DI_1 is (-) as the distance is measured against the direction of incident light.)
- For a thin lens, $BI_1 = DI_1$.



- Adding equation(1) and equation (2)
- $(n_1/OB) + (n_1/DI) = (n_2-n_1)(1/BC_1 + 1/DC_2)$ Equation (3)
- Suppose the object is at infinity, i.e. OB-> ∞ and DI =f,
- Therefore from the Equation(3),
- $(n_1/f)=(n_2-n_1)(1/BC_1 + 1/DC_2)$ (Equation 4)
- The point where image of an object placed at infinity is formed is called the focus F, of the lens and the distance f gives its focal length.



- A lens has two foci, F and F', on either side of it.
- By the sign convention,
- $BC_1 = + R_1, DC_2 = -R_2$
- Therefore equation(4) can be written as,
- $(1/f)=(n_{21} -1)((1/R_1)- (1/R_2))$ Equation(5) (because $n_{21}=(n_2/n_1)$)
- Equation (5) is known as Lens Maker's Formula.
  - It is useful to design lenses of desired focal length using surfaces of suitable radii of curvature.
- **Note** that the formula is true for a concave lens also. In that case R_1 is negative, R_2 positive and therefore, f is negative.
- Therefore from equation 3 and 4 we get,
- $(n_1/OB) + (n_1/DI) =(n_1/f)$
- In the thin lens approximation, we can take B and D so close to the optical centre of the lens.
- Applying sign conventions, BO=-u and DI=+ v
- $(1/v)- (1/u) = (1/f)$. It is thin lens formula.

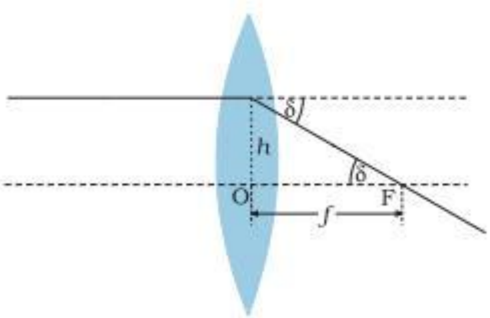
- This formula is valid for both convex and concave lenses.
- The two foci, F and F′, of a double convex or concave lens are equidistant from the optical centre. The focus on the side of the (original) source of light is called the first focal point, whereas the other is called the second focal point.

Power of a Lens

-
  - The power P of a lens is defined as the tangent of the angle by which it converges or diverges a beam of light falling at unit distant from the optical centre.
    - tan δ = (h/f) if h=1
    - tan δ = (1/f)
    - Or δ = (1/f) for small value of δ .
    - Therefore, P =(1/f) Where, p = power of the lens and f = focal length of the lens in meters.
  - Power of a lens is a measure of the convergence or divergence produced by a lens.
  - A lens of shorter focal length bends the incident light more, converging in case of convex and diverging in case of concave.
  - The SI unit for power of a lens is dioptre (D):

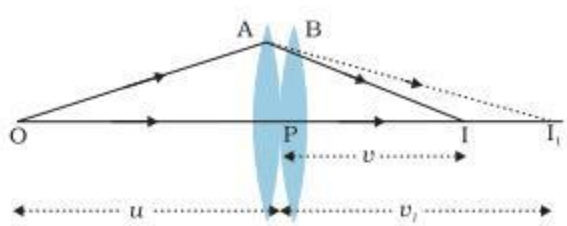
1D = $1m^{-1}$.

  - The power of a lens of focal length of 1 metre is one dioptre.
  - Power of a lens is positive for a converging lens and negative for a diverging lens.



Combination of thin lenses in contact

- Consider two lenses A and B of focal length f_1 and f_2 placed in contact with each other.



- An object is placed at O beyond the focus of the first lens A on the common principal axis.
- The image of point object O will be at I_1 formed by lens A, which act as a virtual object for second lens B producing the final image at I.
- As these lenses are thin, therefore a common optical centre is chosen. Let this common optical centre be P.
- Let Object distance for the first lens(A) PO =u
- Final Image distance PI =v
- Final Image distance $PI_1 = v_1$
- Considering lens A, Image I_1 is produced

- Therefore, $(1/v_1) – (1/u_1) = (1/f_1)$ (Equation (1))
- Considering lens B, Final Image I is produced
- Therefore, $(1/v) – (1/v_1) = (1/f_2)$ (Equation (2))
- Adding (Equation (1)) and (Equation (2))
- $(1/v) – (1/u) = (1/f_1) + (1/f_2)$ (Equation (3))
- If we replace this combination by a single lens of focal length F so that image of O is formed at the same position I,
- Therefore, $(1/v)-(1/u) = (1/F)$ (Equation (4))
- $(1/F) = (1/f_1) + (1/f_2)$ (Equation (5))
- The derivation is valid for any number of thin lenses in contact. 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:
- $(1/f) = (1/f_1) + (1/f_2) + (1/f_3) + …$ (Equation (6))
- In terms of power, Eq. (6) can be written as:
- $P = P_1 + P_2 + P_3 + …$ (Equation (7)) where P is the net power of the lens combination.
- The sum in Equation (7) is an algebraic sum of individual powers, so some of the terms on the right side may be positive (for convex lenses) and some negative (for concave lenses).

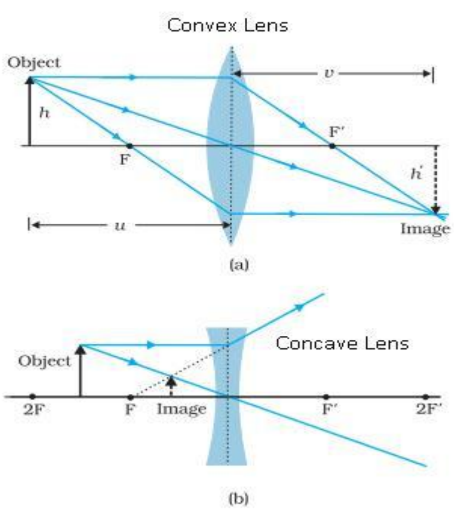
- Combination of lenses helps

(a) To meet desired magnification
(b) It also enhances sharpness of the image.
(c) To make final image erect.
(d) To remove certain defects in the lens.

- Such a system of combination of lenses is commonly used in designing lenses for cameras, microscopes, telescopes and other optical instruments.

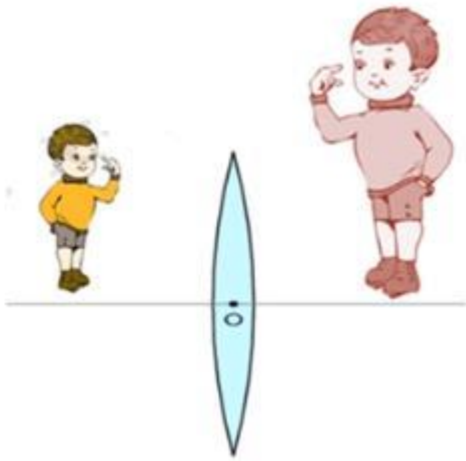
Refraction by Lens: Convex & Concave

1. A ray of light incident on the lens parallel to the principal axis after refraction passes through second principal axis.
2. A ray of light passing through first principal focus after refraction should move parallel to the principal axis.
3. A ray of light passing through the optical centre should go-undeviated after refraction.



Magnification of a lens

- It is the ratio of the size of the image to the size of the object.
- It is denoted as m =(h'/h) = (v/u)
- For a virtual and erect image is formed by a convex lens or by concave lens, m is positive and for real and inverted image m is negative.



Problem:

An object of size 3.0cm is placed 14cm in front of a concave lens of focal length 21cm. Describe the image produced by the lens. What happens if the object is moved further away from the lens?

Answer:

Given:

Size of the object, h_1 = 3 cm

Object distance, u = −14 cm

Focal length of the concave lens, f = −21 cm

Image distance = v

According to the lens formula, we have the relation:

(1/v) – (1/u) = (1/f)

(1/v) = - (1/21) – (1/14)

= (-2-3)/ (42)

= (-5/42)

Therefore, v = - (42/5) =- 8.4cm

Hence, the image is formed on the other side of the lens, 8.4 cm away from it. The negative sign shows that the image is erect and virtual.

The magnification of the image is given as:

m = (h_2)/ (h_1) = (v/u)

Therefore h_2 = ((-8.4/-14) x 3)

h_2 = 1.8cm

Hence, the height of the image is 1.8 cm.

If the object is moved further away from the lens, then the virtual image will move toward the focus of the lens, but not beyond it.

The size of the image will decrease with the increase in the object distance.

Problem:-

Double-convex lenses are to be manufactured from a glass of refractive index 1.55, with both faces of the same radius of curvature. What is the radius of curvature required if the focal length is to be 20cm?

Answer:

Refractive index of glass, $\mu = 1.55$

Focal length of the double-convex lens, f = 20 cm

Radius of curvature of one face of the lens = R1

Radius of curvature of the other face of the lens = R2

Radius of curvature of the double-convex lens = R

Therefore, $R_1 = R$ and $R_2 = -R$

The value of R can be calculated from Lens – Maker formula:

$(1/f) = (\mu - 1)\,[(1/R_1) - (1/R_2)]$

$(1/20) = (1.55 - 1)\,[(1/R) + (1/R)]$

$(1/20) = 0.55 \times (2/R)$

Therefore $R = (0.55 \times 2 \times 20)$

=22cm

Hence, the radius of curvature of the double-convex lens is 22 cm.

Problem:-

The image of a small electric bulb fixed on the wall of a room is to be obtained on the opposite wall 3m away by means of a large convex lens.

What is the maximum possible focal length of the lens required for the purpose?

Answer:

Given:

Distance between the object and the image, d = 3 m

Maximum focal length of the convex lens = f_{max}

For real images, the maximum focal length is given as:

$f_{max} = (d/4) = (3/4)$

=0.75m

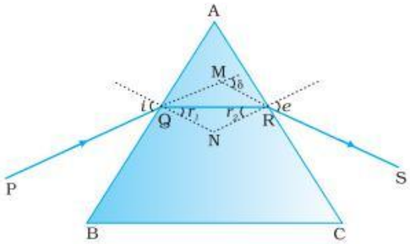
Hence, for the required purpose, the maximum possible focal length of the convex lens is 0.75 m.

Refraction through prism

- Prism is a transparent optical material with flat polished surfaces that refract light.

Terminologies

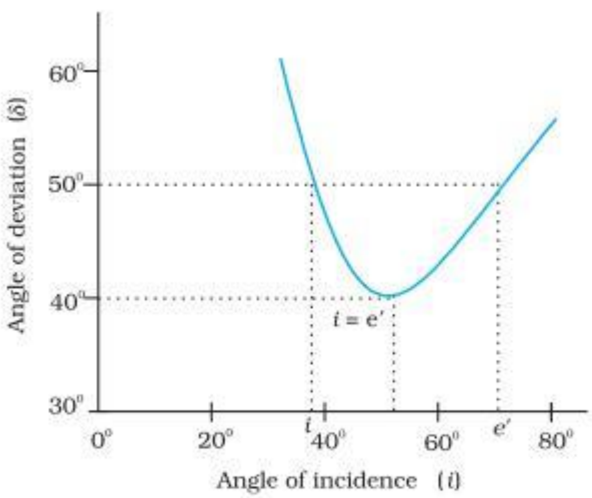
- Incident Ray: - The ray which enters the prism.
- Refracted Ray: - The ray which comes out of prism inside the prism.
- Emergent Ray: - The ray which comes out of prism.
- Angle of deviation δ:-The angle which will tell how much the emergent ray deviated from the original incident ray.
- Angle of Prism: - The angle of the prism <A is known as angle of prism.



- The angles of incidence and refraction at the first face AB are i and r_1, while the angle of incidence (from glass to air) at the second face AC is r_2 and the angle of refraction or emergence (e).
- The angle between the emergent ray RS and the direction of the incident ray PQ is called the angle of deviation, δ.
- Consider the quadrilateral AQNR, in the figure two angles (at the vertices Q and R) are right angles.
- $<A + <QNR = 180^0$ (As sum of other angles of a quadrilateral is 180^0).
- From the triangle QNR,($r_1 + r_2 + \angle QNR$) = 180º
- Comparing these two equations, we get

($r_1 + r_2 = A$) (Equation 1)

- The total deviation δ is the sum of deviations at the two faces,
- $\delta = (i - r_1) + (e - r_2)$ that is,
- $\delta = (i + e - A)$ (Equation 2)
- Thus, the angle of deviation depends on the angle of incidence.
- Relation between angle of deviation and angle of incidence:-



- As the angle of incidence increases the angle of deviation keep on decreasing and when it reaches a point where angle of incidence is equal to angle of emergence, then the angle of deviation is minimum, and again it will start decreasing.
- This implies angle of deviation is minimum

δ_{min} when angle of incidence <i = angle of emergence <e.

<u>Angle of Deviation</u>

- At the minimum deviation D_{min}, the refracted ray inside the prism becomes parallel to its base.
- Therefore, we have $\delta = D_m$, i = e which implies $r_1 = r_2$.
- From (Equation 1) 2r = A or r = (2/A)
- In the same way, (Equation 2) gives

$D_m = (2i – A)$, or $i = ((A + D_m)/2)$ (Equation 3)

- The refractive index of the prism is

$n_{21} = (n_1/n_2)$

$=\sin [(A + D_m)/2]/ (\sin [A/2])$

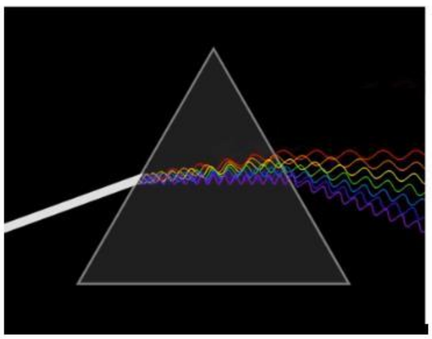
$\approx ((A + Dm)/ (2))/ (A/2)$

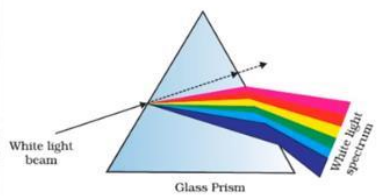
- The angles A and D_m can be measured experimentally. Equation (3) thus provides a method of determining refractive index of the material of the prism.
- For a small angle prism, i.e., a thin prism,

D_m, is also very small $= (n_{21} -1) A$

- It implies that, thin prisms do not deviate light much.

Dispersion of light through Prism

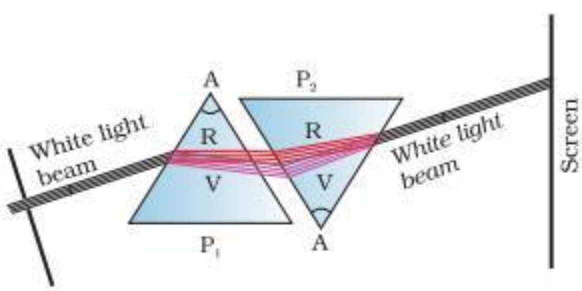




- Splitting of light into its constituent colours.
- The pattern of colors obtained is termed as spectrum.
- The red light bends the least, while the violet light bends the most.
- The phenomenon of splitting of light into its component colours is known as dispersion.

Causes of Dispersion

- Newton performed the experiment in order to explain the phenomenon of Dispersion.
- He took 2 prisms and arranged them in such a manner when a white light enters the first prism it will split the white light into its constituent colours.



- These constituent colours when were allowed to enter second prism which was kept in the inverted position.
- As a result again a white light was obtained.
- This experiment proved that it is the property of the prism because of which white light is getting split into its constituent colours.
- White light consists of different colours and each of these colours have different wavelength.

- Because of different wavelength of each colour it gets deviated by different angles of deviation.
- This proves each of the colours gets deviated differently.

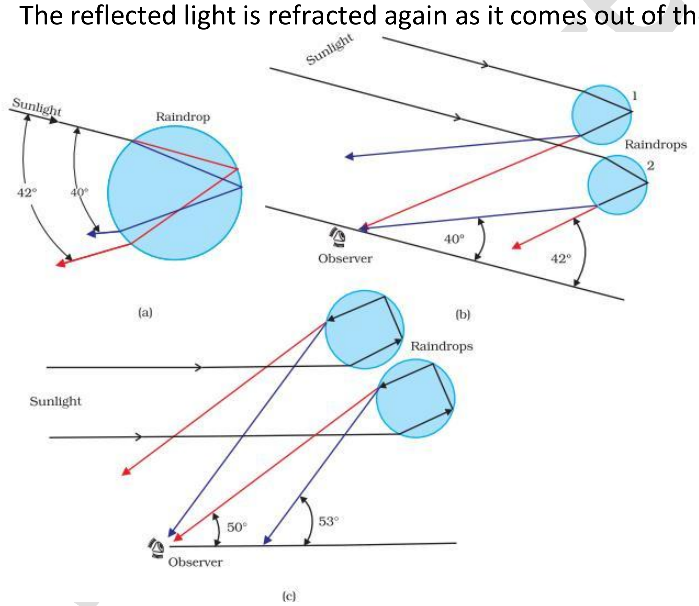
Cauchy's Formula

- The refractive index of the prism varies with wavelength.
- $\mu = (A + (B/\lambda^2))$ where (A and B are Cauchy's constants).
- This shows that $\mu \propto (1/\lambda)$.
- As the wavelength of violet colour is least so the refractive index would be maximum this shows it gets deviated the least.
- Also, $\delta_m \propto \mu$. Angle of minimum deviation will be maximum for violet, so the violet will deviate the most.

Some Natural Phenomena due to Sunlight

Rainbow

- Rainbow is a phenomenon due to combined effect of dispersion, refraction and reflection of sunlight by spherical water droplets of water.
- Rainbow appears when the sun is shining in on one part of the sky (say near western horizon) while it is raining in the opposite part of the sky (say eastern horizon).
- Sunlight is first refracted as it enters a raindrop, which causes the different wavelengths (colours) of white light to separate.
- Longer wavelength of light (red) are bent the least while the shorter wavelength (violet) are bent the most.
- The rays strike the inner surface of the water drop and get internally reflected if the angle between the refracted ray and normal to the drop surface is greater than the critical angle (48º, in this case).
- The reflected light is refracted again as it comes out of the drop as shown in the figure.



- It is found that the violet light emerges at an angle of 40º related to the incoming sunlight and red light emerges at an angle of 42º. For other colours, angles lie in between these two values.
- This lead to the formation of primary rainbow.
- The observer sees a rainbow with red colour on the top and violet on the bottom. Thus, the primary rainbow is a result of three-step process, that is, refraction, reflection and refraction.

- When light rays undergo two internal reflections inside a raindrop, instead of one as in the primary rainbow, a secondary rainbow is formed as shown in Fig. It is due to four-step process.
- The intensity of light is reduced at the second reflection and hence the secondary rainbow is fainter than the primary rainbow.

Problem:-
A prism is made of glass of unknown refractive index. A parallel beam of light is incident on a face of the prism. The angle of minimum deviation is measured to be 40°. What is the refractive index of the material of the prism? The refracting angle of the prism is 60°. If the prism is placed in water (refractive index 1.33), predict the new angle of minimum deviation of a parallel beam of light.

Answer:
Given:
Angle of minimum deviation, δ_m = 40°
Angle of the prism, A = 60°
Refractive index of water, μ = 1.33
Refractive index of the material of the prism = μ'
The angle of deviation is related to refractive index (μ') as:
μ'= (sin (A + δ_m)/2)/ (sin (A/2))
= (sin (600 + 400))/ (sin (600/2))
= (sin (500))/ (sin (300))
= 1.532
Hence, the refractive index of the material of the prism is 1.532.
Since the prism is placed in water,
Let δ_m '= the new angle of minimum deviation for the same prism.
The refractive index of glass with respect to water is given by the relation:
μ_g^w = (μ')/ (μ)
= (sin (A + δ_m ')/ (2)) / (sin (A/2))
(sin (A + δ_m ')/ (2)) = (sin (A/2)) (μ')/ (μ)
(sin (A + δ_m ')/ (2)) = sin (600) (1.532)/ (1.33)
(sin (A + δ_m ')/ (2)) = 0.5759
(A + δ_m ')/ (2) = sin -1(0.5759)
(A + δ_m ')/ (2) = 35.160
(600 + δ_m ') = 70.320
Therefore, δ_m '= (70.320 - 600)
δ_m '=10.320
Hence, the new minimum angle of deviation is 10.32°.

Optical Instruments
- Optical instruments are instruments using reflecting and refracting properties of mirrors, lenses and prisms.
- A number of optical devices and instruments have been designed utilising reflecting and refracting properties of mirrors, lenses and prisms.
- Periscope, kaleidoscope, binoculars, telescopes; microscopes are some examples of optical devices and instruments.
- Some of optical instruments which consists of lenses and prisms are:-
    - Binoculars
    - Telescope

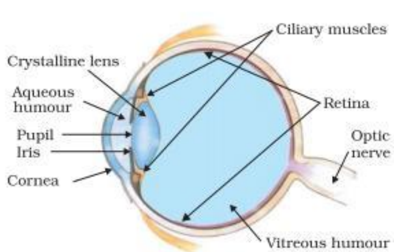
- Microscope
- Eye

Human Eye

- Our eyes are marvellous organs that have the capability to interpret incoming electromagnetic waves as images through a complex process. These are our greatest assets and we must take proper care to protect them.
- Components of Eye:-

1. Cornea
2. Aqueous Humour
3. Pupil
4. Iris
5. Lens
6. Ciliary Muscles
7. Vitreous humour
8. Retina it contains Rods and Cones.

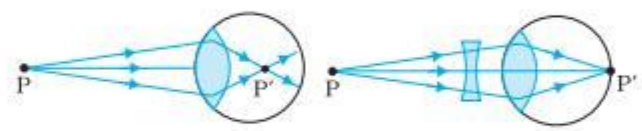
- Light enters the eye through a curved front surface, the cornea. It passes through the pupil which is the central hole in the iris. The size of the pupil can change under control of muscles.
- The light is further focussed by the eye lens on the retina. The retina is a film of nerve fibres covering the curved back surface of the eye.
- 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 somewhat by the ciliary muscles.
    - For example, when the muscle is relaxed, the focal length is about 2.5 cm and objects at infinity are in sharp focus on the retina.



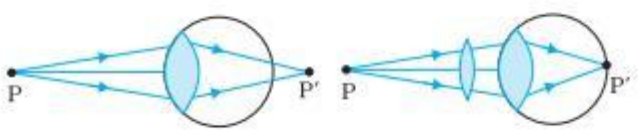
- When the object is brought closer to the eye, in order to maintain the same image-lens distance (≅5 cm), the focal length of the eye lens becomes shorter by the action of the ciliary muscles.

- This property of the eye is called accommodation. If the object is too close to the eye, the lens cannot curve enough to focus the image on to the retina, and the image is blurred.
- The closest distance for which the 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 25 cm. (Often the near point is given the symbol D.) This distance increases with age, because of the decreasing effectiveness of the ciliary muscle and the loss of flexibility of the lens.
- 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.
- 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.

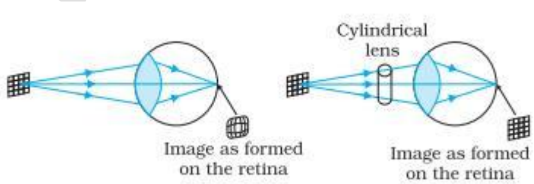
- Some Optical Defects of Eye:-
  - Myopia: - The light from a distant object arriving at the eye-lens may get converged at a point in front of the retina. This type of defect is called near-sightedness or myopia.
  - This means that the eye is producing too much convergence in the incident beam. To correct this, we interpose a concave lens between the eye and the object, with the diverging effect desired to get the image focussed on the retina.



Short-sighted or myopic eye and its correction
- Hypermetropia: - If the eye-lens focusses the incoming light at a point behind the retina, a convergent lens is needed to compensate for the defect in vision. This defect is called farsightedness or hypermetropia.



Farsighted or hypermetropic eye and its correction
- Astigmatism:- This occurs when the cornea is not spherical in shape.
  - For example, the cornea could have a larger curvature in the vertical plane than in the horizontal plane or vice-versa. If a person with such a defect in eye-lens looks at a wire mesh or a grid of lines, focussing in either the vertical or the horizontal plane may not be as sharp as in the other plane.
- Astigmatism results in lines in one direction being well focussed while those in a perpendicular direction may appear distorted.
- Astigmatism can be corrected by using a cylindrical lens of desired radius of curvature with an appropriately directed axis. This defect can occur along with myopia or hypermetropia.



Astigmatic eye and its correction

Problem:-

A myopic person has been using spectacles of power –1.0 dioptre for distant vision.

During old age he also needs to use separate reading glass of power + 2.0 dioptres. Explain what may have happened.

Answer:

Given:

Power P =-1.0D

Therefore, f = (1/P)

= - (1/1.0)

= - 1m

=-100cm

Hence, the far point of the person is 100 cm. He might have a normal near point of 25 cm. When he uses the spectacles, the objects placed at infinity produce virtual images at 100 cm. He uses the ability of accommodation of the eye-lens to see the objects placed between 100 cm and 25 cm.

During old age, the ability of accommodation is partially lost so the near point of the person recedes.

Here u = -25cm; v = -50cm;

Using, (1/f) = (1/v) – (1/u)

= (-1/50) + (1/25)

= (-1 +2)/ (50)

= (1/50)

Therefore f = 50cm

Or P = (1/f) x 100

= (1/50) x100

=+2 dioptres

Therefore, on wearing spectacles of power +2 dioptres, the image of the object lying at a distance of 25cm is formed at a distance of 50cm.

Microscope

- Microscope is an instrument that gives an enlarged image of minute object.
- There are 2 types of microscope:-
    - Simple
    - Compound

Simple Microscope

- An instrument that gives an enlarged image of a minute object.

- A simple magnifier or microscope is a converging lens of small focal length.
- There are 2 types of Microscopes:-

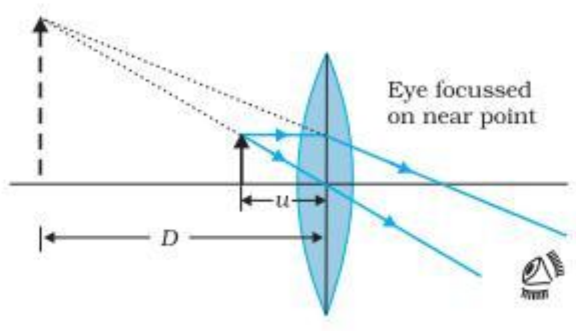
1. Simple Microscope 2. Compound Microscope

Simple Microscope

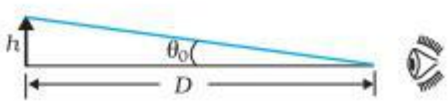
- The lens is held near the object, one focal length away or less, and the eye is positioned close to the lens on the other side.
- Image which we will get is an erect, magnified and virtual image of the object at a distance so that it can be viewed comfortably, i.e., at 25 cm or more.

To Increase Magnifying Power of Simple Microscope

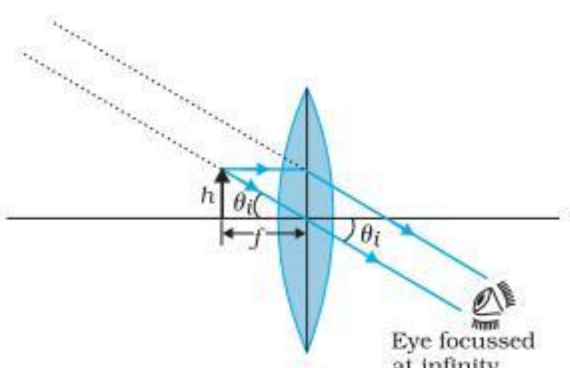
- If the object is at a distance f, the image is at infinity. However, if the object is at a distance slightly less than the focal length of the lens, the image is virtual and closer than infinity.
- Although the closest comfortable distance for viewing the image is when it is at the near point (distance D ≅ 25 cm), it causes some strain on the eye.
- Therefore, the image formed at infinity is often considered most suitable for viewing by the relaxed eye.
- Both the cases can be seen in the figures given below:



(a)



(b)

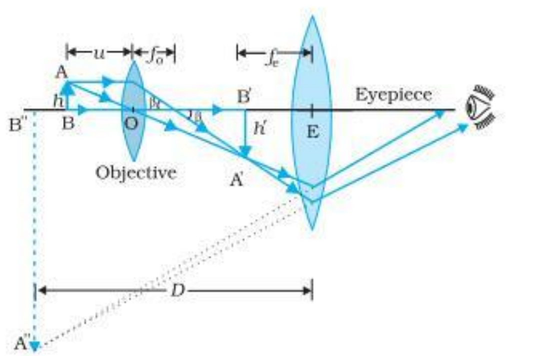


(c)

- The linear magnification m, for the image formed at the near point D, by a simple microscope can be obtained by using the relation:-
  - m=(v/u) = v((1/v)-(1/f))
  - =(1- (v/f))
  - Using the sign conventions, v= (-) ive and same as D.
- Therefore, magnification will be m =(1 +(D/f))
- Since D is about 25 cm, to have a magnification of six, one needs a convex lens of focal length, f = 5 cm.
- Magnification when the image is at infinity.
  - Suppose the object has a height h. The maximum angle it can subtend, and be clearly visible (without a lens), is when it is at the near point, i.e., a distance D.
  - The angle subtended is then given by:-
  - tan θ_0 =(h/D)≈ θ_0
  - To find the angle subtended at the eye by the image when the object is at u.
  - Therefore, (h'/h) = m = (v/u)
  - Angle subtended by the image will be;-
  - tan θ_1= (h'/-v) = (h/-v) x (v/u)
  - = (h/-u) ≈ θ.
  - The angle subtended by the object, when it is at u=-f.
  - θ_i =(h/f).
  - The angular magnification is m =(θ_i/ θ_0) =(D/f)

Compound Microscope

- In order to have large magnifications compound microscope is used.



- 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, produces the final image, which is enlarged and virtual.
- The first inverted image is thus near (at or within) the focal plane 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.
- Using tanβ = (h/f_0) = (h'/L)
- Magnification (m_o) due to objective = (h'/h) =(L/f_0)
  - Where h' = size of the first image
  - h= size of the object
  - f_o = focal length of the objective lens
  - f_e= focal length of the eye-piece

  - L (tube length) = Distance between focal length of the second objective lens and the first focal length of the eye-piece.
- When the final image is formed at the near point, then the angular magnification will be :-
- $m_e=(1+(D/f_e))$
- When the final image is formed at infinity, the angular magnification due to the eyepiece is:-
- $m_e = (D/f_e)$
- Total magnification will be given as:-
- $m=(m_o m_e) =(L/f_0)(D/f_e)$
- **<u>Note</u>**: - In order to achieve a large magnification of a small object (hence the name microscope), the objective and eyepiece should have small focal lengths. In practice, it is difficult to make the focal length much smaller than 1 cm.

Telescope
- An instrument used to view distant objects clearly.
- It consists of:- (a) Objective lens (b) Eyepiece

<u>Working of Telescope</u>
- 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 because object is very far away.
- Light from a distant object enters the objective and a real and inverted image is formed at its second focal point.
- This image acts as an object for the eyepiece; it magnifies this image producing a final inverted image.

<u>Magnification</u>
- The magnifying power m is the ratio of the angle β subtended at the eye by the final image to the angle α which the object subtends at the lens or the eye.
- Therefore, $m \approx (\beta / \alpha) \approx (h/f_e) \times (f_o/h) = (f_o/h)$.
- In this case, the length of the telescope tube is $(f_o + f_e)$.
- In addition, a pair of inverting lenses to make the final image erect.
- Refracting telescopes can be used both for terrestrial and astronomical observations.