Telescope:

A telescope is an optical instrument which enables us to see distant objects clearly. The telescope is used to provide angular magnification of distant objects. It also has an objective and an eyepiece. But here, the objective has a larger focal length and a much larger aperture than the eyepiece.

Types of Telescope:

- Refracting telescopes (These make use of lenses to view distant objects)
  - Astronomical-Telescope
  - Terrestrial-Telescope
- Reflecting Telescopes (These make use of converging mirrors to view the distant objects.)
  - Newtonian telescopes
  - Cassegrain telescopes

Astronomical Telescope:

It is used to see heavenly objects like the sun, satellites, stars, planets etc. The final image is inverted one which is immaterial in the case of heavenly bodies because of their round shape.

Terrestrial Telescope:

It is used to see distant objects on the surface of the earth. The final image formed is erect one. This is an essential condition of viewing the objects on earth's surface correctly.

I: Astronomical Telescope:

A Refracting Telescope: (Astronomical Telescope):

Astronomical telescopes make objects from space appear as bright, sharp and large as possible. It is a refracting type telescope used to see heavenly bodies like satellites and galaxies etc. It consist of two converging lenses mounted co-axially at the outer ends of two sliding tubes. It provides angular magnification for distant objects and uses two lenses objective and eyepiece for this purpose. Objective is closer to object with focal length f_o. Eyepiece is closer to the observer's eye with focal length f_e. Only difference between microscope and telescope is that objective is of quite larger aperture here. This is because an object is located far away and the intensity of light rays coming from object reduces to very low value. objective is taken to be of large aperture so that as many light rays enters into the object which increases the intensity. Light from a distant object enters the objective and a real image is formed in the tube at its second focal point. The eyepiece magnifies this image producing a final inverted image. 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.

Case (I): (when the final image is formed at infinity : Normal Adjustment):

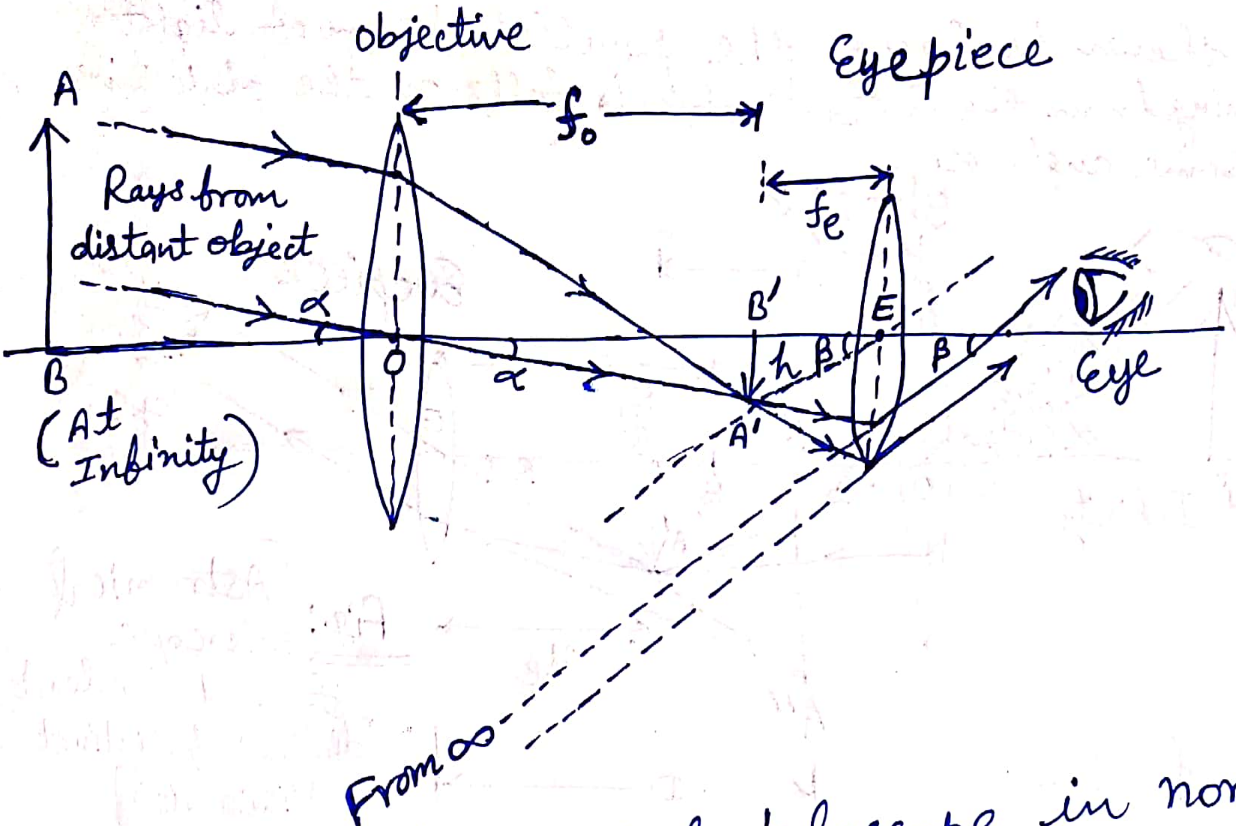

Fig. [Astronomical telescope in normal adjustment (A Refracting Telescope)]

from figure,

$$\tan\alpha = \frac{h}{f_o} \Rightarrow \alpha \simeq \frac{h}{f_o}$$

$$\tan\beta = \frac{h}{f_e} \Rightarrow \beta \simeq \frac{h}{f_e}$$

$$\Rightarrow \text{magnifying power } (m) = \frac{\beta}{\alpha} = \frac{(h/f_e)}{(h/f_o)}$$

$$\Rightarrow \boxed{m = \frac{f_o}{f_e}}^{*} \qquad (f_o >> f_e)$$

In this case, the length of the telescope tube $= f_o + f_e$

* Image is real and inverted. $m \rightarrow$ very large.

Case (II): (When the final image is formed at the least distance of distinct vision):

As shown in figure, the parallel beam of light coming from the distant objects falls on the objective at some angle α.

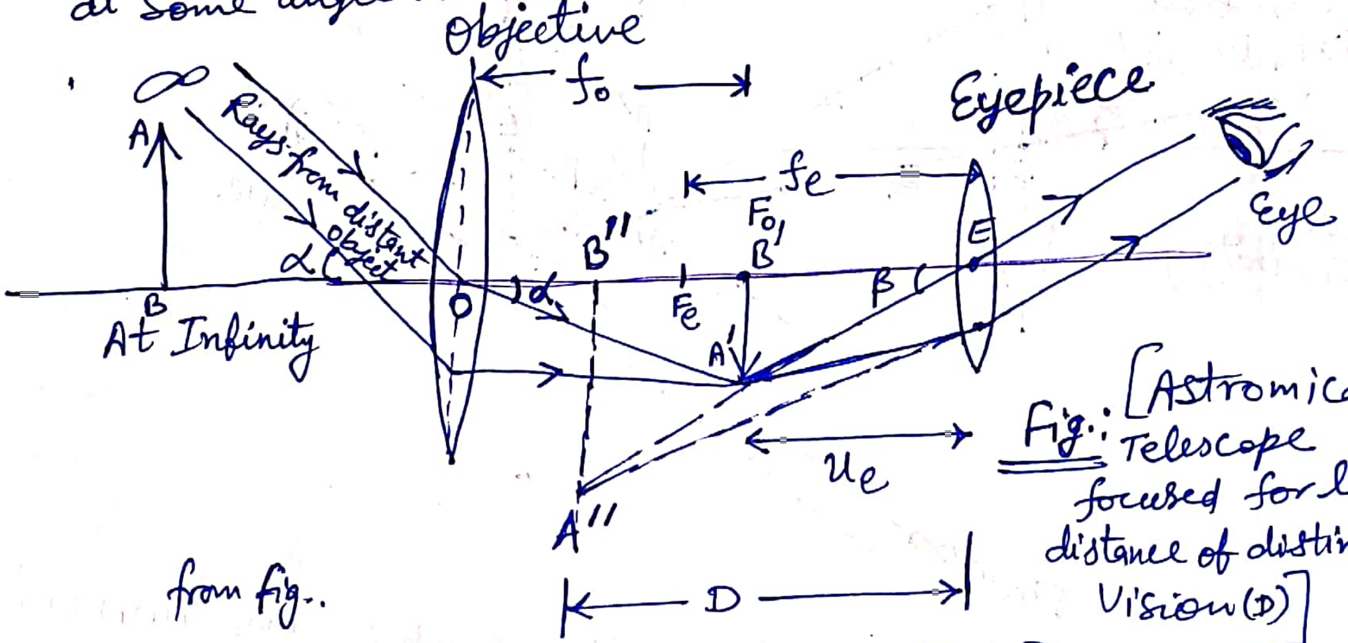

Fig.: [Astromical Telescope focused for least distance of distinct Vision (D)]

from fig..

$$\angle A'OB' = \alpha, \quad \angle B''EA'' = \beta \quad \text{(Say)}$$

$\alpha \to$ angular size of object

$\beta \to$ angular size of image

The intermediate image ($B'A'$) will act as an object for eyepiece and light rays will incident on the eyepiece and finally these light rays will be falling into the observer's eye and final image will be seen by the observer.

$$\tan\alpha = \frac{B'A'}{OB'} = \frac{B'A'}{f_o} \simeq \alpha \quad \text{—— (I)}$$

$$\tan\beta \simeq \beta = \frac{B'A'}{EB'} = \frac{B'A'}{u_e} \quad \text{—— (II)}$$

$$\Rightarrow \text{magnifying power } (m) = \frac{\beta}{\alpha} = \frac{B'A'/u_e}{B'A'/f_o} = \frac{f_o}{u_e} \quad \text{—— (1)}$$

Using lens formula for eyepiece:

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \left(\because \begin{array}{l} u = -u_e \\ v = -D \\ f = +f_e \end{array}\right)$$

$$\Rightarrow \frac{1}{-D} - \frac{1}{-u_e} = \frac{1}{f_e}$$

$$\Rightarrow \frac{1}{u_e} = \left(\frac{1}{f_e} + \frac{1}{D}\right) \text{ ——— (2)} \quad \Rightarrow u_e = \frac{f_e D}{f_e + D}$$

from (1) & (2),

$$m = \frac{f_o}{u_e} = f_o\left(\frac{1}{u_e}\right)$$

$$= f_o\left(\frac{1}{f_e} + \frac{1}{D}\right) \quad (\text{using eq}^n\ (2))$$

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$$\Rightarrow \boxed{m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)}$$

(when the final image is formed at 'D')

D → least distance of distinct vision.

clearly for large magnifying power $f_o >> f_e$.

Final image formed is real & inverted.

☆

[The distance between objective and eyepiece in this case (Tube length) $= f_o + u_e = \left[f_o + \left(\frac{f_e D}{f_e + D}\right)\right]$]

Imp. points:

(1) A telescope is focused on the distant object by varying distance between the objective and the eye-piece with the help of rack and pinion arrangement.

(II). when the final image is formed at the least distance of distinct vision, the magnifying power of the telescope is larger than that in the case of normal adjustment because the factor

$$\left(1+\frac{f_e}{D}\right) > 1.$$

(III). An astronomical telescope forms an inverted image. As the celestial objects are oval in shape, so it does not matter whether the final image is inverted or erect.

(IV). In a telescope, the image is not actually magnified. A telescope simply increases the visual angle. The visual angle β for the image is much larger than the visual angle α for the object. Consequently, the angular magnification β/α is quite large.

(V). The objective of the telescope should have large aperture because then a much wider beam of light is incident on it and is converged into a small cone which, on entering the eye, produces sufficient illumination on the retina. So even two distant faint stars which can not be seen by naked eyes, become visible through such a telescope.

(II). TERRESTRIAL TELESCOPE :

(A Refracting telescope)

Refracting telescopes can be used both for terrestrial and astromical observations. Terrestrial telescope is used to see erect images of distant earthly objects. It uses an additional convex lens between objective and eyepiece for obtaining an erect image.

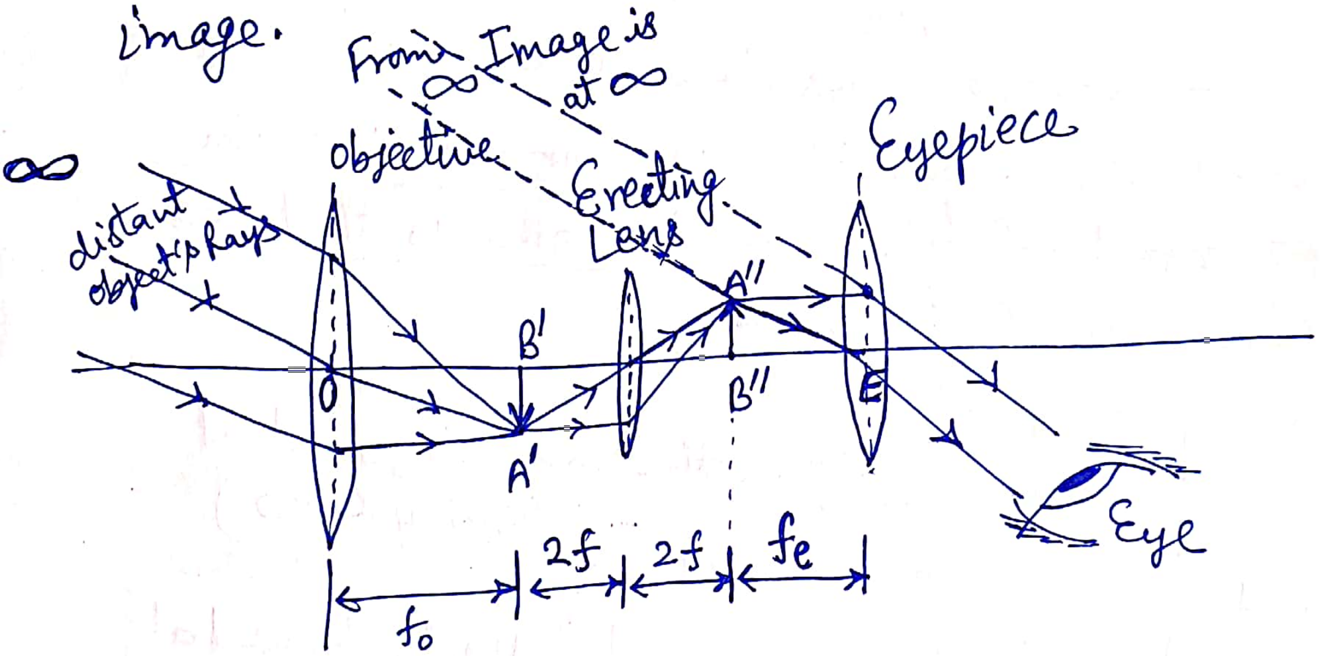

Fig. [Terrestrial Telescope : A refracting telescope]

As shown in fig, the objective forms a real, inverted and diminished image, A'B'' of the distant object in its focal plane. Now the erecting lens is held at twice its focal length from the focal plane of the objective.

This lens forms a real, inverted and equal size image A''B'' of A'B'. This image is now erect with respect to the distant object. The eyepiece is so adjusted that the image A''B'' lies at its principal focus. Hence the final image is formed at infinity and is highly magnified and erect w.r.t. the distant object.

magnification factor of erecting lens,

$$m_e = \frac{A''B''}{A'B'} = 1 \quad (\because A''B'' = A'B')$$

⇒ erecting lens does not contribute any magnification. So, the angular magnification of terrestrial telescope is same as that of the astronomical telescope.

⇒ $$\boxed{m = \frac{f_o}{f_e}}$$ * (when the image is formed at infinity, ∞)

and, $$\boxed{m = \frac{f_o}{f_e}\left(1 + \frac{f_e}{D}\right)}$$ ** (when the is formed at the least distance of distinct vision, D)

Tuble Length (L):

$$\boxed{L = f_o + 4f + f_e}$$ * (if image is at ∞)

and, $$\boxed{L = f_o + 4f + u_e}$$ * (if image is at D)

f → focal length of erecting lens.

Demerits: (I). Larger tube length of terrestrial telescope than astronomical telescope.

(II). Extra reflection at the surface of the erecting lens, reduces the intensity of the final image.

(III) REFLECTING TELESCOPES :

A lens or mirror changes the direction of light to concentrate incoming light at a focus and form an image of the light source at the focal plane. Telescope using lens are refractors, and those using mirrors are reflectors. Most modern telescopes are reflectors.

(A) (Newtonian Reflecting Telescope):

The Newtonian telescope was the first successful reflecting telescope, completed by Isaac Newton in 1668. As shown in figure, it consists of a large concave mirror of large focal length as the objective, made of an alloy of copper and tin. Telescope with mirror objectives are called reflecting telescopes.

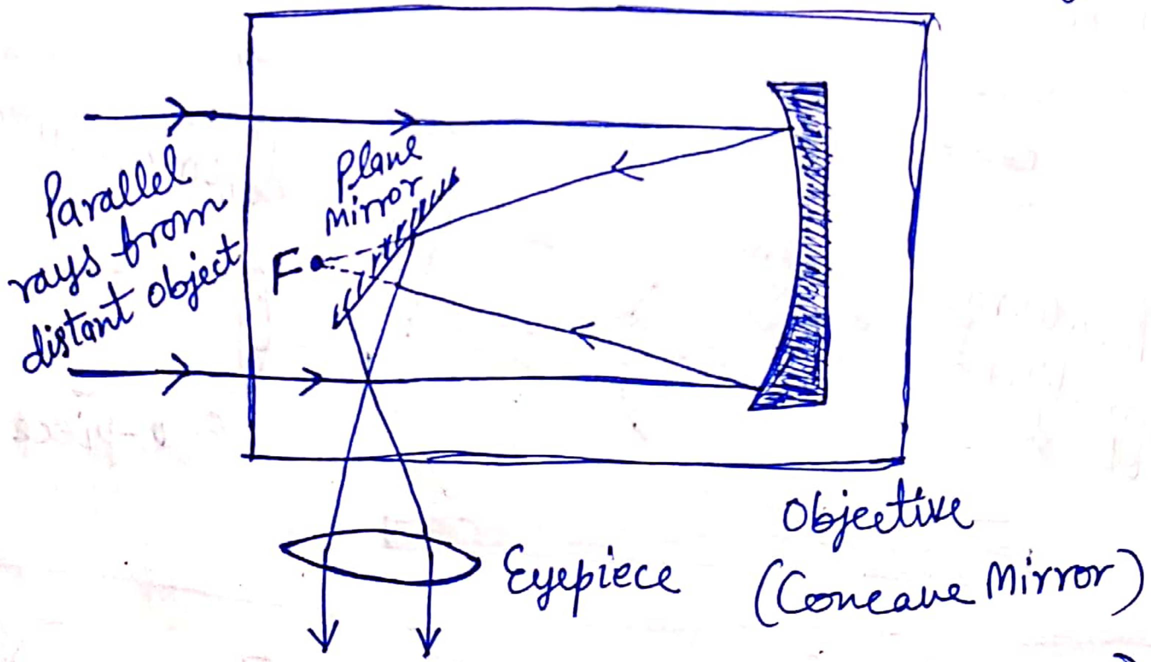

Fig. (Newtonian reflecting telescope)

A beam of light from the distant star is incident on the objective. Before the rays are focused at F, a plane mirror inclined at 45° intercepts them and turns them towards an eyepiece adjusted perpendicular to the axis of the instrument. The eyepiece forms a highly magnified, virtual & erect image of the distant object.

(B) Cassegrain Reflecting Telescope:

Schematic diagram of a reflecting telescope (Cassegrain) is shown in figure. Laurent Cassegrain is inventor of the cassegrain reflector. The cassegrain reflector is a combination of a primary concave mirror and a secondary convex mirror.

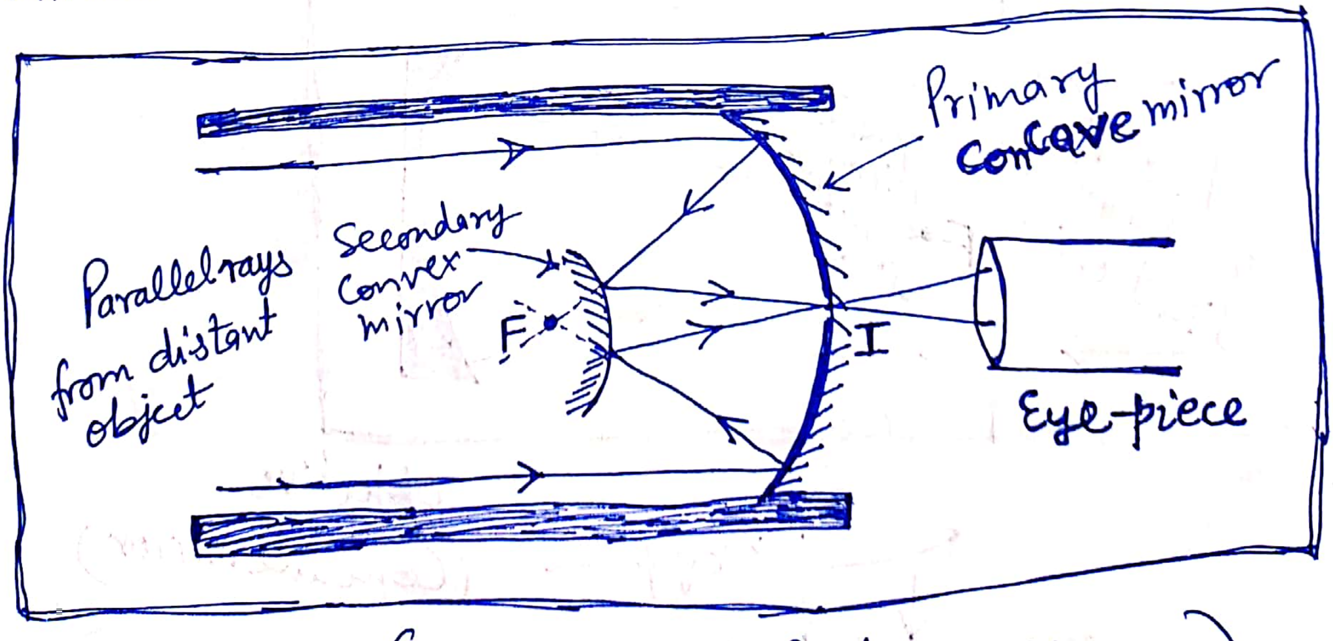

Figure: (Cassegrain Reflecting Telescope)

Large concave paraboloidal mirror (primary) has a hole at its centre. Small convex (secondary) mirror is placed near the focus of the primary mirror. The eyepiece is placed on the axis of the telescope near the hole of the primary mirror.

The parallel rays from the distant object are reflected by the large concave mirror. Before these rays come to focus at F, they are reflected by the small convex mirror and are converged to a point I just outside the hole. The final image is viewed through the eyepiece. As the first image at F is inverted with respect to distant object and the second image I is erect with respect to the first image F, hence the final image is inverted with respect to the object.

$f_o \rightarrow$ focal length of the objective

$f_e \rightarrow$ focal length of the eyepiece

magnifying power (magnification factor, m):

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

(for the final image formed at the least distance of distinct vision)

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

(for the final image formed at infinity)

$f_o = R/2$

(IV): Galilean Telescope:

It is also a terrestrial telescope but of much smaller field of view. It also uses two lenses: Convex (Converging lens) lens as objective and concave lens (diverging lens) as eyepiece (eyelens). The image formed by objective lies at a distance fe from the eyepiece, if final image is produced at infinity(∞). So the rays refracted by the eyepiece are rendered parallel as shown in fig. (a). The image formed by the objective lies at a distance u_e from the eyepiece, if final image is formed at distinct point D, as shown in fig. (b).

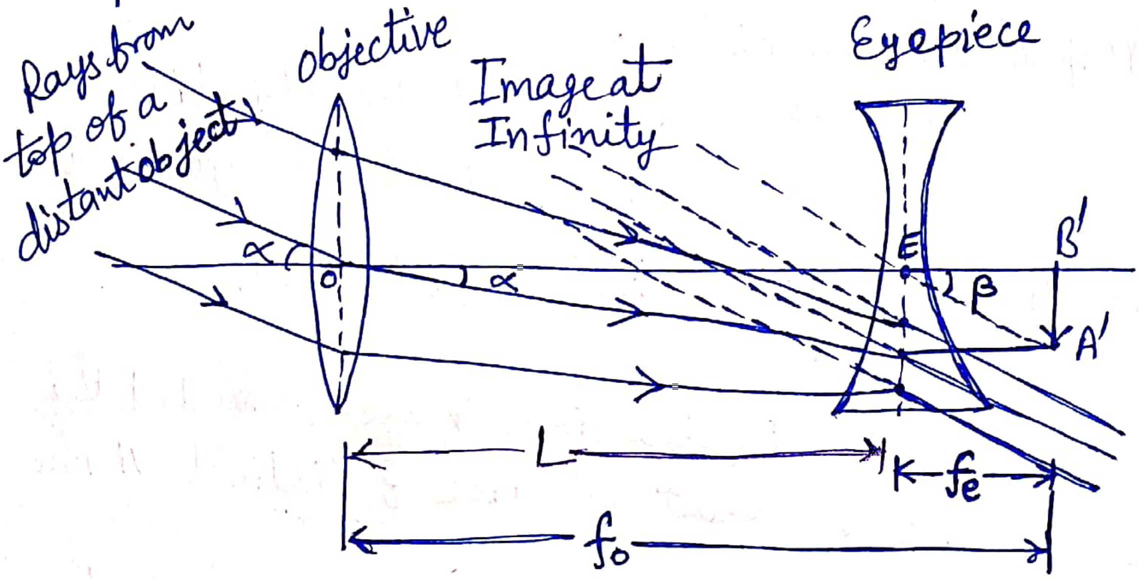
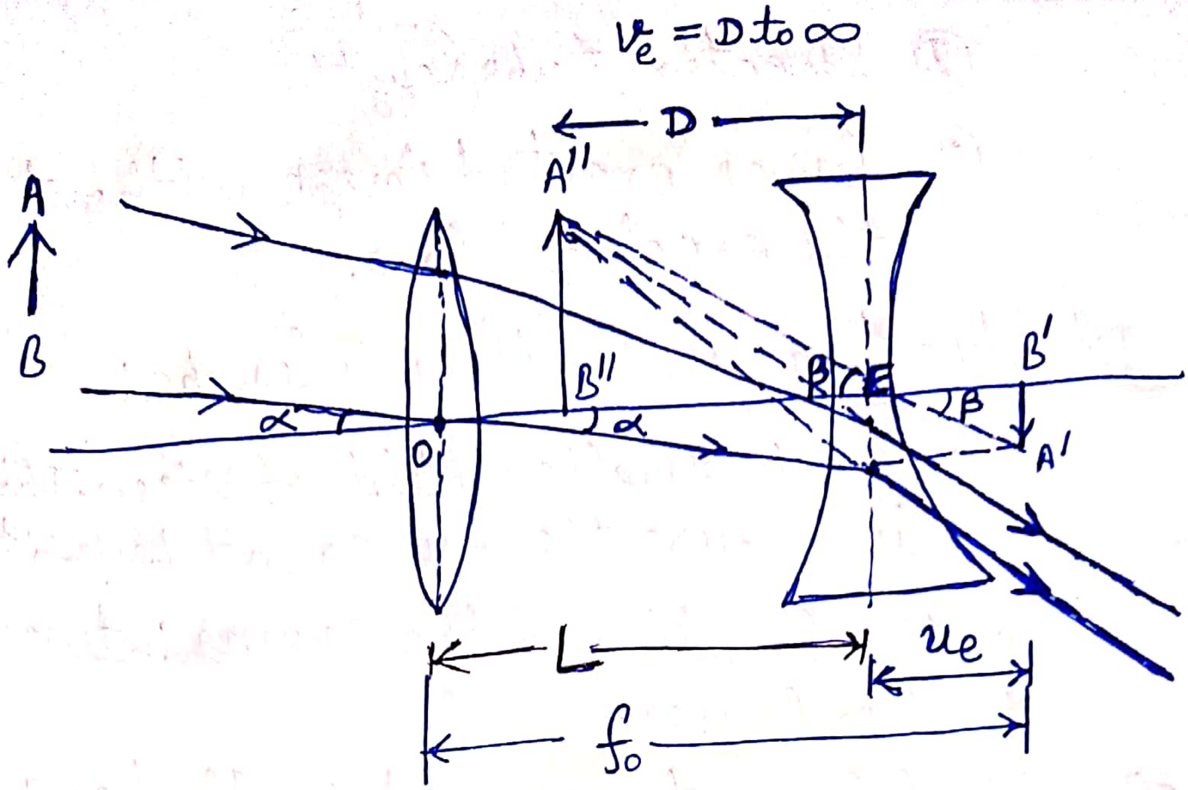


Fig. (a): Galileo's telescope (normal adjustment)



<u>Fig. (b)</u>: [Galileo's telescope if final image is formed at distinct point D]

<u>Magnification (m):</u>

$$m = \frac{f_o}{f_e}$$ * (If final image is formed at ∞)

$$m = \frac{f_o}{f_e}\left(1 - \frac{f_e}{D}\right)$$ * (If final image is formed at distinct point D)

<u>Tube Length (L):</u>

$$\text{Length (L)} = f_o - f_e$$ * (if final image is formed at ∞)

$$\text{Length (L)} = f_o - u_e$$ * (If final image is formed at D)

Advantage of Galilean Telescope:

(I) Shorter tubelength

(II) Gives erected image without the erecting lens.

Disadvantage of Galilean Telescope:

(I) much smaller field of view. This is because the eye cannot be positioned on the location of the eyeing between the two lenses.

(II) A Galilean telescope typically has a field of view of about 15-18 arc minutes.

Advantages of Reflecting type telescope:

(1). There is no chromatic aberration in a mirror.

(2). If a parabolic reflecting surface is chosen, spherical aberration is also removed.

(3). Due to large aperture of the mirror used, the reflecting telescopes have high resolving power.

(4) A lens of large aperture tends to be very heavy and, therefore, difficult to make and support by its edges. On the other hand, a mirror of equivalent optical quality weighs less and can be supported over its entire back surface.

(5) A concave mirror of large aperture has high gathering power and absorbs very less amount of light than the lenses of large apertures. the final image formed in reflecting telescope is very bright. So even very distant or faint stars can be easily viewed.

(6) A mirror requires grinding and polishing of one surface only. So it costs much less to construct a reflecting telescope than a refracting telescope of equivalent optical quality.