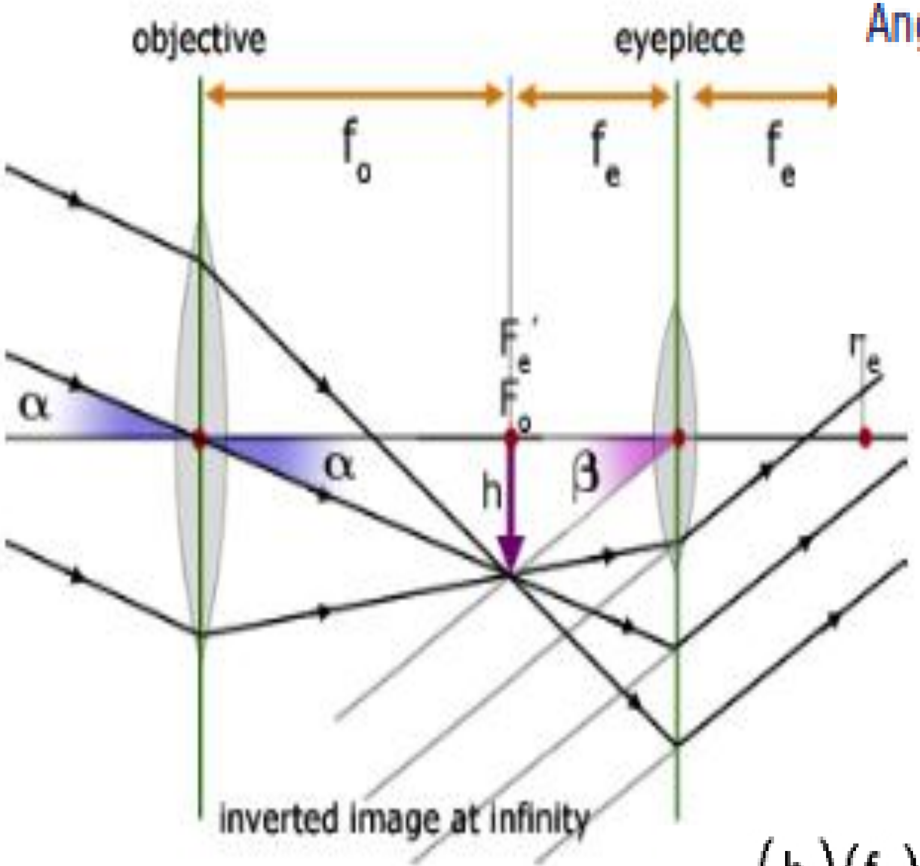
Optical Instruments

ASTRONOMICAL TELESCOPE



Angular magnification is by definition:

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

The angle subtended by the object ***α*** (alpha), is given by:

$$\alpha = \frac{h}{f_o}$$

The angle subtended by the image ***β*** (beta), is given by:

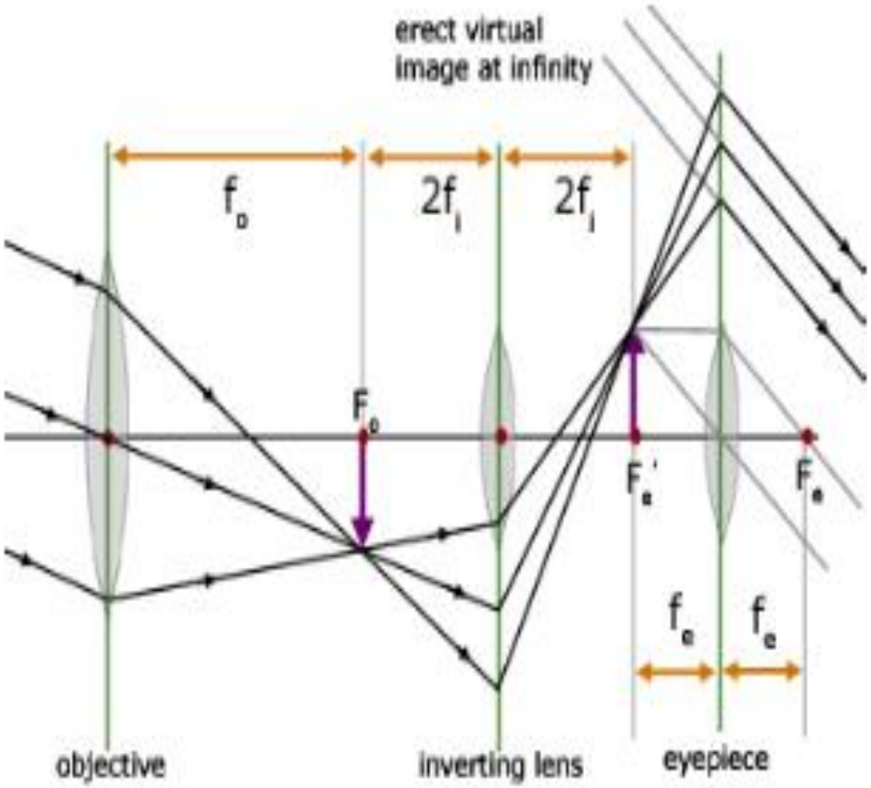
$$\beta = \frac{h}{f_e}$$

$$M = \left(\frac{h}{f_e}\right)\left(\frac{f_o}{h}\right)$$

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

So for maximum magnification, a telescope is requires a long objective focal length and a short eyepiece focal length.

TERRESTRIAL TELESCOPE

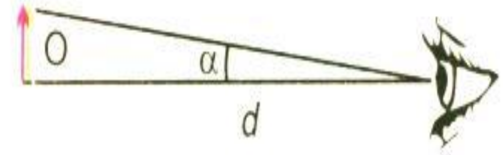


The terrestrial telescope has one more convex lens than an astronomical telescope. The lens is used to invert the intermediary image, while not affecting the image size. This is done by placing the image from the objective at 2f from the lens. Another image is then produced at 2f on the other side of the lens. This image in turn is magnified by the eyepiece.

- What do you know about the Least Distance of Distinct Vision?
- Ans. The minimum distance from the eye at which an object appears to be distinct is called the least distance
- of distinct vision or near point.
- The near point is about 25 cm from the eye. If the object is held closer to the eye than this distance,
- the image formed will be blurred and fuzzy. The location of near point changes with age.

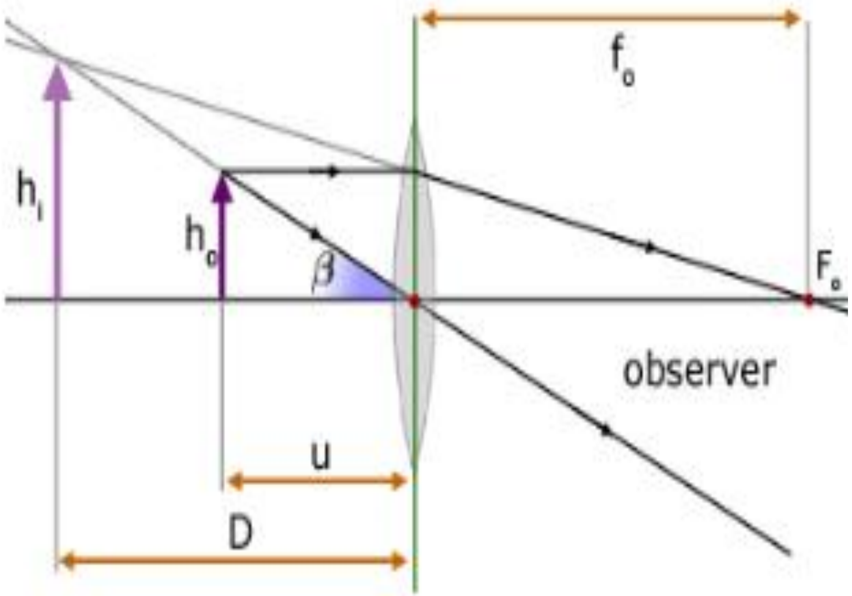
- 2 MAGNIFYING POWER AND RESOLVING POWER OF OPTICAL INSTRUMENT
- Q # 2: What do you understand by linear magnification and angular magnification? Explain how a
- convex lens is used as a magnifier?
- Linear Magnification: The ratio of the size of image to the size of object is called linear magnification.
- Angular magnification: The ratio of the angle subtended by the image as seen through the optical device to
- that subtended by the object at the un-aided eye
- Convex lens used as a magnifier when an object is brought within the focal length of convex lens.
- Q # 3: Explain the difference between the angular magnification and resolving power of optical
- instrument. What limits the magnification of an optical instrument?
- Angular magnification: The ratio of the angle subtended by the image as seen through the optical device to
- that subtended by the object at the un-aided eye
- Resolving Power: It is the ability to disclose the minor details of the object under examination.
- The magnification of an optical instrument is limited due to defects in lenses.

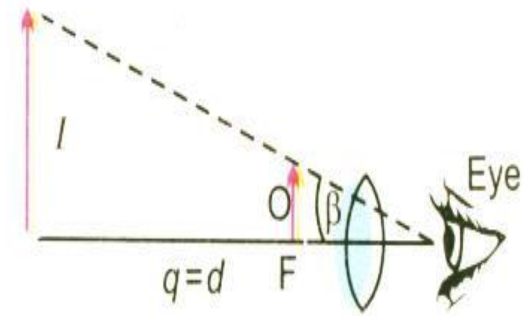
Microscopes



(a)

Magnifying Glass/Simple Microscope (image at Near Point)



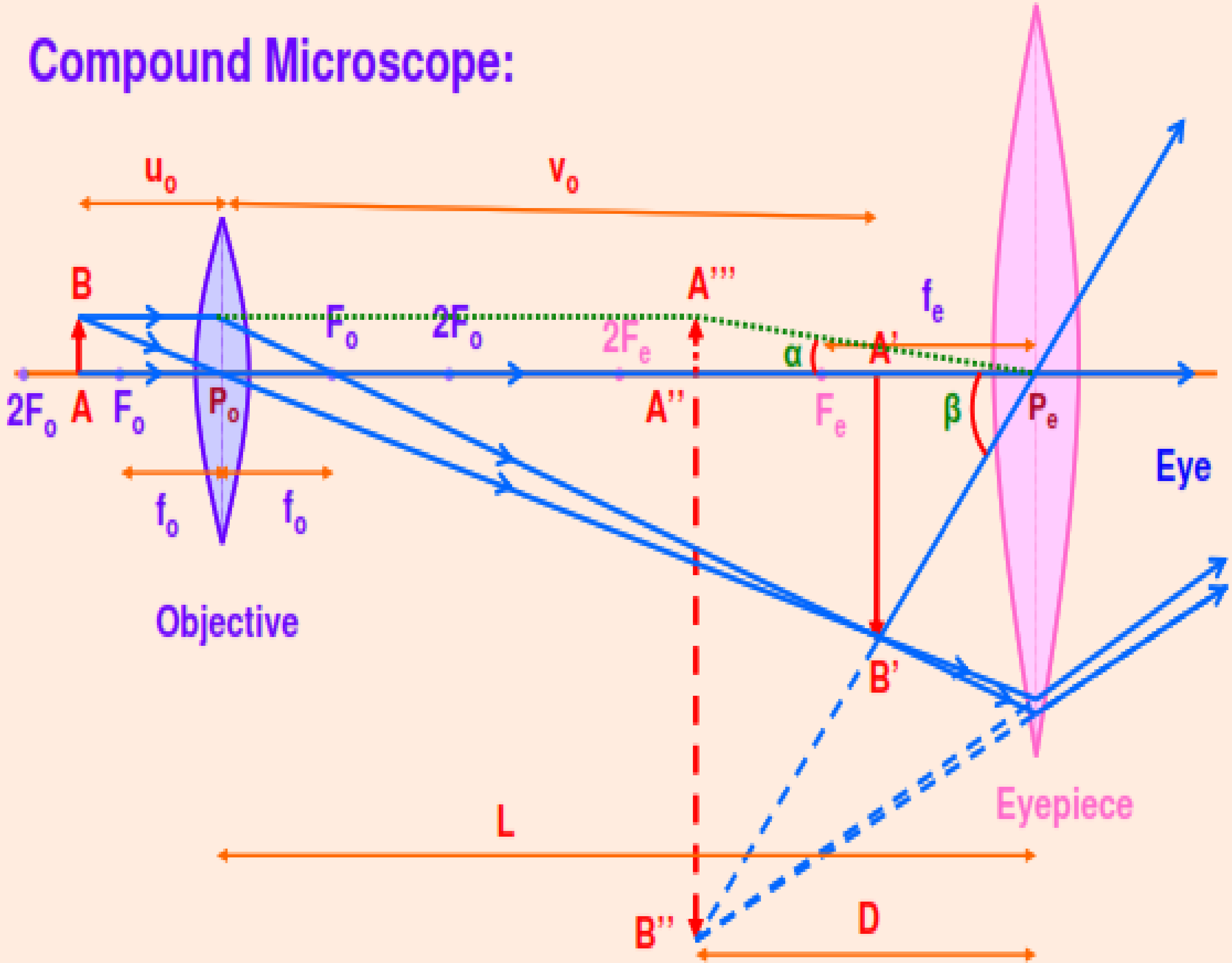


(b)

$$M = 1 + \frac{d}{f}$$

D is the **Near Point** of the eye. This is the closest an object can be to the eye and remain in focus.

Compound Microscope:



Objective: The converging lens nearer to the object.

Eyepiece: The converging lens through which the final image is seen.

Both are of short focal length. Focal length of eyepiece is slightly greater than that of the objective.

Angular Magnification or Magnifying Power (M):

Angular magnification or magnifying power of a compound microscope is defined as the ratio of the angle β subtended by the final image at the eye to the angle α subtended by the object seen directly, when both are placed at the least distance of distinct vision.

$$\boxed{M = \frac{\beta}{\alpha}}$$

Since angles are small,
$\alpha = \tan\alpha$ and $\beta = \tan\beta$

$$M = \frac{\tan\beta}{\tan\alpha}$$

$$M = \frac{A''B''}{D} \times \frac{D}{A''A'''}$$

$$M = \frac{A''B''}{D} \times \frac{D}{AB}$$

$$M = \frac{A''B''}{AB}$$

$$M = \frac{A''B''}{A'B'} \times \frac{A'B'}{AB}$$

$$M = M_e \times M_o$$

$$M_e = 1 - \frac{v_e}{f_e} \quad \text{or} \quad M_e = 1 + \frac{D}{f_e}$$

$(v_e = -D = -25\text{ cm})$

and $M_o = \dfrac{v_o}{-u_o}$ $\therefore$ $\boxed{M = \dfrac{v_o}{-u_o}\left(1 + \dfrac{D}{f_e}\right)}$

Since the object is placed very close to the principal focus of the objective and the image is formed very close to the eyepiece,
$u_o \approx f_o$ and $v_o \approx L$

$$\boxed{M = \frac{-L}{f_o}\left(1 + \frac{D}{f_e}\right)}$$

or $\boxed{M \approx \dfrac{-L}{f_o} \times \dfrac{D}{f_e}}$ (Normal adjustment i.e. image at infinity)

- Whenever high magnification is desired, a compound microscope is used. It consists of two convex

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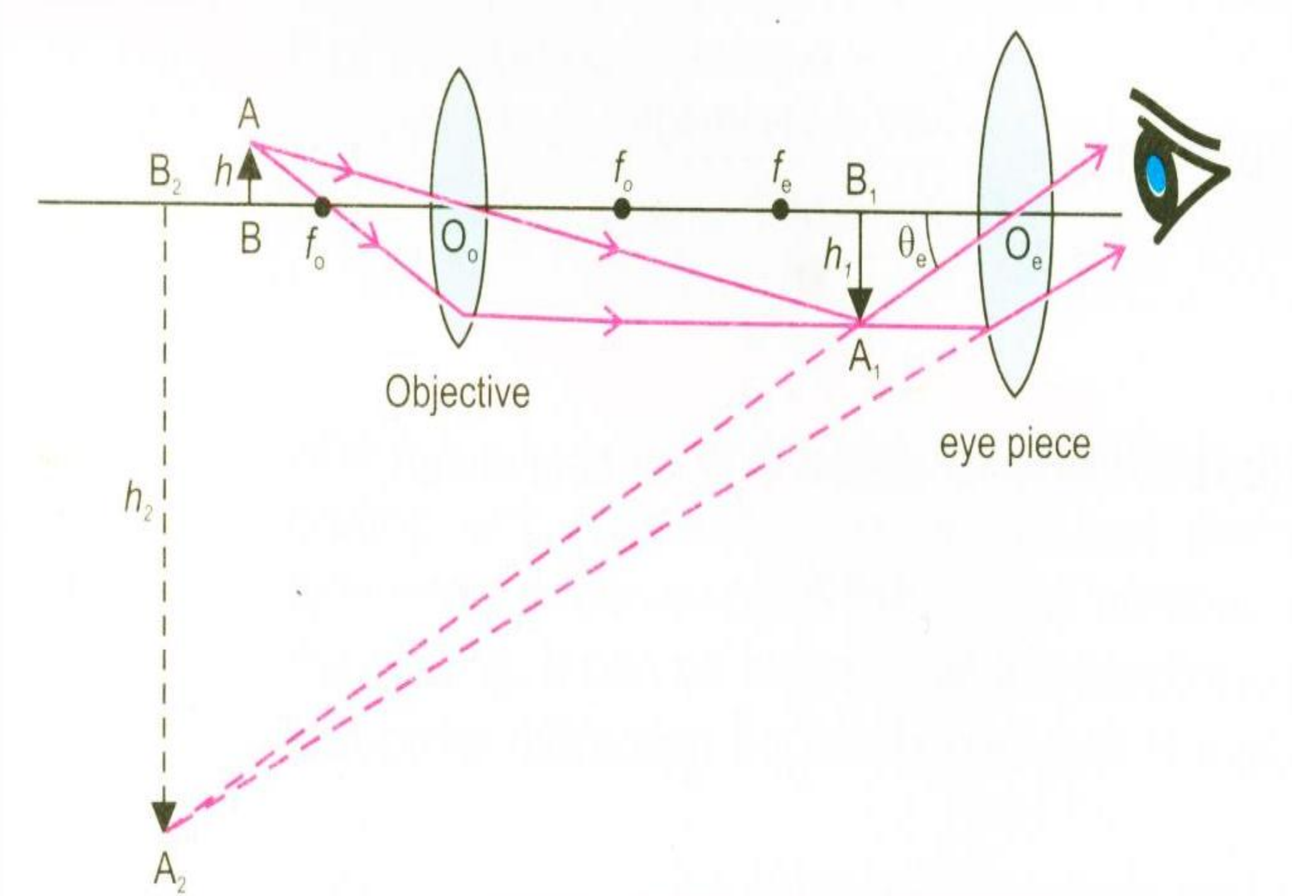
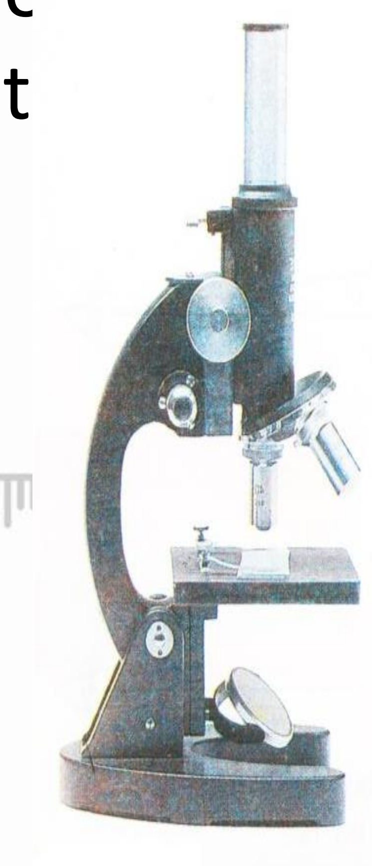


Ray diagram of a Compound Microscope



A Compound Microscope

The object of height h is placed just beyond the principal focus of the objective. This produces a real and magnified image of height $h_1$of the object at a place situated within the focal point of the eye-piece. It is then further magnified by the eye-piece (final image has the height h_2). In normal adjustment, the eye-piece is positioned so that the final image is formed at the near point of the eye at a distance d.

The angular magnification M of a compound microscope is described by the formula:

$$M = \frac{\tan\theta_e}{\tan\theta} \quad ------ \quad (1)$$

where θ_e is the angle subtended by the final image of height h_2 and θ is the angle that th bject of height h subtend at the eye if placed at the near point d. Now, from figure:

$$\tan\theta = \frac{h}{d} \quad and \quad \tan\theta_e = \frac{h_2}{d}$$

Putting values in equation (1), we have:

$$M = \frac{\tan\theta_e}{\tan\theta} = \frac{\left(\frac{h_2}{d}\right)}{\left(\frac{h}{d}\right)} = \frac{h_2}{h}$$

$$\Rightarrow M = \frac{h_1}{h} \times \frac{h_2}{h_1}$$

Where $\frac{h_1}{h}$ is the magnification M_1 of objective and $\frac{h_2}{h_1}$ is the linear magnification M_2 of eye-piece. Hence, total magnification is:

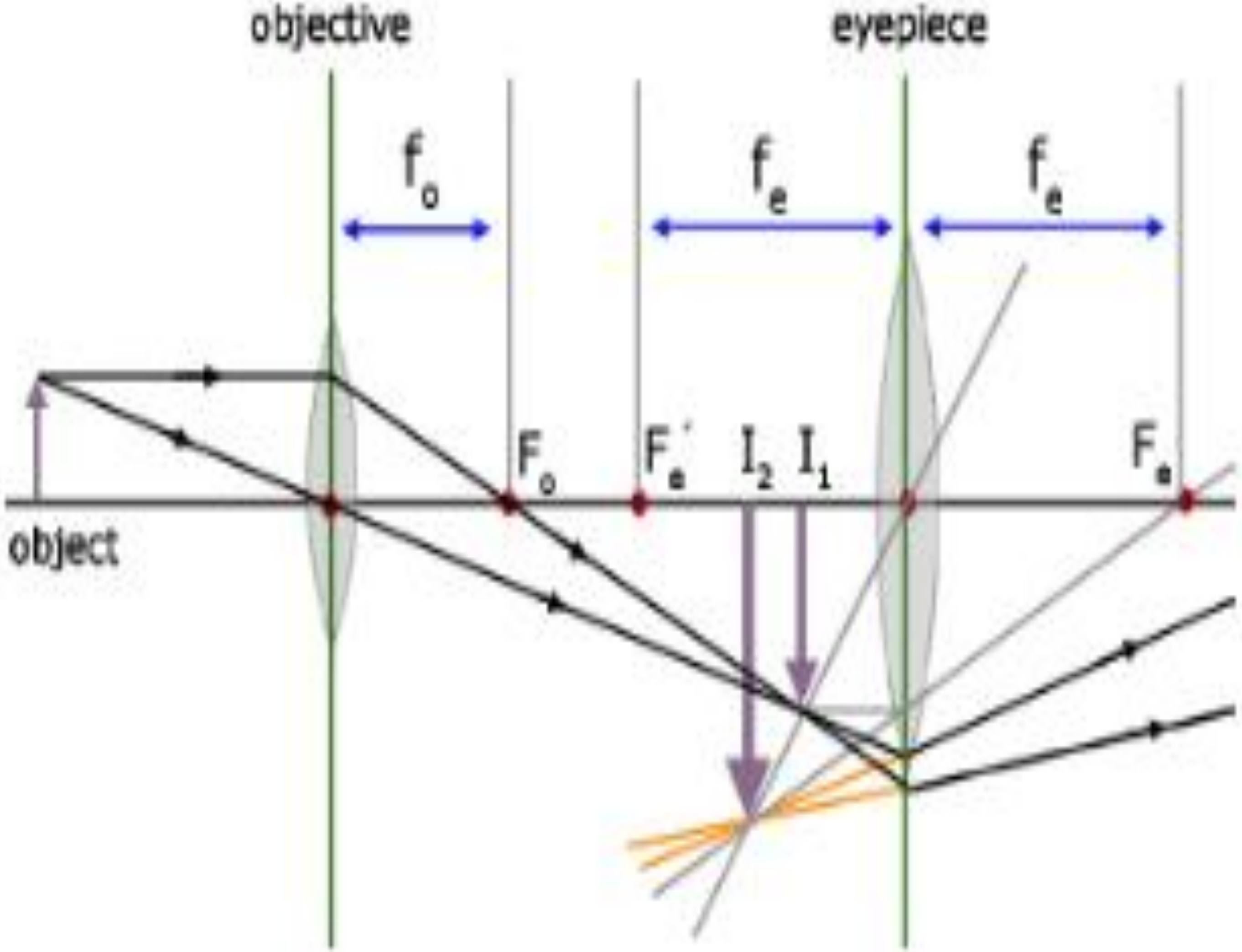
$$M = M_1 \times M_2 \quad ------ \quad (2)$$

- For case of objective (Real and Inverted Image), $M_1 = \frac{q}{p}$
- For case of eye-piece (Virtual Image), $M_2 = 1 + \frac{d}{f_e}$

Equation (2) becomes:

$$M = \frac{q}{p}\left(1 + \frac{d}{f_e}\right)$$

This expression gives the magnifying power of a compound microscope.



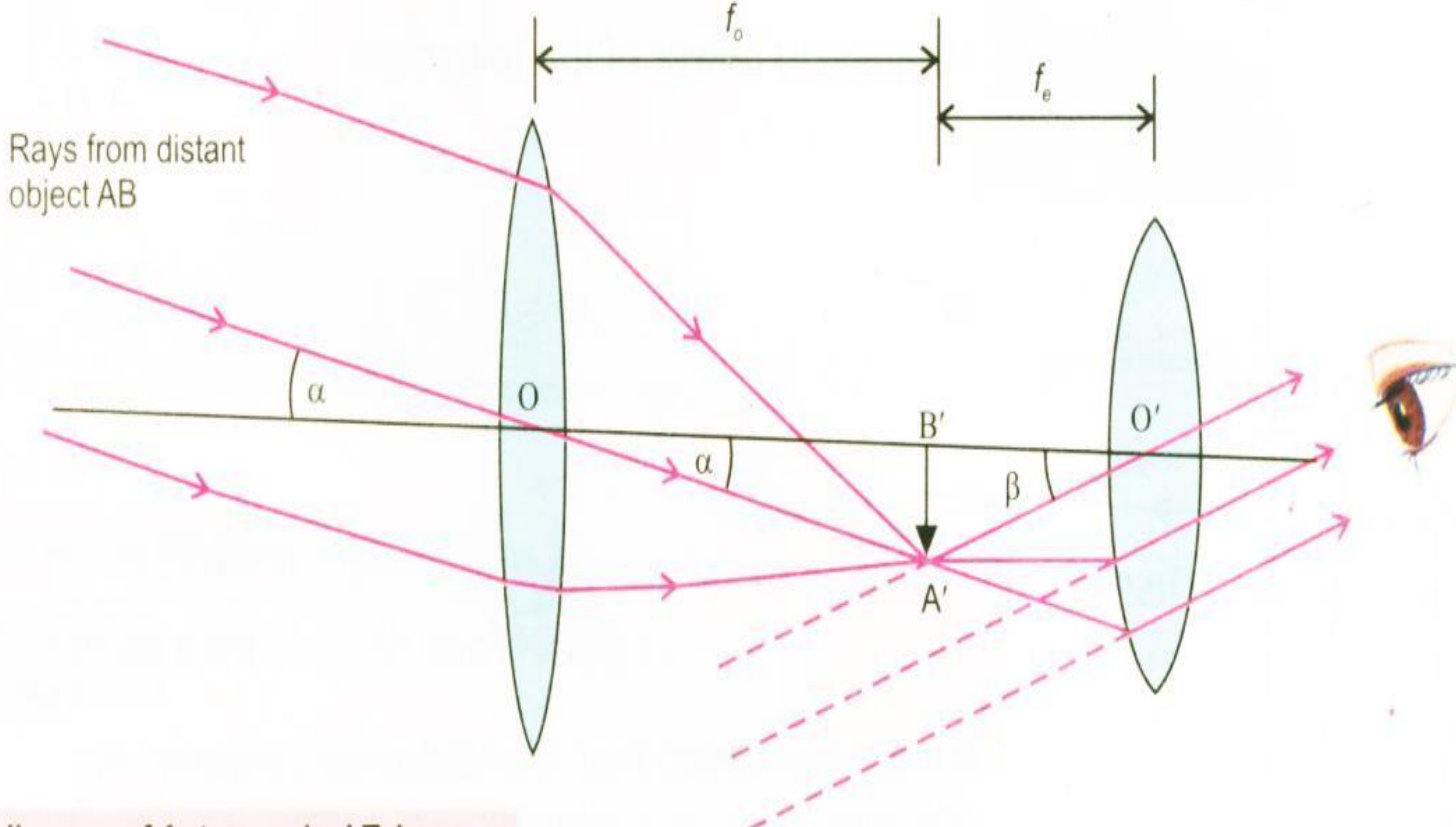
objective
eyepiece
f_o
f_e
f_e
F_o
F_e'
I_2
I_1
F_e
object

A microscope is very similar in arrangement to a telescope, the difference being in the focal length of the objective lens.
Microscope lens focal lengths are measured in mm, while telescope focal lengths can be measured in metres.
Essentially a real image is formed by the objective and this in turn is magnified by the eyepiece to form a virtual, erect image.
The first image (I_1) is positioned infront of the eyepiece, between f and the lens. The eyepiece produces the virtual image (I_2) behind the first image.
For the second image to be in focus, the distance between it and the eye must be at least 25 cm (D).

The **magnifying power** of a microscope is the product of the eyepiece and objective lens magnification.

- Q # 11: What is the basic condition for the normal adjustment of astronomical telescope?
- An astronomical telescope is said to have normal adjustment if the image formed by objective lies at the focus
- of both the objective and the eye-piece. The distance between the objective and eye-piece of a telescope in
- normal adjustment is which is equal to the length of the telescope, where and are the focal
- lengths of objective and eye-piece of astronomical telescope respectively.
- Q # 12: If a person looking through microscope at the full moon, how would the appearance of moon be
- changed by covering of objective lens?
- Ans. He will observe the full image but its brightness will be reduced. In other word, the intensity of light will
- decreased.

- **Ans. Telescope is an optical device used for viewing distant objects. Initially the extensive use of the telescopes was for astronomical observations. These telescopes are called astronomical telescopes. Construction: A simple astronomical telescope consists of two convex lens:**
- Objective of long focal length
- Eye-Piece of short focal length
- **Working: When a very distant object is viewed through astronomical telescope, the rays of light coming from any of its point are considered parallel. These parallel rays are converged by the objective by objective to form a real image at its focus.**
- If it is desired to see the final image through the eye-piece without any strain on the eye, the eye- piece must be placed so that the image lies at its focus.
- The rays after refraction through the eye-piece will become parallel and the final image appears to
- be formed at infinity.



Ray diagram of Astronomical Telescope

Ans. Consider the normal adjustment of an astronomical telescope, having objective lens with long focal length f_0 and eye-piece of short focal length f_e. The angle α subtended at un-aided eye is practically the same as subtended at the objective and is equal to $\angle A'OB'$. Thus in right triangle $A'OB'$, we have:

$$\alpha = \tan\alpha = \frac{A'B'}{OB'} = \frac{A'B'}{f_0} \quad ---- \quad (1) \qquad \therefore \alpha \textit{ is very very small}$$

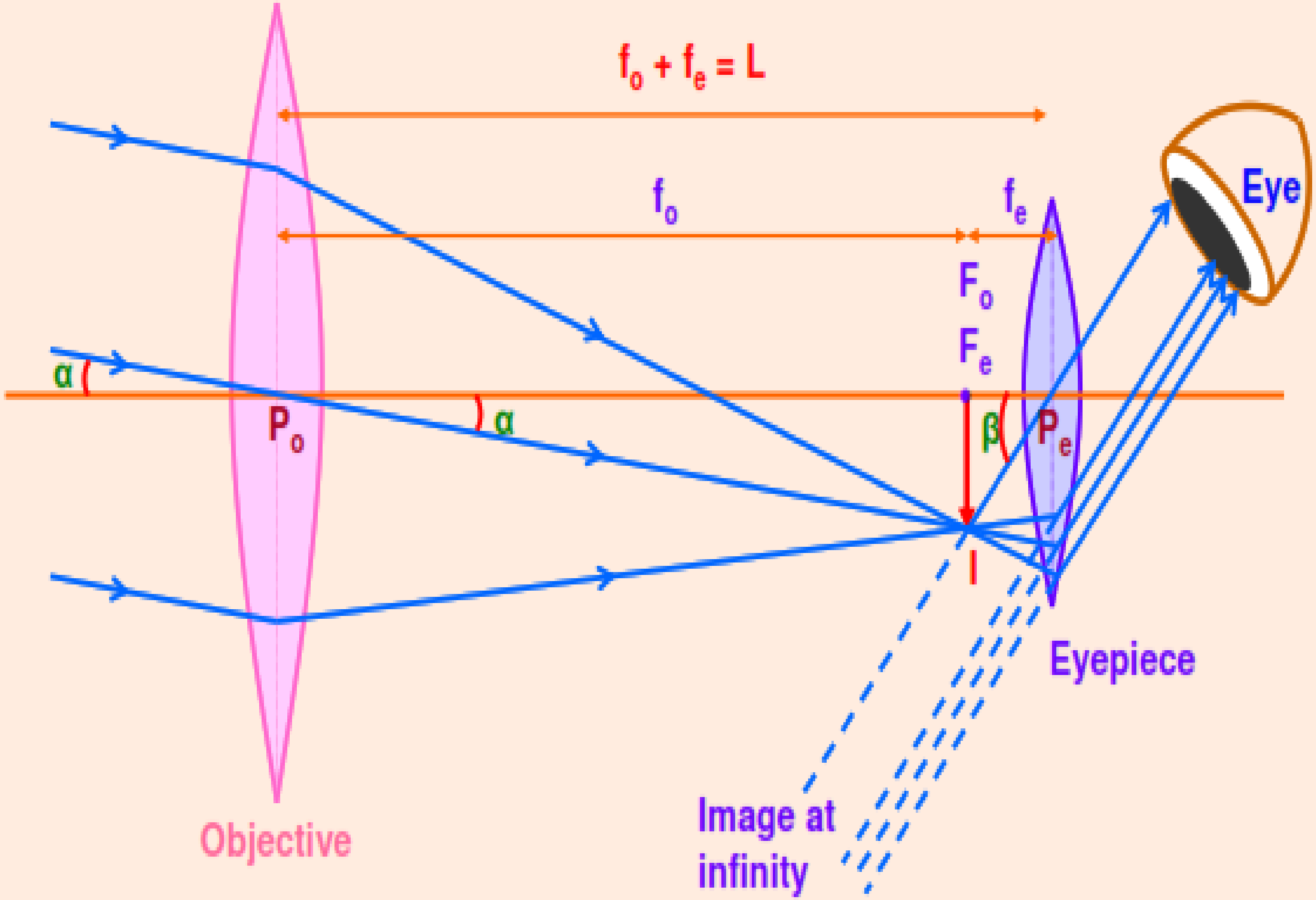
The angle β subtended at the eye by the final image is equal to $\angle A'O'B'$. Thus:

$$\beta = \tan\beta = \frac{A'B'}{O'B'} = \frac{A'B'}{f_e} \quad ---- \quad (2)$$

The magnifying power M of astronomical telescope is described by formula:

$$M = \frac{\beta}{\alpha} = \frac{\left(\frac{A'B'}{f_e}\right)}{\left(\frac{A'B'}{f_0}\right)} = \frac{f_0}{f_e}$$

Astronomical Telescope: (Image formed at infinity – Normal Adjustment)



Focal length of the objective is much greater than that of the eyepiece.

Aperture of the objective is also large to allow more light to pass through it.

Angular magnification or Magnifying power of a telescope in normal adjustment is the ratio of the angle subtended by the image at the eye as seen through the telescope to the angle subtended by the object as seen directly, when both the object and the image are at infinity.

$$\boxed{M = \frac{\beta}{\alpha}}$$

Since angles are small, $\alpha = \tan\alpha$ and $\beta = \tan\beta$

$$M = \frac{\tan\beta}{\tan\alpha}$$

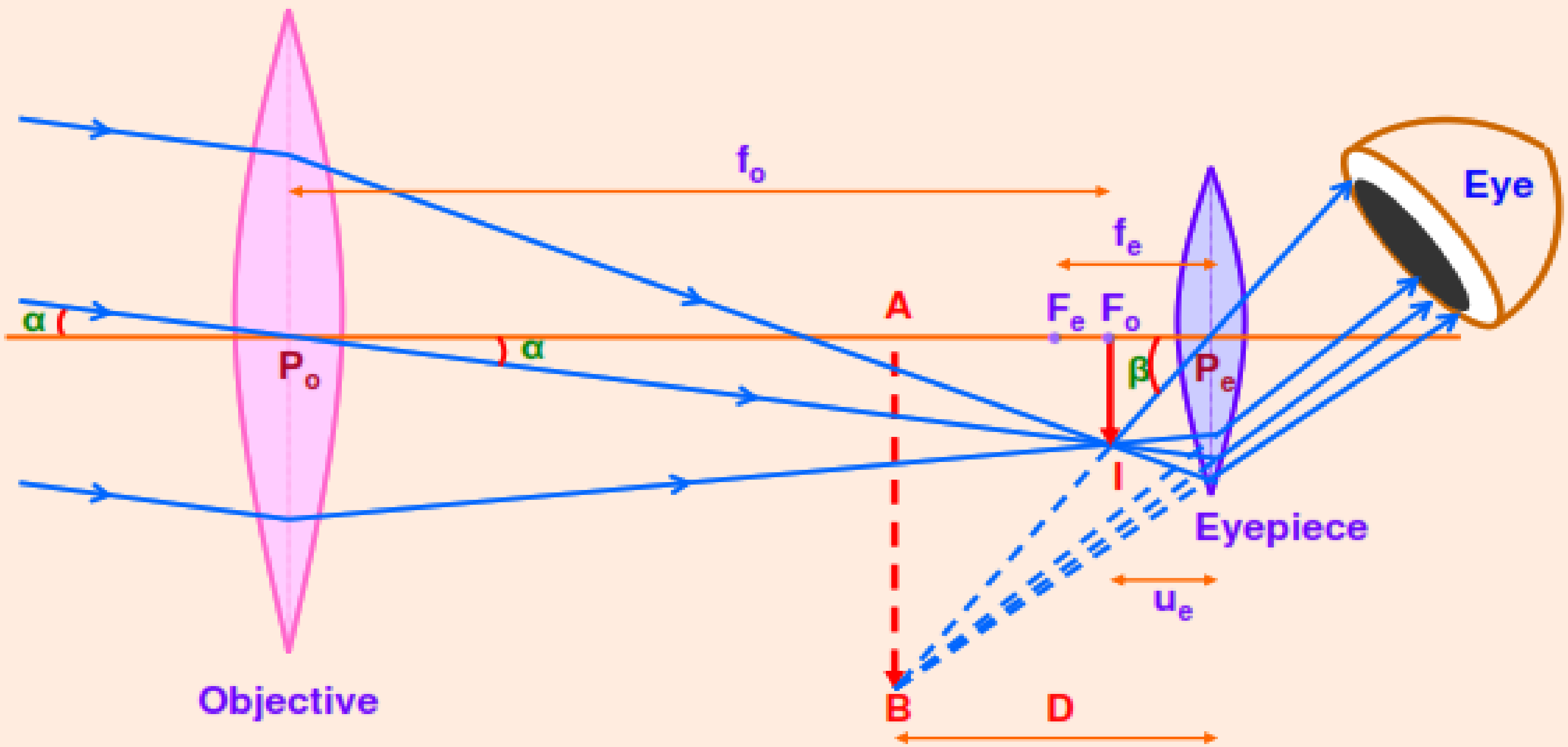
$$M = \frac{F_e I}{P_e F_e} \Big/ \frac{F_e I}{P_o F_e}$$

$$M = \frac{I}{f_e} \Big/ \frac{I}{f_o}$$

$$\boxed{M = \frac{f_o}{f_e}}$$

($f_o + f_e = L$ is called the length of the telescope in normal adjustment).

Astronomical Telescope: (Image formed at LDDV)



Angular magnification or magnifying power of a telescope in this case is defined as the ratio of the angle β subtended at the eye by the final image formed at the least distance of distinct vision to the angle α subtended at the eye by the object lying at infinity when seen directly.

$$\boxed{M = \frac{\beta}{\alpha}}$$

Since angles are small,
$\alpha = \tan\alpha$ and $\beta = \tan\beta$

$$M = \frac{\tan\beta}{\tan\alpha}$$

$$M = \frac{F_oI}{P_eF_o} \Big/ \frac{F_oI}{P_oF_o}$$

$$M = \frac{P_oF_o}{P_eF_o} \quad \text{or} \quad M = \frac{+f_o}{-u_e}$$

Lens Equation

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad \text{becomes}$$

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

$$\text{or} \quad \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{D}$$

Multiplying by f_o on both sides and rearranging, we get

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

Clearly focal length of objective must be greater than that of the eyepiece for larger magnifying power.

Also, it is to be noted that in this case M is larger than that in normal adjustment position.