## 4) OPTICAL INSTRUMENTS AND DISPERSION

### 1. DEFECTS OF VISION

In case of eye, following are the common defects of vision :

a) **Myopia** [or Short-sightedness or Near-sightedness]

A short - sighted eye can see only nearer objects.

In it distant objects are not clearly visible, i.e., far point is at a distance lesser than infinity and hence image of distant object is formed before the retina [Fig. (A)].


This defect is remedied by using spectacles having divergent lens.

$$\frac{1}{-F.P.} - \frac{1}{-(\text{distance of object})} = \frac{1}{f} = P$$

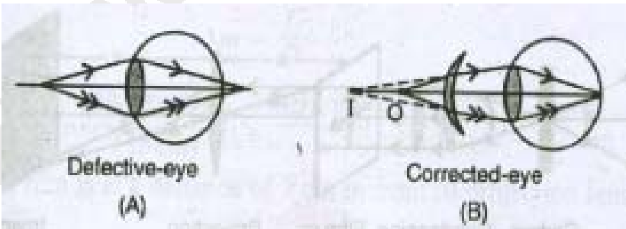
And if the object is at $\infty$, $P = \frac{1}{f} = \frac{1}{-F.P.}$ .

Note : This is due to elongation of eye ball

b) **Hyperopia or Hypermetropia** [or Longsighted-ness or far sightedness]

The far sighted eye can see only farther objects.

In it near objects are not clearly visible, i.e., near point is at a distance greater than 25 cm and hence image of near object is formed behind the retina [Fig.(A)]




This defect is remedied by using spectacles having convergent lens.

$$\frac{1}{-N.P.} - \frac{1}{-(\text{distance of object})} = \frac{1}{f} = P$$

If object is placed at $D = 25cm$ = 0.25cm

$$P = \frac{1}{f} = \left[\frac{1}{0.25} - \frac{1}{N.P.}\right]$$

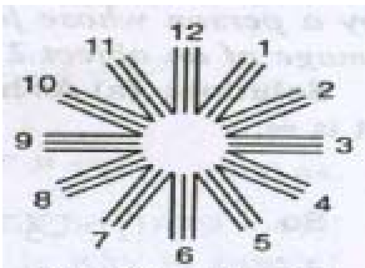
Note : This is due to contraction of eye ball.

c) **Presbyopia**

In this both near and far objects are not clearly visible, i.e., far point is lesser than infinity and near point greater than 25 cm. This is remedied by using bifocal lenses.

d) **Astigmatism**

In it due to imperfect spherical nature of eye lens, the focal length of eye lens in two orthogonal directions becomes different and so eye cannot see objects in two orthogonal directions clearly simultaneously. This defect is directional and is remedied by using cylindrical lens in a particular direction.



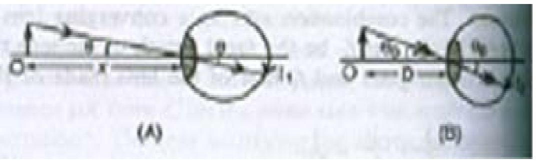
An astigmatism chart

e) The far and near point for normal eye are usually taken to be infinite and 25 cm respectively, i.e., a normal eye can see very distant objects clearly but near objects only if they are at a distance greater than 25 cm from the eye. The ability of eye to see objects from infinite distance to 25 cm from it is called power of accommodation.

f) In eye, convex eye lens forms real, inverted and diminished image at the retina by changing its convexity (the distance between eye lens and retina is fixed).

g) The human eye is most sensitive to yellow-green light having wavelength $5550\ A^0$ and least to violet $\left(4000\ A^0\right)$ and red $\left(7000\ A^0\right)$.

h) The size of an object as perceived by eye depends on its **visual angle.** When object is distant, its visual angle $\theta$ and hence image $I_1$ at retina is small and it will appear small [Fig.(A)] and as it is brought near to the eye its visual angle $\theta_0$ and hence size of image $I_2$ will increase.




i) If object is at infinity, i.e., parallel beam of light enters the eye, the eye is least strained and said to be relaxed


(A) (B)

or **unstrained** [Fig.(A)]. However, if the object is at least distance of distinct vision [L.D.D.V.], i.e., D (=25 cm), eye is under maximum strain [Fig.(B)] and visual angle is maximum.

j) The **limit of resolution** of eye is one minute, i.e., two objects will not be visible distinctly to the eye if the angle subtended by them at the eye is lesser than one minute.

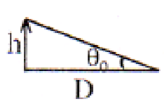
k) The **persistence of vision** is (1/10) sec, i.e., if time interval between two consecutive light pulses is lesser than 0.1 sec, eye cannot distinguish them separately. This fact is taken into account in motion pictures.

**2. Optical Instruments:**

1. The nearest point at which an object is seen clearly by the eye is called the "near point" of the eye.
2. The least distance upto which on object can be clearly seen by a naked eye is called the least distance of distant vision. That is D = 25 cm for normal eye.
3. The farthest point from an eye at which and object is distinctly seen is called far point, for a normal eye it is theoretically at infinity.
4. <u>**Visual angle**</u> :It is the angle subtended by an object at the eye.

   It is maximum when the object is at the least distance of distinct vision.

   It 'h' is the height of the object placed at the near point, the visual angle is $\theta_0 = \frac{h}{D}$

( the angle is small) 

**5. MICROSCOPES :**

It is an optical instrument used to see very small objects. It's magnifying power is given by

$$m = \frac{Visual\ \ angle\ \ with\ \ instrument}{Visual\ \ angle\ \ when\ \ object\ \ is\ \ placed\ \ at\ \ least\ \ distance\ \ of\ \ distinct\ \ vision}$$

**A. Simple microscope:**

It is a single convex lens of lesser focal length.

It is also called magnifying glass or reading lens.

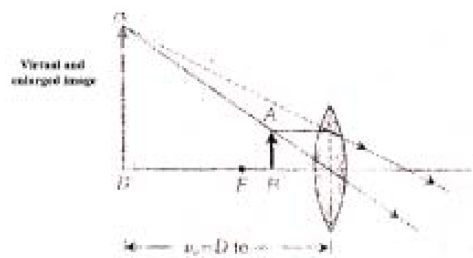
Magnification m = D/u.

Magnification when final image is formed at D and  (i.e. $m_D$ and ).

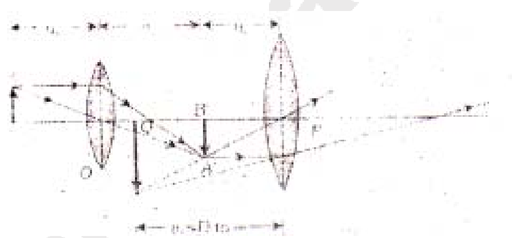
$$m_D = \left(1 + \frac{D}{f}\right)_{max} \text{ and } m_\infty = \left(\frac{D}{f}\right)_{min}$$

If lens is kept at a distance a from the eye then

$$m_D = 1 + \frac{D-a}{f} \text{ and } m_\infty = \frac{D-a}{f}$$




**B. Compound microscope:**



Consist of two converging lenses  called objective and eye lens.

$f_{eye\ lens} > f_{objective}$ and (diameter)$_{eye\ lens}$ > (diameter)$_{objective}$

Intermediate image is real and enlarged.

Final image is magnified, virtual and inverted.

$u_0$= Distance of object from objective (o).

$\upsilon_0$ = Distance of the image $A^1B^1$ formed by objective from eye lens.

$u_e$= Distance of $A^1B^1$ from eye lens.

$\upsilon_e$ = Distance of final image from eye lens.

$f_0$ = Focal length of objective.

$f_e$ = Focal length of eye lens.

Magnification $m = \frac{\upsilon_0}{u_0}\left(\frac{D}{u_e}\right)$ and the length of the tube is $L = \upsilon_0 + u_e$

**Final image formed at D** : Magnification $m = -\frac{\upsilon_0}{u_0}\left(1 + \frac{D}{f_e}\right)$ and length of the microscope tube (distance between two lenses) is . $L_D = \upsilon_0 + u_e$

Generally object is placed very near to the principal focus of the objective hence $\upsilon_0 \cong L_D$ , the length of the tube.

Hence, we can write $m_D = \frac{-L}{f_0}\left(1 + \frac{D}{f_e}\right)$

**Final image formed at** $\infty$

$m_\infty = -\frac{\upsilon_0}{u_0} . \frac{D}{f_e} \approx \frac{LD}{f_0 f_e}$ and length of tube $L_\infty = \upsilon_0 + f_e$

For large magnification of the compound microscope, both $f_0$ and $f_e$ should be small.

The magnifying power os the compoudn microscope may be expressed as $m = m_0 \times m_e$ ; where $m_0$ is the magnification of the objective and me is magnification os eye piece.

**6. Astronomical Telescope**

**(Refracting Type)**

By astronomical telescope heavenly bodies are seen.

1) $f_{objective} > f_{eyelens}$ and $d_{objective} > d_{eyelens}$ (d= diameter)

2) Intermediate image is real, inverted and small (diminshed).

3) Final image is virtual, inverted and diminshed.

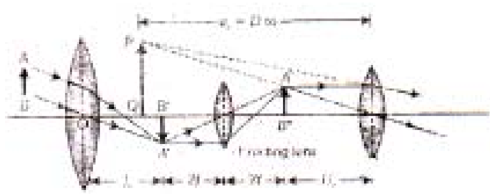
4) Magnification : $m = -\frac{f_0}{u_e}$ and length. $L = f_0 + u_e$

5) Magnification : $m_D = -\frac{f_0}{f_e}\left(1+\frac{f_e}{D}\right)$ and $m_\infty = -\frac{f_0}{f_e}$

(for normal adjustment)

**7 Terrestrial Telescope :**

It is used to see distance object on the earth.



1) It consists of three converging lens: objective, eye lens and erecting lens.

2) Final image is virtual, erect and diminished.

3) Magnification : $m = \frac{f_0}{u_e}$ and $m_D = -\frac{f_0}{f_e}\left(1+\frac{f_e}{D}\right)$

$m_\infty = \frac{f_0}{f_e}$ (for normal adjustment)

4) Length : L= $f_0$ + 4f + $f_e$

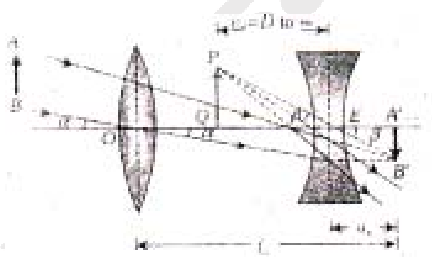
$L_D = f_0 + 4f + u_e$ and

= $f_0$ + 4f + $f_e$

( f = focal length of erecting lens)

**8. Galilean Telescope:**

It is also type of terrestrial telescope but of much smaller field of view.



1) Objective is a converging lens while eye lens is diverging lens.

2) Final image is virtual, erect and diminshed

3) Magnification : $m = \frac{f_0}{u_e}$

$m_D = \frac{f_0}{f_e}\left(1 - \frac{f_e}{D}\right)$ and $m_\infty = \frac{f_0}{f_e}$

4) Length : $L = f_0 + u_e$

$L_D = f_0 - u_e$ and $= f_0 - f_e$

**9. Dispersion :**

a) The splitting of white light into constituent colours is called dispersion and the band of colours is called spectrum.

b) Dispersion of light was discovered by Newton.

c) As the wavelength is minimum for violet and hence R.I is maximum for violet.

d) As the wavelength is maximum for red and hence R.I is minimum for red.

e) A spectrum in which there is overlapping of colours is called impure spectrum.

f) A spectrum in which there is no overlapping of colours is called pure spectrum.

g) **Conditions to get a pure spectrum :**

i) The incident beam should be passed through a narrow slit.

ii) The incident beam is made parallel by using a convergent lens.

iii) The prism should be in minimum deviation position.

iv) The emergent beam is brought to focus on a screen by using a convergent lens.

**10. Angular dispersion :**

a) The difference in deviation between any two colours (generally violet and red) is called angular dispersion.

b) The angular dispersion $= d_V - d_R = (\mu_V - \mu_R)A$ [since for small angled prism, $d_V = (\mu_V - 1)A$ and $d_R = (\mu_R - 1)A$]

**11. Dispersive power :**

a) Dispersive power, $\omega = \frac{\text{angular dispersion}}{\text{mean deviation}}$ $\omega = \frac{d_V - d_R}{d}$ where $d = (\mu - 1)A$ the mean deviation (i.e., for yellow colour) $\therefore \omega = \frac{\mu_V - \mu_R}{\mu - 1}$

Dispersive power is independent of the angle of prism. It depends only on refractive index and nature of material.

b) If $\mu_1$ and $\mu_2$ are the refractive indices of two colours and $\mu$ is the refractive index of the mean colour, then the dispersive power of the two colours is given by $\omega = \frac{\mu_2 - \mu_1}{\mu - 1}$. It is constant for those two colours and for the material of the prism. It is independent of the angle of the prism but angular dispersion depends on the angle of the prism.

c) If $f_1$ and $f_2$ are the focal lengths of a lens for clours 1 and 2 and f is the focal length of the mean colour, then dispersive power of the lens, $\omega = \frac{df}{f}$ where $f = \sqrt{f_1 f_2}$.

12. **Deviation without dispersion :**

a) Deviation with out dispersion means an achromatic combination of the prisms in which net or resultant dispersion is zero and deviation is produced.

b) For the two prisms made of different materials and of different refracting angles the net dispersion is zero if

$(d_V - d_R) + (d_V^1 - d_R^1) = 0 \Rightarrow \frac{A^1}{A} = -\frac{(\mu_V - \mu_R)}{(\mu_V^1 - \mu_R^1)}$ The negative sign indicates that the refracting angles of two prisms are in the opposite directions.

13. **Dispersion without deviation :**

A combination of two prisms in which the deviation produced for the mean ray (yellow colour) by the first prism is equal and opposite to that produced by the second prism. For the deviation to be zero $d+d^1=0 \Rightarrow (\mu - 1)A + (\mu^1 - 1)A^1 = 0$

$$\Rightarrow \frac{A^1}{A} = -\frac{(\mu - 1)}{(\mu^1 - 1)}$$

The negative sign indicates that refracting angles of the two prisms are in the opposite directions.