OPTICAL INSTRUMENTS

- Eye (Natural optical instrument)
- Near point of normal **strained** eye = 25 cm
- Far point of normal relaxed eye = ∞
- **Common defects of human eye :**

A. Short sightedness (myopia)

→ Near point is normal & far point is abnormal

→ Due to decrease in focal length of eye lens image is formed infront of ratina.

→ Diverging lens is used to removed it.

B. Long sighted ness (Hypermetropia)

→ Near point is abnormal, far point is normal.

→ Due to increase in focal length of eye lens image is formed behind retina.

→ Converging lens is used to remove it.

C. Old sightedness or Presbiopia

→ Both near and far points are abnormal

→ Bifocal lens is used to remove it.

D. Astigmatism

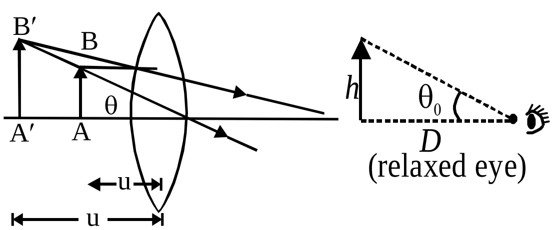
(i) Two mutually perpendicular lines appear of different thickness

(ii) Cylindrical lens is used to remove it.

Simple Microscope

- Magnifying power of a simple microscope (M) = It is the ratio of visual angle with instrument to that of maximum visual angle for un aided eye i.e.,

$$M=\frac{\theta}{\theta_0}=\frac{h/u}{h/D}=D/u$$



When image is formed a least distance of distinct vision v = –D; u = –u using

$$\frac{1}{v}-\frac{1}{u}=\frac{1}{f_e}\Rightarrow\frac{-1}{D}-\left(-\frac{1}{u}\right)=\frac{1}{f_e}$$

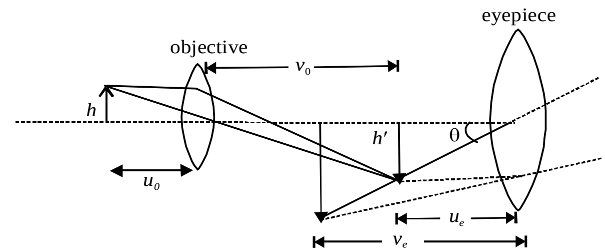
or, $\frac{D}{u}=1+\frac{D}{f_e}$ $\therefore$ $\boxed{M=1+\frac{D}{f_e}}$

When image is formed at ∞ [relaxed eye or normal adjustment) $v=\infty$ $u=-u$

$\Rightarrow u=f_e$ $\therefore$ $D/u=D/f_e$ or $\boxed{M=D/f_e}$

- Large magnification $\Rightarrow$ small focal length.

Compound Microscope :



Magnifying power = $\theta/\theta_0=\frac{h'/u_e}{h/D}=\frac{h'}{h}\cdot\frac{D}{u_e}=\frac{v_0}{u_0}\frac{D}{u_e}$

(i) For the image at the least distance of distinct vision. Length of microscope $\boxed{L=v_0+u_e}$

$$v=D;u=-u_e\Rightarrow\frac{-1}{\mathrm{D}}-\left(\frac{-1}{\mathrm{u_e}}\right)=\frac{1}{\mathrm{f_e}}\text{ or }\frac{\mathrm{D}}{\mathrm{u_e}}=1+\frac{\mathrm{D}}{\mathrm{f_e}}$$

$$\therefore\ \boxed{M=v_0/u_0\left[1+\frac{D}{f_e}\right]}$$

(ii) For normal adjustment $v=\infty$

$\therefore u_e=f_e$ $\boxed{\therefore M=\frac{v_0}{u_0}\frac{D}{f_e}}$ and $\boxed{L=v_0+fe}$

Incase of microscope f_0 is small and object is close to the object hence $u\approx f_0$. Also as intermediate image is infront of eye lens which has very short focal length.

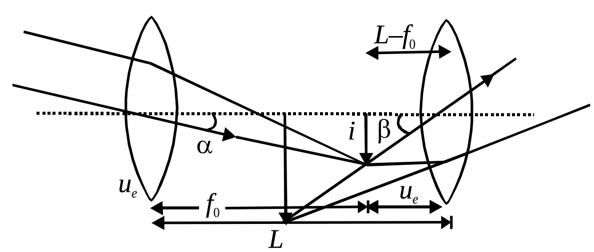
$\therefore L=v_0+u_e=v_0$

$\therefore$ $\boxed{M=\frac{LD}{f_0f_e}}$ $\therefore$ If 'L' inc. M. increase

TELESCOPE

(A) Astronomical Telescope

(i)



$\alpha = i / f_0$

$\beta = i / u_e$

$$M = \frac{\beta}{\alpha} = \frac{f_0}{L - f_0}$$

for image at least distance of distinct vision $\boxed{v_e = -D}$

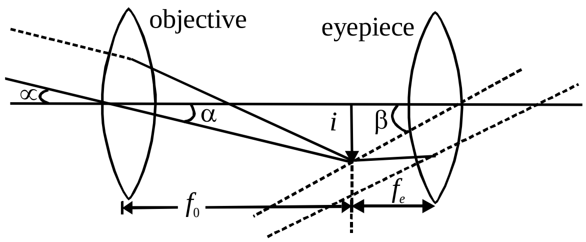
$$\therefore \frac{1}{-D} - \left(\frac{-1}{u_e}\right) = \frac{1}{+f_e}$$

$$\frac{f_0}{u_e} = \frac{f_0}{D} + \frac{f_0}{f_e}$$

$$\boxed{M = \frac{f_0}{f_e}\left[1 + \frac{f_e}{D}\right]}$$

$$\boxed{L = f_0 + u_e}$$

(ii)



$$\alpha = \frac{i}{f_0}$$

$$\beta = \frac{i}{f_e}$$

$$M = \frac{\beta}{\alpha} = \frac{f_0}{f_e}$$

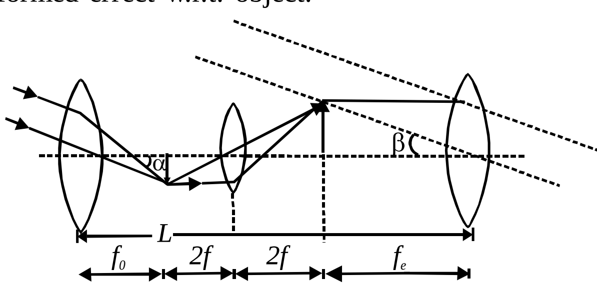
For normal Adjustment

$u_0 = \infty; v_0 = f_0; v_e = \infty \quad \because u_e = f_e \therefore \boxed{L = f_0 + f_e}$

- f_e must be small for better magnification

(B) Terrestrial Telescope:

With the help of three convex lenses image infinally formed errect w.r.t. object.



Magnifying powers $\rightarrow$ Same as astronomical telescope

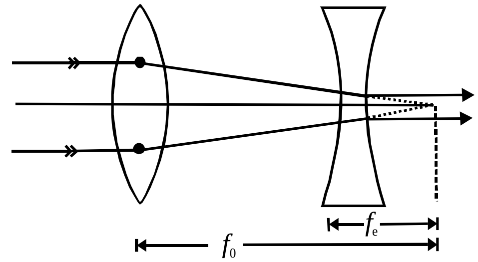
$$\boxed{L = f_0 + f_e + 4f}$$

(C) Galilian Telescope :

Here eye lens is concave and object lens is convex.

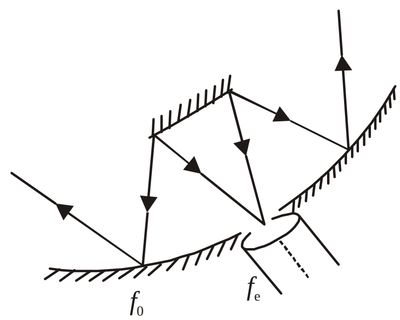
Magnifying power $\boxed{M = f_0 / f_e}$

$\boxed{Length = f_0 - f_e}$



(D) Reflecting Telescope :

If in an astronomical telescope field lens is replaced by converging mirror it becomes a reflecting telescope.



$$\boxed{M = f_0 / f_e}$$

$$\boxed{f_0 = R/2}$$

LENS CAMERA $\rightarrow$ If I is the intensity of light, S is the light transmitting area of the lens and t is exposure time during which shutter was opened then $I \times S \times t$=constt. for proper exposure or $I \times D^2 \times t$=constt where D = diam. of aperture. If intensity I is kept fixed then $D^2 \times t = constt$

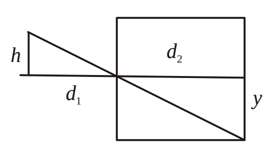
$$\therefore t \propto \frac{1}{(\text{Aperture})^2} \text{ or } \boxed{t \propto \frac{1}{D^2}}$$

The ratio of focal length to the aperture of lens is called f. no. of Camera. If diameter is constant then t is independent of focal length

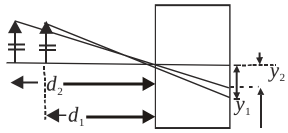
f - Number = f/D i.e. f. no. $\propto \frac{1}{D}$

$$\boxed{t \propto \frac{1}{D^2} \propto (f.No)^2}$$

PIN HOLE CAMERA : If is based on rectilinear propagation of light



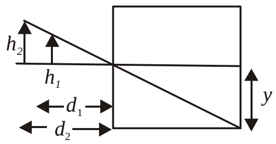
$$\boxed{\frac{h}{y} = \frac{d_1}{d_2}}$$

(a) 

$$\frac{d_1}{d_2} = \frac{y_1}{y_2}$$

When 2 object of same size are placed at different distance.

(b) If their image size is sample



$$\frac{h_1}{h_2} = \frac{d_1}{d_2}$$

RESOLVING-POWER : Ability of an instrument to see two close objects distinctly $R.P. = \frac{1}{\theta}$ where θ = limit of resolution. Limit of resolution for –

(a) Human eye $\theta = \lambda / D$ {D = diameter of pupil} for normal eye θ = 1¢

(b) Telescope $\theta = 1.22\lambda / D$ {D = diameter of lens}

(c) Microscope $\theta = \frac{\lambda}{2\mu \sin i}$ {m"sin i" is called numerical aperture of the microscope. For normal viewing i = 90º

➢ **CHROMATIC ABBERATION :** The image of a white object in white light formed by a lens is usually coloured and blurred. This defect is called chromatic Abberation. It's because focal length of a lens is different for different colours. Combination of lenses is used to remove it.

Condition of Achromatism : $\boxed{\frac{\omega_1}{f_1} + \frac{\omega_2}{f_2} = 0}$ or

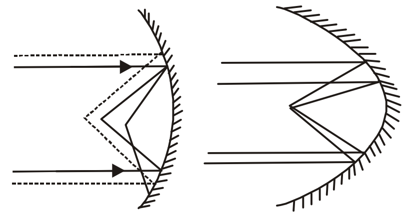
$\omega_1(\mu_1 - 1) + \omega_2(\mu_2 - 1) = 0$ or $\omega_1\delta_1 + \omega_2\delta_2 = 0 \Rightarrow$

$\Delta\mu_1 A_1 + \Delta\mu_2 A_2 = 0$ where ω_1, ω_2 are dispersive powers. Incase of thin lenses separated by a distance 'd' condition for Achromatic doublet is $d = (\omega_1 f_1 + \omega_2 f_2)/(\omega_1 + \omega_2)$

and if $\omega_1 = \omega_2$ $\boxed{d = (f_1 + f_2)/2}$

➢ **Spherical Abberation :** The inability of a lens to form a point image of an axial point of is due to spherical nature of lens. It can be minimised by–using stops, using lenses whose (focal length f) is large as. Spherical Abberation in mirrors is obtained by using

spherical abberation $\propto \frac{1}{(f)^3}$



- Stops cut paraxial or marginal rays bringing the rest practically to one focus.
- In case of plano convex lens spherical abberation is minimised if its curved surface faces the incident light.
- Using two thin lenses separated by a distance $f_2 – f_1$.

Example 1 :

A simple microscope consists of a convex lens of power +25 D and a concave lens of power –20D in contact. Find the magnifying power when final image is formed (a) at infinity (b) at least distance of distinct vision.

Solution :

Here P_1 = +25D, P_2 = –20 D, least distance for distinct vision, D = 25 cm

Since lenses are in contact, so power of the combination

$P = P_1 + P_2 = 25 – 20 = +5D$

Hence, focal length of the combination,

$$f = \frac{100}{P} = \frac{100}{5} = 20\text{cm}$$

When final image is formed at ∞, Magnifying power (M.P.) is

$$\text{M.P.} = \frac{D}{f} = \frac{25}{20} = 1.25$$

M.P. when final image is formed at a distance of distinct vision,

$$\text{M.P.} = 1 + \frac{D}{f} = 1 + \frac{25}{20} = 1 + 1.25 = 2.25$$

Example 2 :

A compound microscope has angular magnification equal to 10. If the object subtends an angle of 0.6° at the eye, what will be the angle subtended by the image at the eye?

Solution :

Here, M.P. = 10, α = 0.6°

Using, $\text{M.P.} = \frac{\beta}{\alpha}$, we get

$$\beta = \text{M.P.} \times \alpha = 10 \times 0.6° = 6°$$

Therefore, the angle subtended by the image at the eye is 6°.

Example 3 :

A compound microscope has a magnification of 30. The focal length of its eye-piece is 5 cm. Assume that the final image is formed at the least distance of distinct vision (D=25 cm). Calculate the magnification produced by the objective.

Solution :

Here M.P. = 30, f_e = 5 cm

M.P. = $m_o \times m_e$

where m_o is magnification produced by the objective and m_e is magnifying power of eye piece

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

$\therefore$ M.P. = $m_0\left(1 + \frac{D}{f_e}\right)$ $\quad \therefore\ 30 = m_0\left(1 + \frac{25}{5}\right) = 6m_0$

$\therefore\ m_0 = 5$

Example 4:

The magnifying power of a telescope is found to be 9 and the separation between the lenses is 20 cm for relaxed eye. What are the focal lengths of the component lenses used in the telescope?

Solution :

Here M.P. = 9, tube length L = 20 cm

$\Rightarrow f_o + f_e = 20$ cm

As $\frac{f_o}{f_e} = 9$, therefore solving, $\quad \therefore\ f_o$ = 18 cm

and f_e = 2 cm

Example 5 :

The objective of an astronomical telescope has a diameter of 150 mm and a focal length of 4.0 m. The eyepiece has a focal length of 25.0 mm. (a) Calculate the magnifying power of the telescope. (b) What is the distance between the objective and the eyepiece?

Solution :

(a) Here, f_o = 4 m

$f_e = 25$ mm $= 25 \times 10^{-3}$ m

$\therefore$ Magnifying power of telescope,

$$\text{M.P.} = \frac{f_o}{f_e} = \frac{4}{25 \times 10^{-3}} = 160$$

(b) Distance between objective and eye-piece

$= f_o + f_e = 4\text{m} + 25 \times 10^{-3}\text{m} = 4.025$ m

TEST YOUR SELF

1. The focal length of the objective and eye piece of a microscope are respectively 1 cm and 2 cm. The distance between them is 12 cm, Where an object should be placed in order to view it at the least distant of distinct vision.

Ans. 1.11 cm

2. The distance between the objective and the eye piece of a microscope are 16 cm and their focal length are respectively 0.4 cm and 0.5 cm. Calculate its magnifying power if the final image is formed at infinity.

Ans. 2000

3. The least distance of distinct vision for a defective eye is 75 cm. What should be the focal length and power of lens which will be used to real a book clearly at 25 cm ?

Ans. Convex lens of the focal length 37.5 cm, + 2.66 diopter.

4. A point object is placed on the principal axis of a convex lens (f = 15 cm) at a distance of 30 cm from it. A glass plate (μ = 1.50) of thickness 1 cm is placed on the other side of the lens perpendicular to the axis. Locate the image of the point object.

Ans. 30.33 cm from the lens

5. An object is to be seen through a simple microscope of focal length 12 cm. Where should the object be placed so as to produce maximum angular magnification? The least distance for clear vision is 25 cm.

Ans. 8.1 cm from the lens

6. A compound microscope consists of an objective of focal length 1 cm and an eyepiece of focal length 5 cm. An object is placed at a distance of 0.5 cm from the objective. What should be the separation between the lenses so that the microscope projects an inverted real image of the object on a screen 30 cm behind the eyepiece ?

Ans. (a) 5 cm

7. The eyepiece of an astronomical telescope has a focal length of 10 cm. The telescope is focussed for normal vision of distant objects when the tube length is 1.0 m. Find the focal length of the objective and the magnifying power of the telescope.

Ans. 90 cm, 9

8. An astronomical telescope is to be designed to have a magnifying power of 50 in normal adjustment. If the length of the tube is 102 cm, find the powers of the objective and the eyepiece.

Ans. 1 D, 50 D