10.1 Laws of reflection (applicable to both the plane as well as the curved surfaces)
(1) The angle of incidence is equal to the angle of reflection.
(2) Incident ray, reflected ray and the normal drawn at the point of incidens, re in the same plane.

### 10.2 Reflection of Light by Spherical Mirrors

Concave mirror is formed by making the inner surface of the circui $r$ crc is-section of a spherical shell reflecting while the convex mirror is formed by nakin ${ }_{b}$ ".e outer surface reflecting.

Some definitions with reference to the mirror (Refer to the f:-rres as under.)
(1) Pole (P) - centre of the reflecting surface
(2) Principal Axis - the imaginary line passing thi ugh ie pole and centre of curvature of the mirror
(3) Aperture ( QQ' $^{\prime}$ ) - diameter of the reflecti ig s rfa' e
(4) Principal Focus

- the point where .n ray parallel to the principal axis meet ( concave mirrr : or , npear to meet (convex mirror), after reflection
(5) Focal Plane
- plane passing through the principal focus and normal to the principal axis
(6) Focal Length - the (istar e Jetween the pole and the principal focus
(7) Paraxial Rays - TVs , lose to the principal axis



### 10.3 Relation Between Focal Length and Radius of Curvature

As shown in the figure, a paraxial ray is incident at point $Q$ on a concave mirror.
$\theta=$ angle of incidence $=$ angle of reflection
$=\angle \mathrm{CQF}=\angle$ QCF (by geometry)
So, for $\Delta \mathrm{CFQ}$,
exterior $\angle \mathrm{QFP}=\angle \mathrm{CQF}+\angle \mathrm{QCF}=2 \theta$.
For paraxial incident ray and small aperture,
$C P^{\prime} \approx C P=R$ and $F P^{\prime} \approx F P=f$.


For small aperture, $2 \theta$ is very small.
$\therefore$ from the figure, $2 \theta \approx \frac{Q P}{F P}=\frac{Q P}{f} \ldots$ (1) and $\theta=\frac{Q P}{C P}=\frac{Q P}{R} \ldots$ (2)
From equations (1) and (2), $\mathbf{R}=\mathbf{2 f} \Rightarrow \mathbf{f}: \mathbf{R}$ :
Thus, focal length of a concave mirror is in' $f$ it. radius of curvature.

## Sign Convention

Sign convention for the object ist a e (u), image distance ( $v$ ), focal length (f) and radius of curvature ( $\mathbf{R}$ ) in the form lae $0 \mathrm{r}=$ derived are as under.
(1) All distances are measur $\sim$ a the principal axis from the pole of the mirror.
(2) Distance in the $r$ '. $e$ 'on incident ray is positive and opposite to it negative.
(3) Height above thi $\mathfrak{F}$.nc pal axis is positive and below it is negative.

## Mirror Formui.

As shown in 'he igure, a ray from object $O$, at 'istance $u$, is incident at poict C on ine concave mirror of sm $\sim 11$, Dt. re making an angle $\alpha$ $w . h$ h. principal axis. It gets -afi cted in the direction QI making he ame angle $\theta$ with the normal - T as the incident ray.

Another ray from O , moving along the axis, is incident at point $P$ and gets reflected in the direction PC.


Both these rays meet at $I$ on the principal axis forming image of the object at a distance $v$ from the pole.

According to the laws of reflection, angle of incidence, $\angle \mathrm{OQC}=$ angle of reflection, $\angle \mathrm{CQI}=\theta$

CQ and IQ make angles $\beta$ and $\gamma$ respectively with the principal axis.
In $\Delta$ OCQ, exterior angle $\beta=\alpha+\theta$
In $\Delta$ CQI, exterior angle $\gamma=\beta+\theta$ Eliminating $\theta, \quad \alpha+\gamma=2 \beta$
Now, $\quad \alpha(\mathrm{rad}) \approx \frac{\operatorname{arc} \mathrm{QP}}{\mathrm{OP}}, \quad \beta=\frac{\operatorname{arc} \mathrm{QP}}{\mathrm{CP}} \quad$ and $\gamma \approx \frac{\operatorname{arc} \mathrm{QP}}{\mathrm{IP}}$
Putting these values in the above equation,
$\frac{\operatorname{arc} Q P}{O P}+\frac{\operatorname{arc} Q P}{I P}=2 \frac{\operatorname{arc} Q P}{C P} \quad \therefore \quad \frac{1}{O P}+\frac{1}{I P}=\frac{z}{C P}$
But as all distances are in direction opposite to the inciden' in.
$O P=-u, \quad C P=-R \quad$ and $\quad I P=-v$,

$$
\therefore \frac{1}{-u}+\frac{1}{-v}=\frac{2}{-R} \quad \therefore \quad \frac{1}{u}+\frac{1}{v}=\frac{2}{R}
$$

This is called Gauss' equation for a curved 1 r ror. $\therefore$ is also valid for a convex mirror.

## Magnification due to a Mirror

$A B$ is the object at a distance $\perp C$ th. axis of a concave mirror as sh wr n the figure.

A ray $A Q$, parallel to ${ }^{-}$- pt ncipal axis and ray AP, incident or the pole, meet at point $A$ ' after refle '.on and form the image of $A$. $A^{\prime}{ }^{\prime}$ ' normin. to the axis is the image of $A B$.

The ratio ' $t$ a 1. ight of the image to the heigi $o$, he object is called the transv, magnification or lateral
 ma nifi atı.
.. . teral magnification, $m=\frac{\text { height of the image }}{\text { height of the object }}=\frac{h^{\prime}}{h}$
$\Delta s \quad A B P$ and $A^{\prime} B^{\prime} P$ are similar. $\quad \therefore \frac{A^{\prime} B^{\prime}}{A B}=\frac{B^{\prime} P}{B P}$
Hence, using proper sign convention, $\frac{-h^{\prime}}{h}=\frac{-v}{-u}=\frac{v}{u}$
$\therefore$ Lateral magnification $=\frac{-h^{\prime}}{h}=\frac{v}{u}$
The same equation is obtained for a convex mirror.

### 10.4 Refraction of Light

When a ray of light goes from one transparent medium to another, its direction changes at the boundary surface (unless it is incident normally to the surface). This phenomenon is called refraction.

## Laws of Refraction

(1) The incident ray, refracted ray and the normal drawn to the point of 1 , idence are in the same plane.
(2) "For the two given media if $\theta_{1}$ is the angle of incidenc and $i_{c}$ is the angle of refraction, then the ratio $\frac{\sin \theta_{1}}{\sin \theta_{2}}$ is a constant." (Snell's law)

This ratio, $n_{21}$, is called the refractive index of medium ' 2 . witr respect to medium (1).
$\therefore n_{21}=\frac{\sin \theta_{1}}{\sin \theta_{2}}=\frac{v_{1}}{v_{2}}$
where $\mathrm{v}_{1}$ and $\mathrm{v}_{2}$ are the velocities of liaht a mearum (1) and (2) respectively.
$\mathbf{n}_{21}$ depends upon (i) the type o' tı, mejia, (ii) their temperatures and (iii) the wavelength of light.

The refractive index, $n$, of a mı div a vith respect to vacuum (or in practice air) is called its absolute refractive index.
$\therefore n=\frac{c}{v}$, where - 's ti e velocity of light in vacuum and $v$ its -.ocit in the medium.

In the figure. ray $P Q$ incident at an angle $\boldsymbol{\theta}_{1}$ to the norma. n'n at point $Q$ on the surface separatin". ${ }^{\circ} \cdot \mathrm{rm}(1)$ and medium (2). QR is the refrac id ray making an angle $\theta_{2}$ with the norma.

Ab olute refractive index of medium (1) and 1. $M_{1} \cdot \mathrm{~mm}(2)$ are respectively,
$n_{1}=\frac{c}{v_{1}} \quad$ and $\quad n_{2}=\frac{c}{v_{2}}$,
$\therefore \frac{n_{2}}{n_{1}}=\frac{v_{1}}{v_{2}}=n_{21}=\frac{\sin \theta_{1}}{\sin \theta_{2}}$
$\Rightarrow n_{1} \sin \theta_{1}=n_{2} \sin \theta_{2}$


The ratio of the absolute refractive index of medium (2) to the absolute refractive index of medium (1) is the relative refractive index of medium (2) with respect to medium (1).

For the media shown in the figure, $n_{2}>n_{1} \Rightarrow \sin \theta_{1}>\sin \theta_{2} \Rightarrow \theta_{1}>\theta_{2}$.
Thus, when a ray of light goes from a rarer medium to a denser medium, the angle of refraction is smaller than the angle of incidence and the ray bends towards the normal and when it goes from a denser medium to a rarer medium, it bends away from the normal.

As above, $n_{21}=\frac{v_{1}}{v_{2}} . \quad \therefore \quad n_{12}=\frac{v_{2}}{v_{1}} \Rightarrow n_{21} \times n_{12}=1$
This result can be generalized for any number of mediums.

## Lateral shift

As shown in the figure, if a ray of light traveling in a rarer, homogeneous medium, remains in the same medium, it will move along the path PQR'S'. But if it enters into a rectangular slab of denser medium, it will get refracted twice at surfaces, $A B$ and CD.

As the media on both sides of the rectangular slab is the same,
$n_{21}=1 / n_{12}$ and $\theta_{1}=\theta_{1}$,
Thus the emergent ray RS is p. ra' el to the incident ray but due to refraction it shifts by an int RN = $x$. Such a derintion of the incident ray is called ate' al si ift.

From the figure.


Lateral shift, . . (R $\boldsymbol{\operatorname { s i n }}\left(\theta_{1}-\theta_{2}\right)$

$$
\begin{aligned}
& =Q T \sec \theta_{2} \sin \left(\theta_{1}-\theta_{2}\right) \\
& =t \sec \theta_{2} \sin \left(\theta_{1}-\theta_{2}\right)
\end{aligned}
$$

If $n_{1} \cdot k_{2}$; small, $\theta_{2}$ is also small $\Rightarrow \sin \left(\theta_{1}-\theta_{2}\right) \approx\left(\theta_{1}-\theta_{2}\right)$ radian and $\sec \theta_{2} \approx 1$

$$
\therefore \quad=t\left(\theta_{1}-\theta_{2}\right)=t \theta_{1}\left(1-\frac{\theta_{2}}{\theta_{1}}\right)
$$

Now according to Snell's law,

$$
\begin{aligned}
& \frac{\theta_{2}}{\theta_{1}} \approx \frac{\sin \theta_{2}}{\sin \theta_{1}}=\frac{n_{1}}{n_{2}} \\
& \therefore x=t \theta_{1}\left(1-\frac{n_{1}}{n_{2}}\right)
\end{aligned}
$$

## Another example of refraction:

An object inside water when viewed from outside appears raised due to the phenomenon of refraction.

As shown in the figure, suppose an object is at real depth $h_{o}$ in a denser medium ( like water of refractive index, $n_{2}$ ). Ray OQ from $O$ refracts at $Q$ and reaches eye of the observer along $Q E$. EQ extended in denser medium meets the normal PN at I. So the observer sees the image at $I$ at an apparent depth, $\mathbf{h}_{\mathbf{i}}$.

If the angle of incidence, $\boldsymbol{\theta}_{1}$ is very small, $\theta_{2}$ will also be small.

$\therefore \sin \theta \approx \theta \approx \tan \theta$
By Snell's law, $n_{1} \sin \theta_{1}=n_{2} \sin \theta_{2} \quad \rightarrow \quad n_{1}, ~ n ~ \theta_{1}=n_{2} \tan \theta_{2}$

$$
\therefore n_{1}\left(\frac{P Q}{P I}\right)=n_{2}\left(\frac{P L}{1}, \Rightarrow \frac{\text { apparent height, } h_{i}}{\text { real height, } h_{0}}=\frac{n_{1}}{n_{2}}=\frac{n(\text { rarer })}{n(\text { denser })}\right.
$$

Now suppose that the obsu. - is a fish inside the water and " viev s the eye of the person along OQ (as sh,wn in the figure). Ray OQ extended in air reet, the normal drawn from point $E$ to the sur....e at $E$ '. Thus the fish sees the person'. eye ot $E$ ' instead of $E$.

Here, EP - -ea ht.ght and E'P apr ent height.

Thi: ex $\mathrm{m}_{\mu}$, shows that if an object in a rarer m . diur. is viewed from denser medium, it -nt ars to be raised.
? us, if an object is kept in a rarer medium, at height $h_{o}$ from the interface and is viewed normally from the denser medium, then it appears to be at a height $h_{i}\left(h_{i}>h_{o}\right)$ and in


Fish this case

$$
\frac{\text { apparent height, } h_{i}}{\text { real height, } h_{0}}=\frac{n_{2}}{n_{1}}=\frac{n(\text { denser })}{n(\text { rearer })}
$$

## One more interesting case:

As we go higher in the Earth's atmosphere, it becomes optically rarer. Thus light coming from the sun and stars reaches the observer on Earth passing through the medium of continuously increasing refractive index and hence its direction continuously changes.


As shown in the figure, light rays 0 . actull position, $\mathrm{S}_{1}$, of the sun below the horizon reach the observer after continuous ofrac. on in the Earth's atmosphere. The tangent to the curved path of the ray at poir' , pu 'ses through the apparent position, $\mathrm{S}_{2}$, of the sun above the horizon.

Taking the refractive indev $n$ air $\omega$ 1.00029, the apparent shift in the position of the sun is approximately half a dearee 1 licu. corresponds to a time interval of 2 minutes. Thus sunrise is seen 2 minutes ear rer nd iunset is seen 2 minutes later than the actual event.

### 10.5 Total Internal , ,ntection

Higher the re nt e index of the medium, more is its optical density which is independent of the materi. ' de 7Si., ( mass / volume) of the medium.

When .ht is refracted, it is partially reflected also. For a given intensity, $\mathrm{I}_{0}$, of the incident liei. th., It..ensity of the reflected light, $I_{r}$, depends upon the angle of incidence. For normal inc denc on a surface separating two media of refractive indices, $n_{1}$ and $n_{2}$, the intensity of ․ It ted light is
$I_{r}=I_{0} \frac{\left(n_{2}-n_{1}\right)^{2}}{\left(n_{2}+n_{1}\right)^{2}}$
For air ( $n=1.0$ ) and glass ( $n=1.5$ ), nearly $4 \%$ of the incident energy is reflected.
Refer to the figure on the next page. A is a point object (or a light source) in a denser medium. Rays $A B, A B_{1}, A B_{2}, \ldots$ undergo partial refraction and partial reflection at points of incidence $B, B_{1}, B_{2}$, etc. on the surface separating the two media. As the angle of incidence keeps on increasing, the angle of refraction also increases and for the incident ray $A B_{3}$, the
refracted ray is along the surface separating two media, i.e., the angle of refraction is $90^{\circ}$.
"The angle of incidence for which the angle of refraction is $90^{\circ}$ is called the critical angle, C , of the denser medium with respect to the rarer medium."

Using Snell's law,
$n_{1} \sin \theta_{1}=n_{2} \sin \theta_{2}$
For critical angle of incidence,
$\theta_{1}=C$ and $\theta_{2}=90^{\circ}$
$\therefore \mathrm{n}_{1} \sin \mathrm{C}=\mathrm{n}_{2}$
$\therefore \sin C=\frac{n_{2}}{n_{1}}=\frac{1}{n}$

( taking the refractive
index, $n_{2}$, of rarer medium air as 1 and of $t$. der. © medium, $n_{1}$, as $n$ )
At the critical angle of incidence, the ref ecte ${ }^{\prime}$ ra, is called the critical ray.
If the angle of incidence is more han ve critical angle, there is no refraction and the incident ray gets completely refl .. ${ }^{\text {d }}$ a 'd its intensity also increases. This is known as total internal reflection and it obeys ne a 's of reflection.

## Uses of Total Internal Riflectiun:

(1) The refractive ind $x$ of diamond is 2.42 and its critical angle is $24.41^{\circ}$. Hence with proper cutting , its faces, light entering into it undergoes many reflections and the diamond s'arkles.
(2) Using s ac les right angled prisms and taking advantage of total internal reflection, lighi on be eviated by $90^{\circ}$ and $180^{\circ}$ as shown in the figures.
A. cu. be seen -. 1 the figures that in both cases, the critical angle of the prism w.r.t. to air must be less than $45^{\circ}$.

Prisms of crown glass ( $\mathrm{C}=41.14^{\circ}$ ) and flint glass ( $\mathrm{C}=37.31^{\circ}$ ) are used for this.


In the adjoining figure, the direction of light rays does not change but the image is inverted. This prism is called 'amici prism'.

In all the above cases, the size of the image remains the same as the size of the object.


## (3) Mirage formation in hot regions during <br> summer due to total internal reflection:

In summer, due to intense heat, the air in contact with the around becomes hot and optically rarer as compared to the air above which is cold and optir ally iens .r.


As sh . . $n$ the figure, a ray of light going from the top of the tree (D) to the ground trav.' c intı. uously from a denser medium to a rarer medium. Its angle of incidence to the su cess. z layers continuously increases due to refraction and when it exceeds the critical - $\cap$. ?, the ray undergoes total internal reflection and reaches the eye of the observer. This ray opu irs to the observer as coming from a point $D$ ' directly below $D$ as if it is coming from ter. This kind of image formation is called a mirage (often seen in the deserts).

## (4) Optical Fibres:

Optical fibres are long thin fibres made of glass or fused quartz of 10 to $100 \mu \mathrm{~m}$ diameter. The outer cladding of the fibres has a lower refractive index than the core of the fibre. The core (refractive index $=n_{2}$ ) and the cladding (refractive index $=n_{1}$ ) are so chosen that the critical angle of incidence is small.

As shown in the figure, a ray of light entering the optical fibre, entering at an angle of incidence greater than the critical angle, comes out of it after undergoing multiple total internal reflections.

Even if the fibre is bent light remains within it. This is how endoscopy is done for viewing the human lungs, stomach, intestines, etc.

In communications, optical fibres are used to make distortionless signal transmission.


In absence of the cladding layer, due to dust particle oil or other impurities, some leakage of light occurs. Fused quartz is used for rak quical fibres because it is highly transparent.

As shown in the figure, a ray incident at an angle $\theta_{i}$ to the axis of the fibre is refracted at an angle $\theta_{\mathrm{f}}$.

This ray is incident on the wa. $r$ the fibre at an angle $90^{\circ}-\theta$ which if greater than the ainal angle for fibre-air ( . . lad ing) interface, will undergr to al internal reflection.

Thus, $90^{\circ}-\theta_{f}, C \Rightarrow \sin \left(90^{\circ}-\theta_{f}\right)>\sin C(=1 / n)$, where $\mathbf{n}=\mathrm{re}^{\prime}$ '9ct. 'e it.jex of the material of the fibre.
$\therefore n \cos \theta_{f} \quad 1 \quad \ldots \quad \ldots$ (1)
Ar. rdi.g a Snell's law, $\sin \theta_{i}=\mathbf{n} \sin \theta_{f}$

$$
\therefore \quad \cos \theta_{f}=\sqrt{n^{2}-n^{2} \sin ^{2} \theta_{f}}=\sqrt{n^{2}-\sin ^{2} \theta_{i}}>1
$$

Now the maximum value of $\sin \theta_{i}=1$. Hence if the above condition is satisfied for $\theta_{1}=90^{\circ}$, it would be satisfied for any value of $\theta_{i}$.

$$
\therefore \sqrt{n^{2}-1}>1 \Rightarrow n>\sqrt{2}
$$

Thus, if the value of refractive index is greater than $\sqrt{2}$, then the rays incident at any angle will undergo total internal reflection.

### 10.6 Refraction at a Spherically Curved Surface

As shown in the figure, a point object $P$ is kept at a distance $u$ from the centre, $O$, of the refracting curved surface on its axis OC. C is the centre of curvature of the refracting surface and $R$ its radius. According to the sign convention, $u$ is negative and $R$ is positive.

(1) The ray PO is incident at $O$ norm I to 'he curved surface and hence travels undeviated along the axis OC of the curver sl face.
(2) Another ray PA is incider , a the point $A$ on the curved surface at an angle $\theta_{1}$ to the normal AC. Suppose the re rac..e index, $n_{1}$, of medium 1 is less than the refractive index, $n_{2}$, of medium : As result, the refracted ray bends towards the normal and moves along AP'. $A_{2}$ is ne angle of refraction.

Both these rays meet $z^{\prime} \mathbf{P}^{\prime}$ 'orming the image of $\mathbf{P}$.
Applying Snell's iw and noting that the angles $\theta_{1}$ and $\theta_{2}$ are small,
$n_{1} \sin \theta_{1}=$ n . in $\mathrm{v}_{2} \Rightarrow n_{1} \theta_{1}=n_{2} \theta_{2} \quad \ldots \quad \ldots$ (1)
$\theta_{1}$ is 'te terior angle in $\triangle P A C, \quad \therefore \theta_{1}=\alpha+\beta$
$\beta$ is L. exterior angle in $\triangle P^{\prime} A C, \quad \therefore \theta_{2}=\beta-\gamma$

1 Itting these values of $\theta_{1}$ and $\theta_{2}$ in equation (1) above,
$n_{1}(\alpha+\beta)=n_{2}(\beta-\gamma) \quad \therefore n_{1} \alpha+n_{2} \gamma=\left(n_{2}-n_{1}\right) \beta$
As angles $\alpha, \beta$ and $\gamma$ are small, using proper sign convention and neglecting $\Delta$ which is small as compared to $u, v$ and $R$,
$\alpha \approx \tan \alpha=\frac{\mathrm{h}}{-\mathrm{u}}, \quad \beta \approx \tan \beta=\frac{\mathrm{h}}{\mathrm{R}} \quad$ and $\quad \gamma \approx \tan \gamma=\frac{\mathrm{h}}{\mathrm{v}}$

Putting these values in equation (2),
$n_{1}\left(\frac{h}{-u}\right)+n_{2}\left(\frac{h}{v}\right)=\left(n_{2}-n_{1}\right) \frac{h}{R} \Rightarrow-\frac{n_{1}}{u}+\frac{n_{2}}{v}=\frac{n_{2}-n_{1}}{R}$
This equation is valid for a concave surface also. While using this equation: pr ner sign convention has to be used.

If the image distance $\mathbf{v}$ is positive, then the refracted rays are to the right of vigin $\mathbf{O}$ where they actually meet and the image has to be real. If the image distance is i. gaive, then the refracted rays are to the left of origin 0 where they can meet only by extet ding backwards and hence the image has to be virtual.

### 10.7 Thin Lenses

In general, a transparent medium bounded by two refract no st faces is called a lens. The radii of curvature of the two refracting surfaces need -nt e e ual. The lens for which the distance between the two refracting surfaces is nes igible as compared to $u$, $v$ and $R$ is called a thin lens. For a thin lens, the distances can $\mathrm{L}^{2}$ ? me sured from either surface.

Consider a convex lens as shown in the figure.
Radius of curvature of surface (1) $=R_{1}$ Radius of curvature of surface (2) $=\mathrm{R}_{\text {! }}$

Refractive indices of :
$\begin{array}{ll}\text { medium to the left of the lens } & =r_{1} \\ \text { material of the lens } & =n_{2} \\ \text { medium to the right of the } n & =n_{3}\end{array}$

(Contact lens is an $x^{\prime} \cdot \mathrm{p}^{\prime} \geqslant$ of different media on both sides of the lens. On one side is air and on the other sil is he medium of the eye.)

For surface (. $-\frac{n_{1}}{u}+\frac{n_{2}}{v_{1}}=\frac{n_{2}-n_{1}}{R_{1}} \quad \ldots \ldots \ldots$ (1)
For st.ret (1), $R_{1}$ is positive as it is to the right.
FC sur. 冫e (2), $v_{1}$ is the object distance and is positive as it is to the right of the surface. $\therefore$ or .efraction by the second surface, the rays go from medium of refractive index $n_{2}$ to the I. dium of refractive index $n_{3}$.

$$
\begin{equation*}
\therefore \quad-\frac{n_{2}}{v_{1}}+\frac{n_{3}}{v}=\frac{n_{3}-n_{2}}{R_{2}} \tag{2}
\end{equation*}
$$

Adding equations (1) and (2),
$-\frac{n_{1}}{u}+\frac{n_{3}}{v}=\frac{n_{2}-n_{1}}{R_{1}}+\frac{n_{3}-n_{2}}{R_{2}}$

This is a general equation for a thin lens and is valid for concave lens also. If both sides of the lens has the same medium, then $\mathrm{n}_{1}=\mathrm{n}_{3}$.

$$
\begin{aligned}
& \therefore \quad-\frac{n_{1}}{u}+\frac{n_{1}}{v}=\frac{n_{2}-n_{1}}{R_{1}}+\frac{n_{1}-n_{2}}{R_{2}} \\
& \therefore \quad n_{1}\left(\frac{1}{v}-\frac{1}{u}\right)=\left(n_{2}-n_{1}\right)\left(\frac{1}{R_{1}}-\frac{1}{R_{2}}\right) \\
& \therefore \quad \frac{1}{v}-\frac{1}{u}=\frac{\left(n_{2}-n_{1}\right)}{n_{1}}\left(\frac{1}{R_{1}}-\frac{1}{R_{2}}\right)
\end{aligned}
$$

## Focal Point of a Thin Lens

A group of paraxial rays, incident on a convex lens, con $\boldsymbol{y r}_{j}$ e $t$ a point $F_{2}$ after refraction on the other side of the lens. This point is called tic pr, al focus of the lens and its distance from the optical centre, $P$, is the focal length $f$, of the lens.

For a concave lens, the incident paraxial rays are. ?fracted away from the axis and when


$f$ is positive :- convex lens and negative for a concave lens. $\mathbf{R}_{1}$ and $\mathbf{R}_{\mathbf{2}}$ have opposite signs for $u$, $\urcorner v, x$ aııd concave lenses. Putting $u=\infty$ and $v=f$ in the formula

$$
\begin{aligned}
\frac{1}{v} \frac{1}{V} & =\frac{\left.n_{2}-n_{1}\right)}{n_{1}}\left(\frac{1}{R_{1}}-\frac{1}{R_{2}}\right), \quad \text { we get } \\
\frac{1}{f} & =\frac{\left(n_{2}-n_{1}\right)}{n_{1}}\left(\frac{1}{R_{1}}-\frac{1}{R_{2}}\right)
\end{aligned}
$$

This is called lens-maker's formula as for a given material and given focal length, it gives the radii of curvature of the surfaces. Combining the above equations,
$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$
This is called the Gaussian equation for a thin lens valid for both types of lenses.

## Magnification of the image formed by a lens

As shown in the figure, $A B$ is the object placed normal to the axis of the convex lens. Paraxial ray $A Q$ after refraction passes through the principal focus $F_{2}$ on the other side. Ray AP passes through the optical centre of the lens and moves ahead as ray PA'.

Rays $\mathrm{QF}_{2} \mathrm{~A}^{\prime}$ and $\mathrm{PA}^{\prime}$ meet each other at point $A^{\prime}$ forming image of $A$. $B^{\prime}$ is the foot of normal from $A$ ' to the axis. Ray BP travels along the axis and after passing through the lens moves along path PB'. By symmetry, $B$ ' is the image of $B$ and $A^{\prime} B$ ' is the image of $A B$.


Now, magnification, $m=\frac{\text { heightof image }}{\text { height of object }}=\frac{\therefore}{h}=\frac{\dot{u}}{u}$
positive $\mathbf{m} \Rightarrow$ erect and virtual image - nd r , rative $\mathrm{m} \Rightarrow$ inverted and real image.
This formula can be used for a conca e leı.s also.

## Power of a Lens:

Converging capacity of a ...nv lens and diverging capacity of a concave lens is defined by the power of a lens. $P$-r o a lens is the reciprocal of its focal length.
$\therefore$ Power of a lens, $-\quad-$
Power of a $1, n, \ldots$ so defined because a convex lens of a short focal length focuses the rays witr n . wry short distance and hence its converging capacity or power is more. In the same 'vay lens of longer focal length has less power. Hence, the power of a lens is defined as the $N^{i}$. rocal of its focal length.

Pc ver - a convex lens is positive as its focal length is positive and that of the concave i. ns is negative as its focal length is negative.
$S_{1}$ unit of power of a lens is dioptre. Its symbol is $D .1 D=1 \mathrm{~m}^{-1}$

### 10.8 Combination of Thin Lenses in Contact

As shown in the figure ( next page), two convex lenses $L_{1}$ and $L_{2}$ with focal lengths $f_{1}$ and $f_{2}$ are kept in contact in such a way that their principal axes coincide.

A point like object $O$ is kept away from the principal focus of lens $L_{1}$ and its image due to this lens alone would have been at $I^{\prime}$. This image behaves like a virtual object for lens $L_{2}$ ond ite imono farmod hul lone 1 a ic antoinod of $I$

As the lenses are thin, their contact point can be taken as the optical centre of the combination. Distances $u$, $v$ and $v$ ' are shown in the figure.

For lens $L_{1}, \frac{1}{v^{\prime}}-\frac{1}{u}=\frac{1}{f_{1}}$
For lens $L_{2}, \frac{1}{v}-\frac{1}{v^{\prime}}=\frac{1}{f_{2}}$


Adding these two results, $\frac{1}{v}-\frac{1}{u}=\frac{1}{f_{1}}+\frac{1}{f_{2}} \quad \ldots \quad \ldots \quad .$. ,
If the focal length of the lens equivalent to the given sombi cation of lenses is $f$, then
$\frac{1}{v}-\frac{1}{u}=\frac{1}{f}$
From equations (1) and (2), $\frac{1}{f}=\frac{1}{f_{1}} \quad \underset{f_{2}}{1} \quad$ ?nd, in general,
$\frac{1}{f}=\frac{1}{f_{1}}+\frac{1}{f_{2}}+\frac{1}{f_{3}}+$ $\qquad$
Here $f$ is smaller than the ${ }^{n}$ ) $\mathfrak{l l}$ lest of $f_{1}, f_{2}, f_{3}, \ldots \ldots \ldots . f_{n}$.

## Power:

Replacing $\frac{1}{f}=\supset, \frac{1}{f_{1}}=P_{1}, \ldots \ldots \ldots \ldots \ldots \frac{1}{f_{n}}=P_{n}$ respectively in the above equation, we get $P=P_{1}+D_{2}$. . + $\qquad$ $+P_{n}$

This : . $\quad$ algebraic. $P$ for some lenses (convex) will be positive and for some lenses ( cr rca \%) ill be negative.
+. 'r. the figure above, magnification for lens $L_{1}, m_{1}=\frac{v^{\prime}}{u}$

$$
\text { magnification for lens } L_{2}, m_{2}=\frac{v}{v^{\prime}}
$$

and magnification for the lens-combination, $m=\frac{v}{u}$
$\therefore \mathbf{m}=\frac{\mathbf{v}}{\mathbf{u}}=\frac{\mathbf{v}}{\mathbf{v}^{\prime}} \times \frac{\mathbf{v}^{\prime}}{\mathbf{u}}=\mathrm{m}_{2} \mathrm{~m}_{1}$
For a combination of more than two lenses,
$m=m_{1} \times m_{2} \times m_{3} \times$ $\qquad$ $\times m_{n}$

## Position and Nature of Image formed by Mirrors / Lenses

| Type of Mirror / Lens |  | Position of Object | Position of Image | Nature of Image |
| :---: | :---: | :---: | :---: | :---: |
| Concave Mirror <br> OR <br> Convex Lens | 1 | At infinity | At focus | Rea inverted, L. 're. oly din nished |
|  | 2 | Beyond the centre of curvature ( Mirror ) <br> Beyond 2f (Lens) | Between focus and centre of curvature ( Mirror ) <br> Between f r . 2 (Lens ${ }^{\text {' }}$ | Real, Inverted Diminished |
|  | 3 | At the centre of curvature ( Mirror) <br> At $2 f$ (Lens) | $A^{+} \quad$ : centre of urv . ire (Mirror) <br> At $\approx$ (Lens) | Real, Inverted, Same Size |
|  | 4 | Between focus $a^{r}$. entre of curvature ( $N \cdot \cdot$ ror ) <br> Between fand (. ans) | Beyond the centre of curvature ( Mirror) <br> Beyond 2f (Lens) | Real, Inverted, Magnified |
|  | 5 | At Fral! | At infinity | Extremely Magnified |
|  | 6 | E 'we' a the pole and princıpal focus (Mirror) <br> Within f (Lens) | Behind the mirror, beyond the pole (Mirror) <br> On the object side (Lens) | Virtual, Erect, Magnified |
| $\begin{aligned} & \text { C } \sim \text { M. Mirrur } \\ & \text { Ot } \\ & \sim^{n} \text { n ave Lens } \end{aligned}$ | 1 | At infinity | At focus | Virtual, Erect, Diminished |
|  | 2 | Between infinity and Mirror / Lens | Between the focus and the pole (Mirror) <br> Between the lens and $f$ | " |

### 10.9 Refraction of Light Due to a Prism

The cross-section perpendicular to the rectangular surfaces of a prism, made up of a transparent material, is shown in the figure.

A ray of monochromatic light incident at point $Q$ on the surface $A B$ of the prism gets refracted and travels along QR undergoing deviation $\delta_{1}$ at point $Q$. It is then incident at point $R$ on the surface $A C$ and emerges after refraction along RS undergoing deviation $\boldsymbol{\delta}_{\mathbf{2}}$ at R .

When the emergent ray RS is
 extended backwards, it meets the extended incid~nt $\boldsymbol{T V}^{\prime} \boldsymbol{V}^{\prime} E$ in $D$. Angle, $\delta$, between the incident and the emergent rays is called the ang e o deviation.

As shown in the figure, in $\square A Q L R, \angle A Q L$ and ' $A R L$ are right angles.

$$
\therefore \angle A+\angle Q L R \quad 0^{\circ} \quad . . . \quad . . . . . \text { (1) }
$$

and in $\Delta$ QLR, $r_{1}+r_{2}+\angle$ QLF $=181^{\circ} \ldots \ldots \ldots$ (2)
$\therefore r_{1}+r_{2}+\angle A=180^{\circ} \quad$ fr $m$ juations (1) and (2))
$\therefore r_{1}+r_{2}=A \quad . . \quad$... .. $(3$.
In $\triangle$ DQR, exterior an e $\boldsymbol{j}=\delta_{1}+\delta_{2}=i-r_{1}+e-r_{2}$

$$
=i+e-\left(r_{1}+r_{2}\right)
$$

$$
\therefore \delta=i+e-A \quad \ldots \quad \ldots \text { (4) (from equation (3)) }
$$

Thus, the ar. il $f$ deviation depends on the angle of .. it once. The graph of angle of deviation vs. angle of incidence for an equila ' 1 ', rism is shown in the figure.

As can e seen from the graph, the angle of $\therefore v_{1}$ tion is the same for two values of angle of clu.nce. This means that if the ray PQRS is 'ersed along path SRQP, i.e., if the angle of incidence is $e$, the angle of emergence will be $i$, but the angle of deviation will remain the same. As shown in the graph, for a particular value of the angle of deviation, $\delta=\delta_{m}$ which is minimum, there is only one angle of incidence.

Putting $\delta=\delta_{m}$ and $i=e$ in equation (4),
 $\delta_{m}=2 i-A$

Using Snell's law for incident ray PQ at Q and SR at R, $n_{1} \sin i=n_{2} \sin r_{1} \quad$ and $\quad n_{1} \sin e=n_{2} \sin r_{2}$

For minimum angle of deviation, $\mathrm{e}=\mathrm{i}$.
$\therefore \sin \mathrm{r}_{1}=\sin \mathrm{r}_{2} \Rightarrow \mathrm{r}_{1}=\mathrm{r}_{2}=\mathrm{r} \quad$ (suppose)
$\therefore n_{1} \sin i=n_{2} \sin r_{1}=n_{2} \sin r=n_{2} \sin \left(\frac{A}{2}\right) \quad\left(\because r=\frac{A}{2}\right.$ from equé on $\left.\left(^{\prime}\right)\right)$
$\therefore \frac{n_{2}}{n_{1}}=\frac{\sin i}{\sin r}=\frac{\sin \left[\frac{A+\delta_{m}}{2}\right]}{\sin \left[\frac{A}{2}\right]} \quad\left(\because \delta_{m}=2 i-A\right)$
If the prism is kept in air, $n_{1}=1$ and $n_{2}=n$,
$\therefore n=\frac{\sin \left[\frac{A+\delta_{m}}{2}\right]}{\sin \left[\frac{A}{2}\right]}$

This equation shows that for a given $m$ ism, 'he value of $\delta_{m}$ depends upon (i) the angle of the prism, (ii) the refractive indp. $O$, the material of prism and (iii) the refractive index of the medium in which the prism is ept.

When $\delta$ is minimum, the ray $Q . i^{\prime}$ as $g$ through the prism is parallel to the base $B C$ of the prism (taking $A B=A C$ ).

Using the above equa* - on can calculate the refractive index of the prism with respect to the medium by meas rir, $!$ and $\delta_{m}$.

For a prism witt small $A, \delta_{m}$ is also small.
Hence ta' ins in $\left[\frac{A+\delta_{m}}{2}\right] \approx \frac{A+\delta_{m}}{2}$ (radian) and $\sin \left[\frac{A}{2}\right] \approx \frac{A}{2}$ (radian),
$\left.n=\frac{A \cdot S_{m}}{2}\right) /\left(\frac{A}{2}\right)=\frac{A+\delta_{m}}{A} \quad \therefore \delta_{m}=A(n-1)$

## -0.1, Dispersion of light due to a prism

The phenomenon in which light gets divided into its constituent colours is known as dispersion of light.

As shown in the figure ( next page), when a beam of white light or sun rays pass through a prism, the emergent light is seen to be dispersed into various colours.

Newton arranged two identical prisms of the same material as shown in the second figure and observed that when white light is incident on the first prism, emergent light from the second prism was also white. Hence it is clear that the first prism disperses the colours of white light and the second prism brings them together again to produce white light.

Visible light is made up of electromagnetic waves of wavelengths between $4000 \AA$ and 8000 A having different colours. All these waves have equal velocity in vacuum. Hence vacuum is called non-dispersive medium. But their velocities in some other medium of refractive index, $n$, are different. Such a medium is called a dispersive medium. So, as per $\mathbf{n}=\mathbf{c} / \mathbf{v}$, the refractive indices of light having different wavelengths are different in a dispersive medium. For example, the velocity of violet light ( $v_{v}$ ) is less than the velocity of red light ( $v_{r}$ ). So the refractive index of violet light ( $\mathrm{n}_{\mathrm{v}}$ ) is greater than the refractive index for red light ( $\left.n_{r}\right) .\left(n_{v}>n_{r}\right)$.

For other colours, values of refractive indices lie between $n_{r}$ and $n_{v}$. If the angles of minimum deviation for red
 and violet colours are $\delta_{R}$ and $\delta_{v}$ respectively, then $\delta_{R}=A\left(n_{r}-1\right)$ anc $\delta_{V}=A\left(n_{v}-1\right)$
$n_{v}>n_{r} \Rightarrow \delta_{V}>\delta_{R}$. Thus, , ole coilar deviates more than red colour.

For two given colours, the iffer nr ; of their angles of deviation is ...nn as the angular deviation corrf, ndii $g$ to those colours. Value of $n$ - n is more for flint glass than for co mor crown glass. So, the spectru , obtained from such a prism is wide*. $n$. re © 'spersed and more detailed.

### 10.11 Rä nbow

S. hi.. hi retracted and dispersed by the Wâ $\neq r$ roplets suspended in the a. $\eta_{1}$, sphere during monsoon form the - inı jw pattern. Rainbow is a good - ample of dispersion and internal reflection of light.

As shown in the figure, $P$ and $Q$ are two of the innumerable water droplets. Two rays $R_{1}$ and $R_{2}$ from the sun behind the observer incident on water droplets $P$ and $Q$ get refracted and dispersed. All colours undergo internal reflection and emerge after second refraction.


From the drop $P$, red colour light reaches the eye of the observer at an angle, $\theta_{2}=42.8^{\circ}$, with the horizontal. Thus, from all such droplets on the arc of a circle making this angle with the horizontal, red colour light reaches the eye of the observer. Similarly, from the drop $Q$, violet colour light reaches the eye of the observer at an angle $\theta_{1}=40.8^{\circ}$, with the horizontal and from all such droplets making this angle with the horizontal, violet colour light reaches the eye of the observer. All the remaining colours of light are seen bet eet. red and violet. Thus rainbow is seen in the form of a semicircle. This rainbow is $\mathrm{kr} .$. , as rimary rainbow. All the colours of a primary rainbow are accommodated within $2^{\circ} n, r$ the eye.

Sometimes, a faint secondary rainbow is seen above the primary raink w $1 . w_{1}$.ich order of the colours gets reversed. Here, the internal reflection of light occurs vice s compared to once in the primary rainbow. The red and violet colours of secor ary lan jw coming from water droplets $D_{1}$ and $D_{2}$ at an angle of $\theta_{3}=50.8^{\circ}$ and $\theta_{4}=54.5^{\circ}$ respi stively are shown in the figure. All the colours of a secondary rainbow are accommoda... within $3.7^{\circ}$ near the eye. If the rainbow is observed from the height of a mour.... or "he top of a tower, some portion of rainbow below the horizon can also be seen.

### 10.12 Scattering of Light

Light incident on atmospheric atoms and molecules and small suspended particles like cloud droplets is absorbed by them and immediately reradiated in different directions in different proportions of intensity. This process is called the scattering of light.

If the size of the particle vhic scatters the light is smaller thar, wavelength of the incident y ...., the scattering is KII vn as Rayleigh's scatterin :. F. yyleigh observed that the s. $\mathbf{7 t t}$ ing of light is inverse, proportional to the fourth $p$ wer of the wavelength $t$ ght. As the waveleng ' \& blue light is 1.7 times sm. Ier nan that of red light, \& atters 8 to 9 times $\mathbf{m} \boldsymbol{r}_{\mathrm{c}}$ th n ine red light. Although vic ot a.. i indigo light also have s. $n$. wavelengths, their proportion in light is much less and our eyes are not sensitive to inesu colours. So their scattering is not so important. The light having wavelength close to $\therefore$ wavelength of yellow colour has maximum intensity and even our eyes are more sensitive to the light of these colours.

The figure shows the light of the rising sun reaching the earth's atmosphere. In this condition, white light has to travel more distance through the atmosphere during which light of most of the colours is scattered and only red colour reaches the observer on the earth. So the sun appears reddish and the sky above appears bluish due to scattered blue colour. Similar situation prevails at the time of sunset also. The same reason is responsible for a reddish full-moon, while rising or setting.

If the size of particles due to which light is scattered are larger than the wavelength, the
scattering is known as Mie-scattering. This type of scattering was first studied by Gustav Mie in 1908 A.D. In this type of scattering, the relation between the intensity and wavelength of the scattered light is complicated. However, as the size of the particle increases, the proportion of diffused reflection also increases. Size of the water particles forming white clouds being large, diffused reflection of sun-light takes place. As the diffused reflection is independent of the wavelength, all the wavelengths of visible light are reflected nd so the clouds appear white.

### 10.13 Optical Instruments

### 10.13 (a) Simple Microscope:

Apparent size of an object as seen by us depends on the actual size 1 : the object and the angle subtended by it with our eye. When we see the railway trac - standing between the tracks, at far distance rails seem to be meeting each other $-\cdots$ is is because the rays coming from the points far away on the rails, one from each rai, $\mathbf{s}^{\prime} \cdot \mathrm{o}^{+}$?na a very small angle with our eye. For this reason, to see a microscopic object ${ }^{\prime} \mathrm{le}_{\mathrm{c}} \mathrm{y}$, ve tend to keep it very near our eyes. But this strains the eyes and we can't ser the onjuct clearly. In fact, to see any object clearly without straining the eyes we have to , ?ep i at some minimum distance from the eyes. This minimum distance is called the rec $\mathrm{r}_{\mathrm{c}}$. . or the distance of most distinct vision. Hence to see a microscopic object clea ly w place it within the focal length of a convex lens so that its virtual, magnified, ere t in ige is formed at a comfortable distance of distinct vision and we can see it clearly. This onvex lens is known as simple microscope.

Suppose a linear object with heig'، $h_{0}$, kept at the near point ( $\approx 25 \mathrm{~cm}$ ) $\mathrm{f}_{\mathrm{m}} \mathrm{m}$ on eye, subtends an angle $\theta_{0}$ with us " $^{e y}$ as shown in the figure.

Now, suppose the object :- ept ac such a distance within the foral lel ju, f, of a convex lens that i's virtue', erect and magnified image is fc $r d t$ the near point as shown in the figure.

Here, as the ${ }^{\circ} \mathrm{V}$ i is very near the lens, the : rle $t$, subtended by the object an "imm. with the lens is the same .- he angle subtended with the eve

Acc rding to the definition:
4 Igular magnification or
Magnifying power of the lens (M)

$=\frac{\text { Angle subtended by the image, } \theta \text {, on the near point with the eye }}{\text { Angle subtended by the object, } \theta_{0} \text {, on the near point with the eye }}=\frac{h_{i} / D}{h_{0} / D}$ ( $\because \theta$ and $\theta_{0}$ are very small)
$=\frac{h_{i}}{h_{0}}$

Magnifying power is same as linear magnification.

$$
\begin{aligned}
& \therefore m=\frac{v}{u}=\frac{D}{u} \quad(\because v=D, \text { the distance of most distinct vision }) \\
& \text { Now, } \frac{1}{v}-\frac{1}{u}=\frac{1}{f} \quad \therefore \quad-\frac{1}{D}+\frac{1}{u}=\frac{1}{f} \quad(\because v=D \text { and } u \text { are nema ive, } \\
& \therefore m=\frac{v}{u}=1+\frac{D}{f}
\end{aligned}
$$

If the image is at a very large distance (theoretically at infinity) magi ification will be very large and 1 can be neglected as compared to $D / f$.

Thus the value of $m$ would be between $\frac{D}{f}$ and $1+\frac{D}{f}$.
To obtain the enlarged, clear object which can be set , wit out straining the eyes, the object should be kept near $f$, but at a distance less the'.


## 

In a s'mp.' mic.oscope, magnifying power depends on D/f. So to obtain more magnification, we ma.. . s tempted to use a small focal length. But this distorts the image. Hence, f cannot br in 'e, very small and a simple microscope gives a maximum magnification of 20 X . Now if $w \in$ use . is magnified image as an object for another convex lens, we can further magnify it. $\therefore$ a compound microscope is made using two convex lenses.
$\therefore y$ diagram for a compound microscope is shown in the figure on the next page.
The lens kept near the object is called 'objective' and the lens kept near the eye is known as 'eye-piece'. Distance between the second focal point ( P ) of the objective and the first focal point ( $Q$ ) of the eye-piece is known as 'tube-length ( $L$ )' of the microscope.

As can be seen from the figure, the real, inverted and magnified image obtained by the objective near the focal-point ( $Q$ ) of the eye-piece acts as an object for the eye-piece which behaving as a simple microscope gives a virtual and highly magnified final image at a very large distance.

## Magnification obtained by a compound microscope

From the figure,
magnification due to the objective,
$m_{0}=\frac{h_{i}}{h_{0}}=\frac{L}{f_{0}}$
$\left(\because h_{i} \approx P Q \tan \beta=L \tan \beta\right.$;
$h_{0}=f_{0} \tan \beta$ ), where
$h_{i}=$ size of the first image,
$f_{0}=$ focal length of objective

Now, magnification due to the eye-piece,
$m_{e}=\frac{D}{f_{e}}, \quad$ where
$f_{e}=$ focal length of the eye-piece.
$\therefore$ magnification of the compound $m_{1}$ "osccpe, $m=m_{0} m_{e}$
$\therefore m=\frac{L}{f_{o}} \times \frac{D}{f_{e}}$

### 10.13 ( c ) Astronc nir al T lescope:

## Astronomical

Telescope is ust $y$ to observe vel. $h_{1}$ 'ge celestial : dit: und stars wh th , far away : $n$ in and fro:` ei $\mathrm{e}_{\mathrm{h}}$. .her.
'ts ray diagram is ih $h^{\prime}$ in the figure. t. ? re two convex lenses are kept on the same principal axis. The lens facing the object is called objective whose diameter and focal length are greater than the lens known as eye-piece kept
 near the eye.

When the telescope is focused on a distant object, parallel rays coming from this object form a real, inverted and small image $A_{1} B_{1}$ on the second principal focus of the objective. This image is the object for the eye-piece. Eye-piece is moved to or fro to get the final and magnified inverted image $A_{2} B_{2}$ of the original object at a certain distance.

Magnification of the telescope,

$$
\begin{aligned}
m & =\frac{\text { Angle subtended by the final image with eye }}{\text { Angle subtended by the object with the objective or eye }}=\frac{\beta}{\alpha}=-\frac{'_{1} B_{1}}{1_{\epsilon}} \cdot \frac{f_{0}}{A_{1} B_{1}} \\
\therefore m & =\frac{f_{0}}{f_{e}}
\end{aligned}
$$

Hence, to increase the magnification of the telescope, $f_{o}$ nol $d$ be increased and $f_{e}$ should be decreased. $f_{0}+f_{e}$ is the optical length of the telescone. ${ }^{\circ} \mathrm{o}$, I ngth of the telescope,
$L \geq f_{0}+f_{e}$.
If $f_{0}=200 \mathrm{~cm}$ and $f_{e}=1 \mathrm{~cm} ; m=200$. Using suc a tesescope, if the stars having angular distance 1' are observed, they would be seen 3t $2 \Gamma$ ' ${ }^{\prime}$ : $\delta .33^{\circ}$ angular distance between them.

For a telescope light gathering power and esc ing power (power to view two nearby objects distinctly ) are very important. Amount of "qh. entering the objective of the telescope is directly proportional to the square is ©e dismeter of the objective. With increase in the diameter of the objective, resolving $p$ wer .'so increases.

In the telescope described abo $\boldsymbol{\geq},{ }^{\prime} \lambda_{,}$, from the object are refracted by the objective to form the image. Such a telescop is :all a a refractive telescope. Image formed in this type of telescope is inverted. To ret rid $\iota$. dhis problem, there is an extra pair of inverting lenses in the terrestrial telescope so thi \& ...e erect image of the distant object is obtained.

For better resolution p،d magnification, mirrors are used in modern telescopes. Such a telescope is known as $\boldsymbol{r}$ decting telescope. In such a telescope, problems of chromatic and spherical aberra, on are also overcome if a parabolic mirror is used. Construction of such a telescope is " $\supset \mathrm{u}$, in the following figure.

Parallel : $y_{s}$. ming from a distan ob, ect ale incident on the re. ' $\epsilon,{ }^{i \cdot} \cdot \mathrm{y}$ surface of the pr'mi. varabolic concave mi. or. .. convex mirror is $n_{1} n_{1}$ in the path of the 1 ?fleuced rays which would -. ve focused at $F$ forming the image. Rays reflected by the secondary mirror are focused on the eye-piece after passing through the hole kept in the primary mirror. Diameter and focal length of the primary mirror are kept large in such a telescope.

### 10.13 (d) Human Eye:

As shown in the figure, the ray entering the eye is first refracted in the cornea and then in the eye lens which is the main refractor. This forms inverted, real image on the retina which is processed in the brain and a final erect image is seen.

Retina has two types of cells:
(1) Rods: These cells receive the sensations 1 le, intense light.
(2) Cones: These cells receive the sensatio of ('sur and more intense light.

In the eye, the distance between the $\mathrm{r}^{+}$1a a d ine lens is fixed. Hence to form the image of objects at different distances exactl/ 0 . the retina, focal length of the lens has to be changed. This is done by ciliary mus 'es which make the lens thick or thin as required. The iris controls the amount of ligh' $\epsilon$ terı 1 the eye by controlling the size of the pupil (front aperture). When we see the ol er $n$ on the side, lens of the eye rotates and brings the image on the central region $f$ th re ina (fovea).

## Defects of Vision


I. age of distant object formed in front of retina


Image of nearby object formed on the retina

concave lens between object and eye

If the thickness of the eye lens cannot be altered as needed, then the rays coming from distant objects which are parallel, undergo extra refraction and focus in front of the retina as shown in the first figure. So distant objects cannot be seen clearly. But the image of the nearby object is formed on the retina as shown in the second figure. This type of defect is called 'near sightedness (myopia)'.

To correct this defect, concave lenses are used as shown in the third figure above.

If the lens remains thin and does not become thick as needed, the rays from a nearby object undergo less refraction and focus behind the retina as shown in the first figure. Such an image cannot be seen clearly. Image of a distant object is formed on the retina and can be seen clearly, but nearby objects cannot be seen clearly. This type of defect is called 'far sightedness ( hypermetropia )'.


This type of defect is due to less convergenc $0^{\prime}$ ivs and can be corrected by using a convex lens of proper focal length as shown ith sf sond figure above.

Some persons can see only horizontal $c$ orth l wires in a wire mesh clearly but not both. This defect is called 'astigmatism'. is $\omega$ fect is due to unequal curvatures of the lens and cornea. Here horizontal curvatu's $a_{1}$ 'same but not the vertical. So rays are refracted equally in the horizontal plane but uni rually in the vertical plane. As a result horizontal wires are seen clearly, but not the ve ace wirs. To remove this defect, cylindrical lenses are used.

### 10.13 (e) Photographic_凖

As shown in the figur , , a photographic camı a. a combination of 3 cl vex lenses at one nd ana a photo sensiti"e : Irfac, at the other enc a kept in a light $p^{\prime} x^{-} b, ~ x$.

When thotograph is tak . he shutter opens an' s. s quickly. Light , ntt s through the lens na $s$ incident on the film * ring the time when the shutter remains open. Thus, due to the lens, a real and inverted image of the object is formed on the film. The amount of light entering the camera is controlled using the aperture of the lens.


The distance between the lens and the film can be adjusted for better pictures.

As the focal length of a lens in a camera is small (app. 50 mm ), the changes required in the distance between the lens and the film are very small even for large object distance.

For clear and good quality photographs, the following points are important.

## (1) Exposure Time:

The time for which the light is incident on the film is known as the expr sui. time. Less exposure time is kept in sunlight or more light. For indoor photography al. unt if light is less, so more exposure time is kept. For fast moving objects, less expo ... th. ? is kept. For a given aperture in a camera, usual exposure times are $\frac{1}{500} \mathrm{~s}, \frac{1}{\mathrm{a}^{n}} \mathrm{~s}, \frac{1}{125} \mathrm{~s}, \frac{1}{60} \mathrm{~s}$, $\frac{1}{30} \mathrm{~s}, \ldots$

## (2) Aperture of the Lens:

Diameter of the circular passage of light kept in : camara is the aperture. Some useful apertures known as f-number are $\frac{f}{2}, \frac{f}{2.8}, \frac{f}{4}, \quad \frac{f}{5}, \quad \frac{f}{11}, \frac{f}{16}, \ldots$ where $f$ is the focal length of the lens. If the film is exposed eq: " lly $f_{1}$ " , erture diameter, $d_{1}=\frac{f}{4}$ and $d_{2}=\frac{f}{8}$, then for diameter $d_{1}$, the shutter shoulr $b_{c} \mathrm{ke}_{\mathrm{r}}$ ' open for 4 times longer compared to that for diameter $d_{2}$. Thus exposure time $i$, 1 ' 'erse. $j$ proportional to the area of the aperture.

## (3) Speed of the film:

How quickly the film can be exp ser is known as its speed. Fast film needs less exposure time and is used when ligh is ...s whereas slow film needs more exposure time and is suitable for the still photograp g .
(4) Exposure meter:

Some cameras a e furnished with exposure meters which consists of a photosensitive surface. Electric curr 't ; p. oduced in accordance with the intensity of light incident on the photosensitive $\mathrm{Su}_{4}$ ce which automatically adjusts the aperture and exposure time.
(5) D~0th of Fucus or Depth of Field:

If oth $\quad$ 'ect at a distance $u$ can be perfectly focused on a film, $\Delta u$ is the depth of focus $v h 1 h$ means that all objects within $\Delta u$ distance of the object can be satisfactorily focused. '/u. the aperture size, less is the depth of focus.

### 10.13 (f) Spectrometer:

Spectrometer is used in the laboratory to get a clear spectrum and determine the refractive index of the material of the prism.

It consists of a collimator, telescope and prism table. There is the scales below the prism table and the base of the spectrometer and leveling screws at the base. In the collimator, light entering through the adjustable slit is made parallel and incident on the refracting surface of the prism kept in a specific position on the prism table. Telescope is arranged to receive the refracted light and its eye-piece is moved to focus and get a clear spectrum of
the original light. We can know the angular position $(\theta)$ of the spectral lines of various colours by using a cross-wire and can be read from the scale. Prism table and telescope are arranged such that the angle of minimum deviation $\left(\delta_{m}\right)$ is obtained for each colour. Thus refractive index for the material of prism for a particular wavelength can be determined using the formula
$n=\frac{\sin \left[\frac{A+\delta_{m}}{2}\right]}{\sin \left[\frac{A}{2}\right]}$

To measure the angle of the prism, A, prism table and telescope re oo arranged that the rays refracted from one surface forming angle $A$ enters the tolescope and the same happens for the second surface. By knowing the angular position o' the telecope in these two cases, angle of the prism can be calculated. The complete pat sf ght is shown in the figure below.


