jee LIVE daily

Telescope & Resolving Power

Ray Optics: Optical Instruments

Lecture - 2

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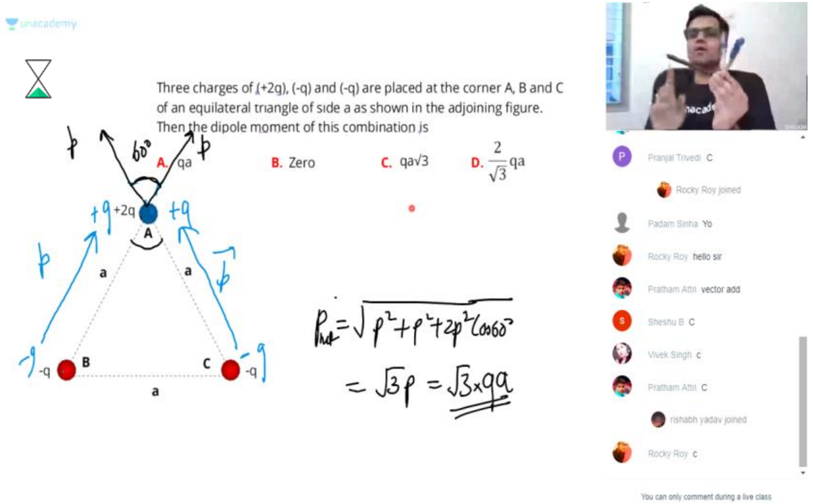

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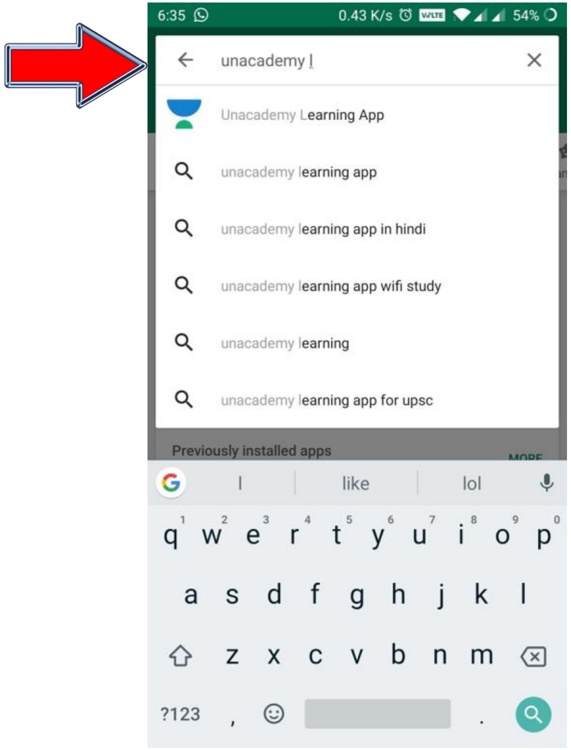
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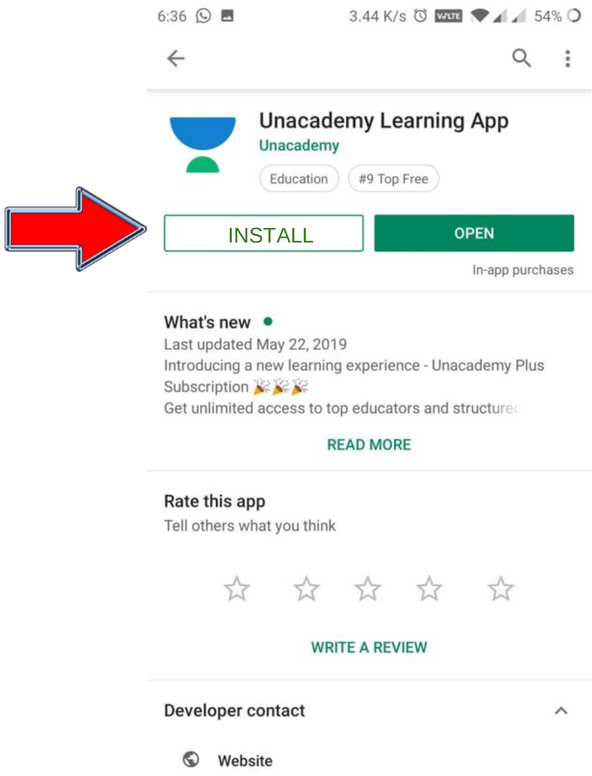
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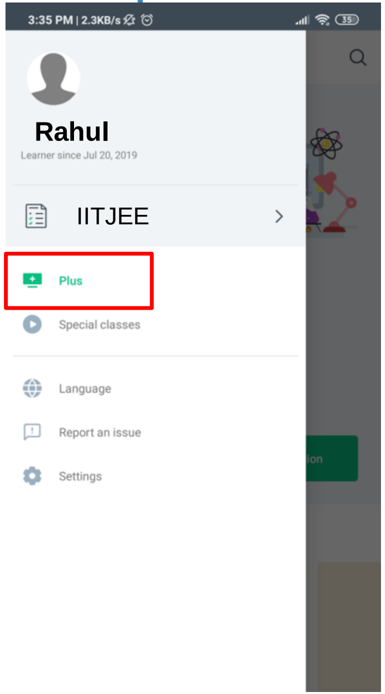

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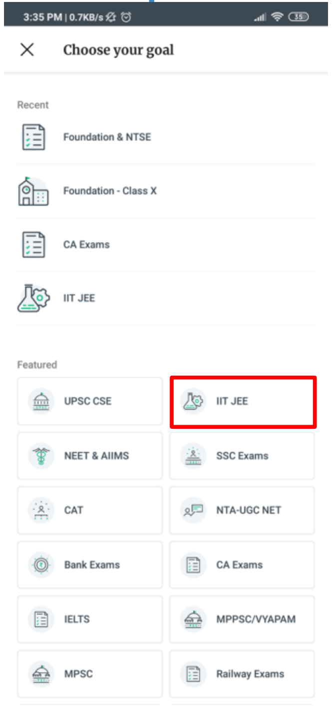

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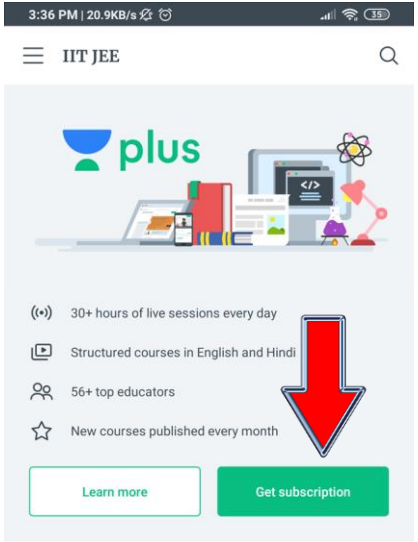

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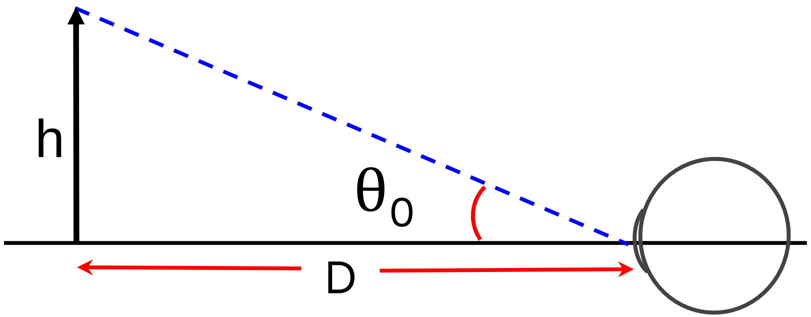
Near Point

The **maximum Visual Angle** θ_o is subtended on the eye when the **object is at** the Near Point.



$$\boxed{\theta_0 = \frac{h}{D}}$$

Where **h** is the size of the object and

D is the least distance for clear vision.

Magnifying Power of Optical Instruments

Magnifying Power of any optical instrument is θ/θ_0.

$$\boxed{m = \theta/\theta_0}$$

Where θ_0 is the angle subtended on the naked eye when the object is placed at the near point.

And θ is the angle subtended by final image on eye

This is **also known as** the **Angular Magnification**.

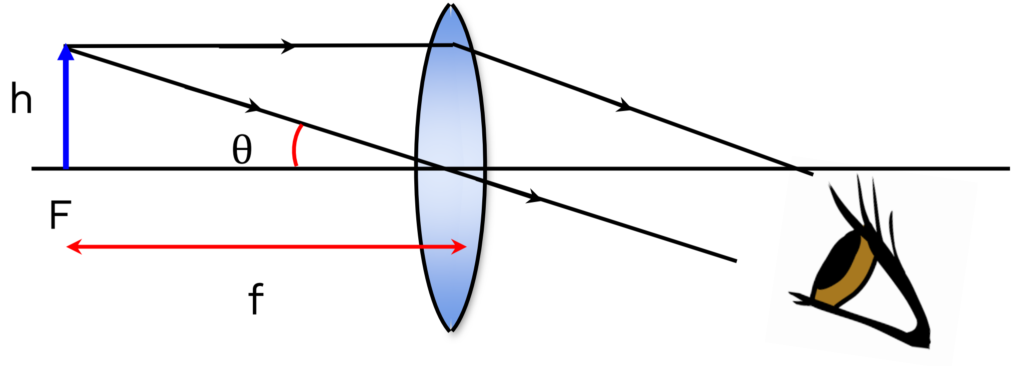
Simple Microscope

Case 1

As the image is situated at infinity,

the **Ciliary Muscles are least strained**

This situation is is known as "**Normal Adjustment**."



$$\theta_0 = \frac{h}{D} \quad \theta = \frac{h}{f}$$

$$\boxed{m = \frac{D}{f}}$$

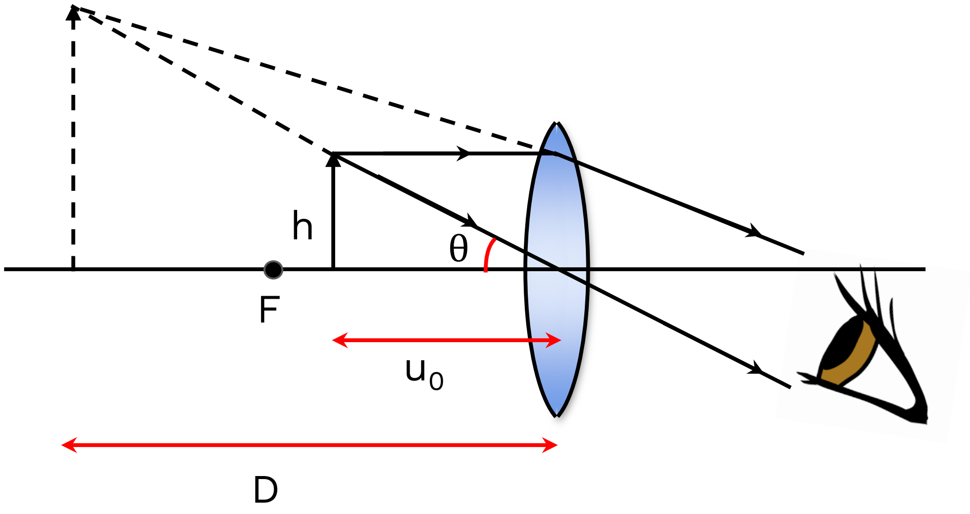
If **f** < D,, **θ** > **θ_0**

Simple Microscope

Case 2

Magnifying Power can be further increased

Object to a distance u_0 from the lens such that the virtual erect **image is formed at** the Near Point.



$$m = \frac{\theta'}{\theta_0} = \frac{h/u_0}{h/D}$$

$$= \frac{D}{u_0}$$

$$\boxed{= 1 + \frac{D}{f}}$$

Compound Microscope

It consists of **two converging lenses arranged coaxially.**

The one close to the eye is called the Eyepiece or **Ocular.**

The one facing the object is called the Objective

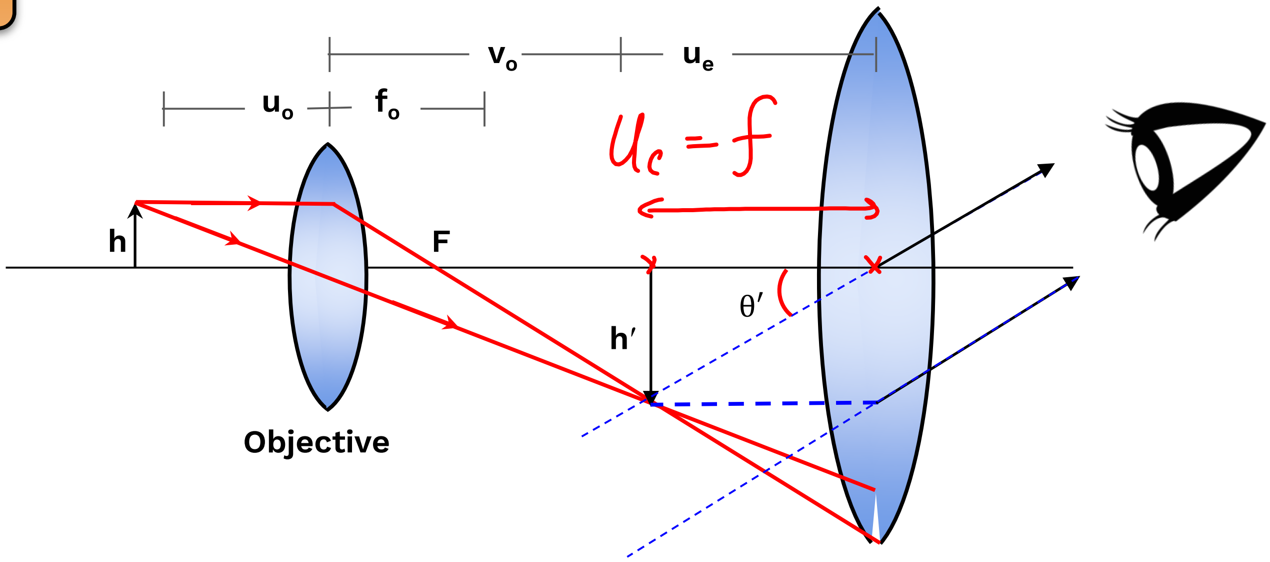
Eyepiece has larger aperture & larger focal length

Objective has smaller aperture & smaller focal length

Compound Microscope

Case 1

The object is placed at a distance u_o



A real, inverted & magnified image is formed at a distance v_o on the other side of the objective.

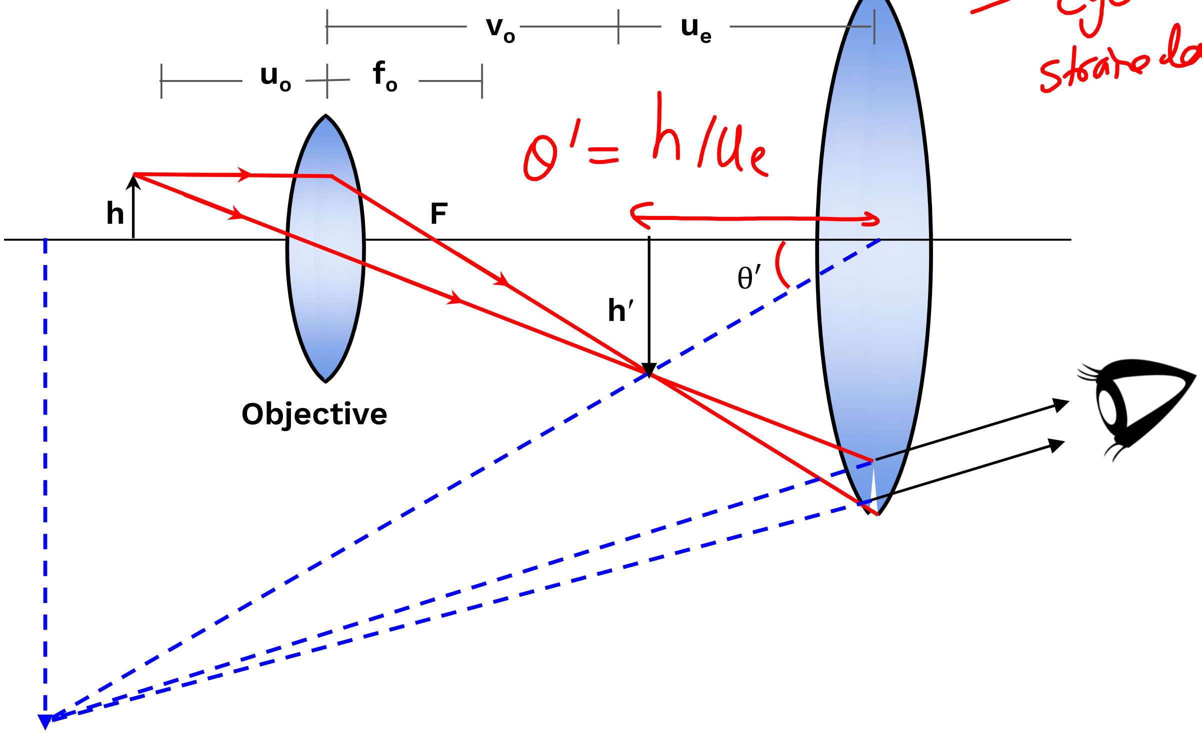
For Normal Adjustment, **final image** is then **formed at infinity.**

Compound Microscope

Case 2

The position of the eyepiece can also be adjusted in such a way tha
the **final virtual image** is **formed at the** **Near Point**.

Eyes are strained



Compound Microscope

The largest angle formed by the object on the unaided eye when no microscope is used

$$\boxed{\theta_0 = \frac{h}{D}} \quad \text{(i)}$$

When a compound microscope is used, the final image subtends an angle θ′ on the eyepiece (and hence on the eye) given by

$$\boxed{\theta' = \frac{h'}{u_e}} \quad \text{(ii)}$$

Where h′ is the height of the first image and u_o is its distance from the eyepiece.

Magnifying Power

The magnifying power of the compound microscope is, therefore,

$$m = \frac{\theta'}{\theta_0} = \frac{h'}{u_e} \times \frac{D}{h} = \left(\frac{h'}{h}\right)\left(\frac{D}{u_e}\right)$$

Where $\frac{h'}{h} = -\frac{v_0}{u_0} = \frac{v}{u}$

for Objec $u = -u_0$
$v = +v_0$

D/u_e is the magnifying power of the eyepiece treated as a simple microscope.

$u_e = f_e$

Case I D/f_e in **normal adjustment (image at infinity)** and

$u_e =$

Case II $1 + D/\ f_e$ for the adjustment when the **image** is formed **at** the **least distance for clear vision.**

Magnifying Power

Hence Magnifying Power of compound microscope is

$m = m_o m_e$

Case I $$m = \frac{v}{u}\left(\frac{D}{f_e}\right)$$ **For Normal adjustment and**

Case II $$m = \frac{v}{u}\left(1 + \frac{D}{f_e}\right)$$ At the **least distance for clear vision.**

Magnifying Power

$$v \times \left(\frac{1}{v} - \frac{1}{u} = \frac{1}{f}\right)$$ or, $$1 - \frac{v}{u} = \frac{v}{f_0}$$ or, $$\frac{v}{u} = 1 - \frac{v}{f_0}$$

Using some approx

In general, the focal length of the objective is very small so that $v/f_0 >> 1$.

Also, the first image is close to eyepiece so that $v \approx l$,

where l is the **tube length** (separation between the objective and the eyepiece).

$$\boxed{\frac{v}{u} = 1 - \frac{v}{f_o} \approx -\frac{v}{f_0} = -\frac{l}{f_0}}$$

Magnification of Compound Microscope

Thus,

For **normal adjustment**

Case I

$$\boxed{m = -\frac{l}{f_0}\frac{D}{f_e}}$$

$m = -ve$

$\Rightarrow$ final image inverted

For adjustment for the final image **at the least distance for clear vision.**

Case II

$$\boxed{m = -\frac{l}{f_0}\left(1 + \frac{D}{f_e}\right)}$$

Example

MCQ type Question [+4 , -1]

A compound microscope has magnifying power as 32 and magnifying power of eye-piece is 4, then the magnifying power of objective is

A. 8 **B.** 10 **C.** 6 **D.** 12

$$m = m_o \times m_e$$

$$32 = m_o \times 4$$

$$m_o = 8$$

Example

MCQ type Question [+4 , -1]

The focal length of a simple convex lens used as a magnifier is 10 cm. For the image to be formed at a distance of distinct vision D = 25 cm, the object must be placed away from the lens nearly at a distance of

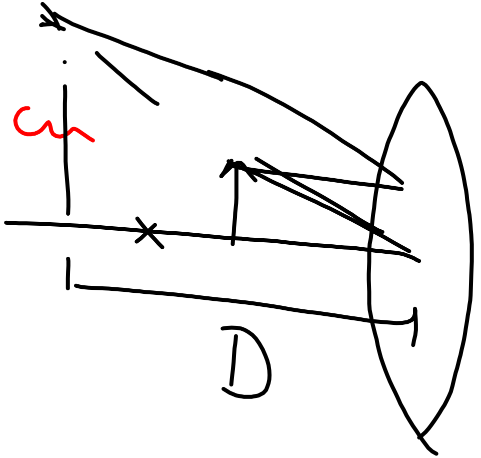
A. 5 cm B. 7 cm C. 8 cm D. 16 cm

$f = 10\text{ cm}$

$v = -25\text{ cm}$

$f = +10\text{ cm}$

$u = ?$



$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$$

$$\frac{1}{-25} - \frac{1}{u} = \frac{1}{10}$$

$$\frac{1}{u} = \frac{1}{-25} - \frac{1}{10}$$

$$\frac{-100}{4-10}$$

Ans : B

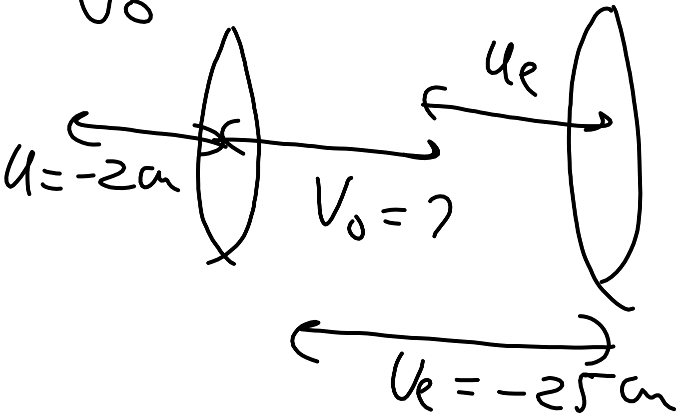
Example

MCQ type Question [+4 , -1]

In a microscope the focal lengths of two lenses are 1.5 cm and 6.25 cm. If an object is placed at 2 cm from objective and final image is formed at 25 cm from eye – lens, the distance between two lenses is → Case II, $l = ?$

A. 6 cm **B.** 7.75 cm **C.** 9.25 cm **D.** 11 cm

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f_o} \qquad f_o = 1.5\ cm \qquad f_e = 6.25\ cm$$



$u_e = ?$

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

$$l = u_e + V_o$$

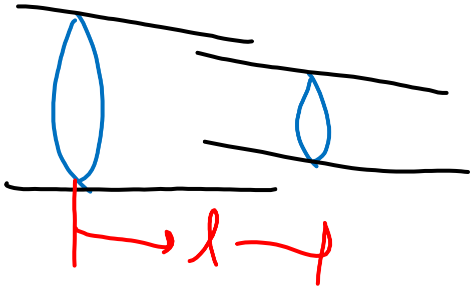
Ans : D

Telescopes

To look at **distant objects** such as a star, a planet or a distant tree, etc, we use another instruments called a **Telescope**.

1. Astronomical Telescope

Two converging lens
placed coaxially,
Objective and **Eyepiece**



One facing the distant object
is called the **Objective**
It has a **large aperture**
and a **large focal length**.

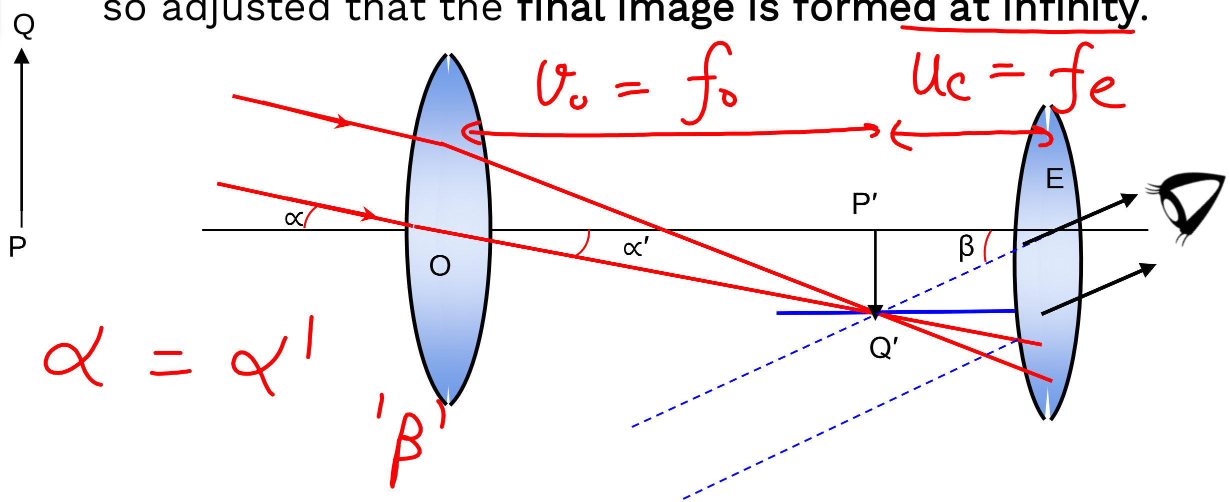
The other is called **Eyepiece** as
eye is placed close to it,
Has a **smaller aperture** and a
smaller focal length.

1. Astronomical Telescope

Case I

relaxed

In **Normal Adjustment**, the position is so adjusted that the **final image is formed at infinity**.



$\alpha = \alpha'$

'β'

u_o is very large, the **first image P′Q′** is formed in the **focal plane of the objective.**

$\alpha = \frac{P'Q'}{OP'} = \frac{P'Q'}{f_o}$ $\left|\frac{\beta}{\alpha}\right| = ?$

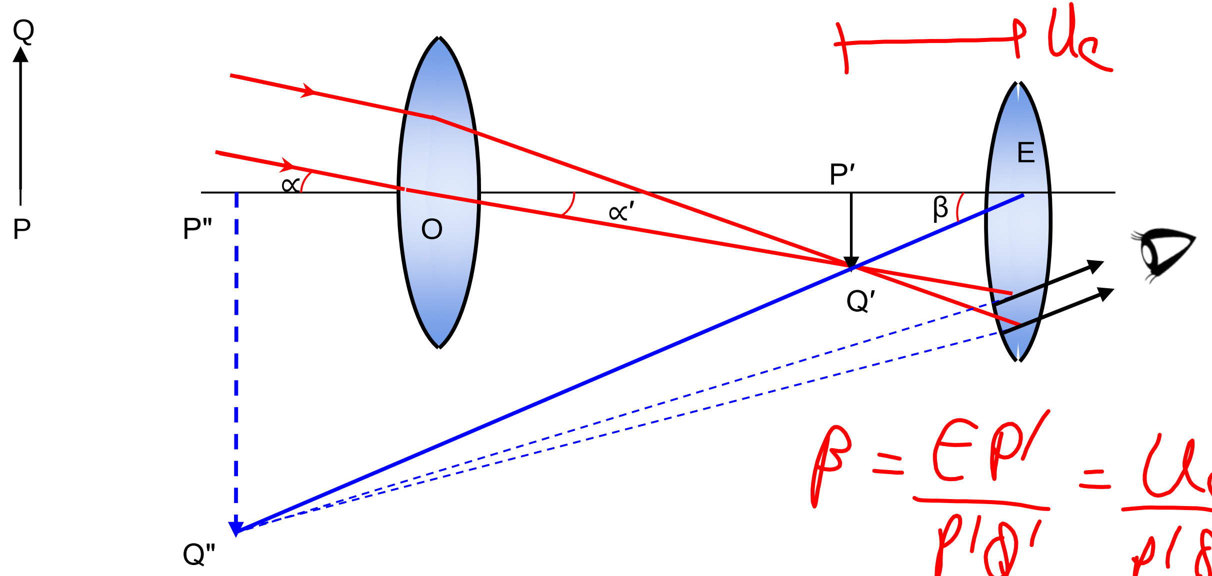
$\beta = \frac{P'Q'}{f_e}$ $\left|\frac{\beta}{\alpha}\right| = \frac{f_o}{f_e}$

1. Astronomical Telescope

The image can be brought closer by pushing the eyepiece closer to the first image.

Case II

Maximum angular magnification is produced when the **final image is** formed **at the Near Point**.



$$\beta = \frac{EP'}{P'Q'} = \frac{u_e}{P'Q'}$$

Magnifying Power of a Telescope

Angular Magnification or the Magnifying Power of the telescope is defined as

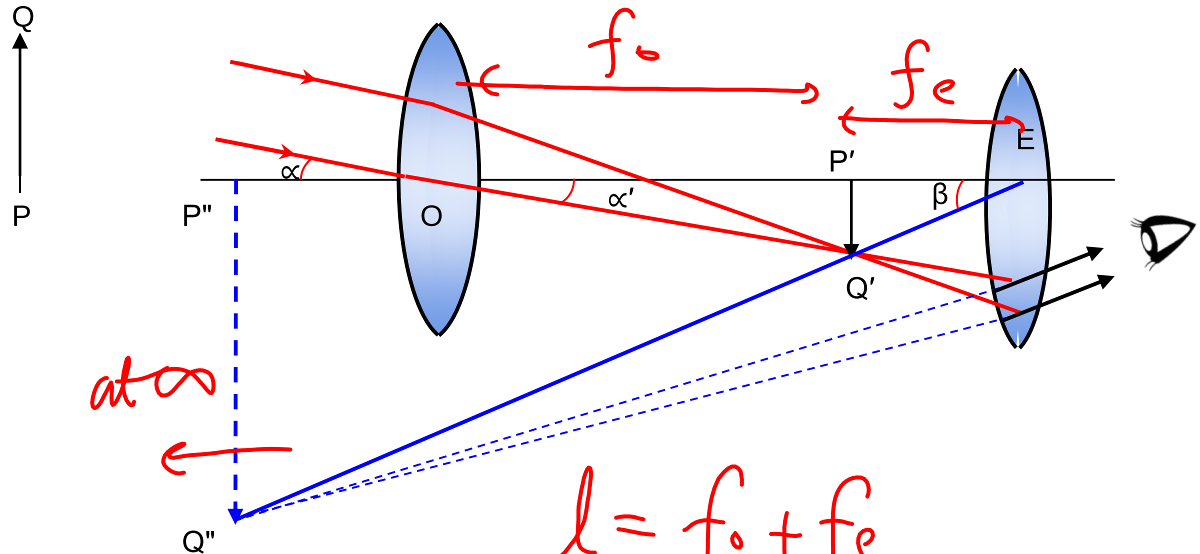
$$m = \frac{\text{angle subtended by the final image on the eye}}{\text{angle subtended by the object on the unaided eye}}$$

$$m = \frac{\theta}{\theta_0} \qquad m = \frac{\beta}{\alpha}$$

Magnification

Case I

For Normal Adjustment
the **final image is formed at infinity**, then EP′ = f_e



$l = f_o + f_e$

$$\left|\frac{\beta}{\alpha}\right| = \frac{f_o}{f_e}$$

$\beta/\propto$ **is negative.**

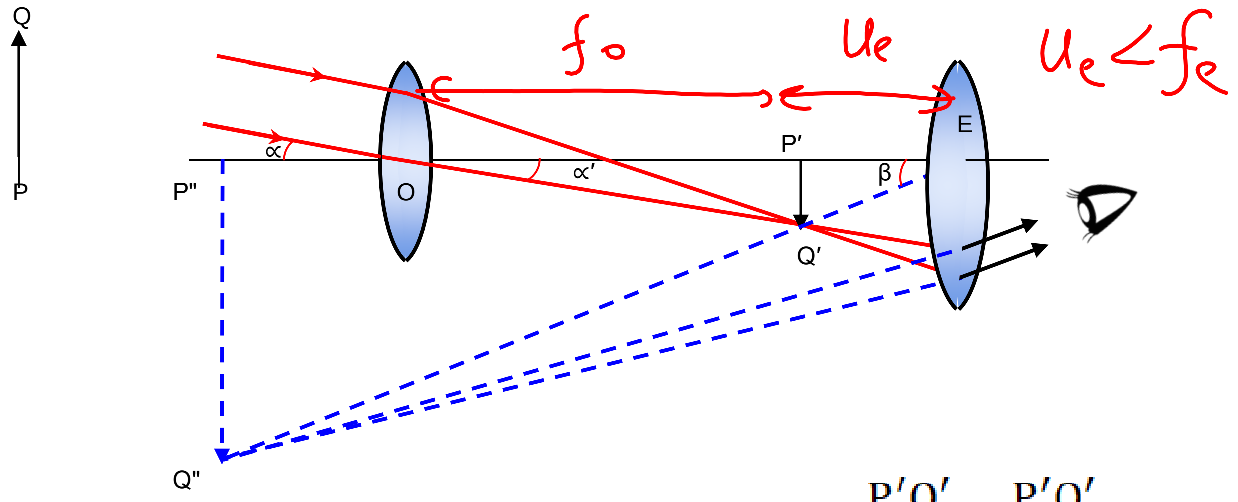
$$m = \frac{\beta}{\alpha} = -\left|\frac{\beta}{\alpha}\right|$$

$$\boxed{m = \frac{-f_o}{f_e}}$$ *

Magnifying Power of a Telescope

u_o is very large, the **first image P′Q′** is formed in the **focal plane of the objective.**

Case II



$$|\alpha| = |\alpha'| = |\tan\alpha'| = \frac{P'Q'}{OP'} = \frac{P'Q'}{f_0} \quad (1)$$

P″Q″ subtends an angle β on the eyepiece

$$|\beta| \approx |\tan\beta| = \frac{P'Q'}{EP'} \quad (2)$$

or, $$\left|\frac{\beta}{\alpha}\right| = \frac{f_0}{EP'}$$

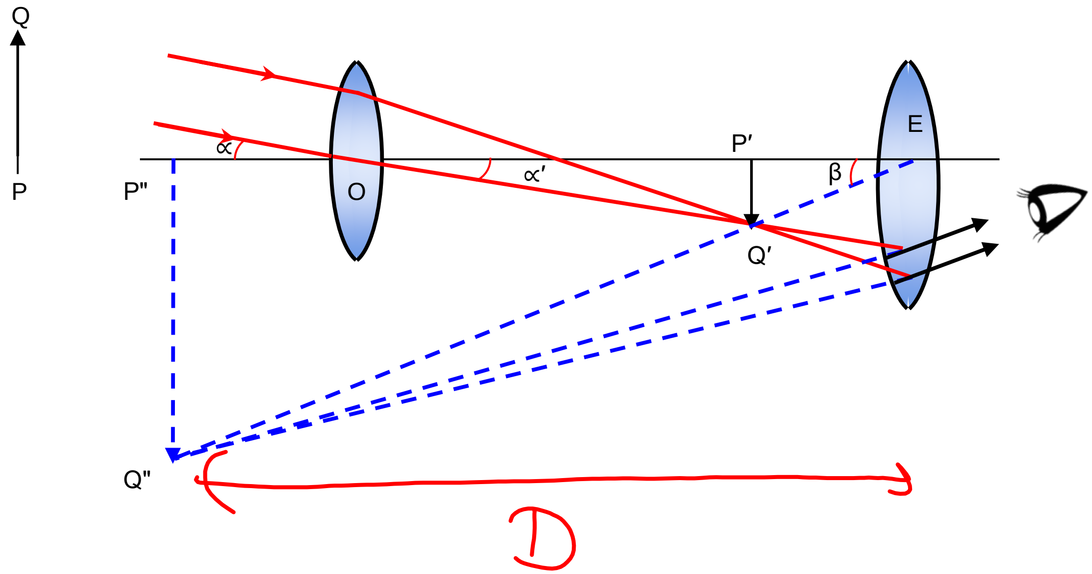
Magnification

Case II

If **final image is formed at the Near Point** of the eye, the angular magnification is further increased.

Here $u = -EP'$ and $v = -EP'' = -D$

The **lens equation** is $\frac{1}{v} - \frac{1}{u} = \frac{1}{f}$



$$\frac{1}{-D} - \frac{1}{-EP'} = \frac{1}{f_e}$$

$$\frac{1}{EP'} = \frac{1}{f_e} + \frac{1}{D} = \frac{f_e + D}{f_e D}$$

$$\boxed{\left|\frac{\beta}{\alpha}\right| = \frac{f_0(f_e + D)}{f_e D}}$$

Magnification

Case II

If **final image is formed at the** Near Point of the eye, the angular magnification is further increased.

The **magnification** is

$$m = \frac{\beta}{\alpha} = -\left|\frac{\beta}{\alpha}\right|$$

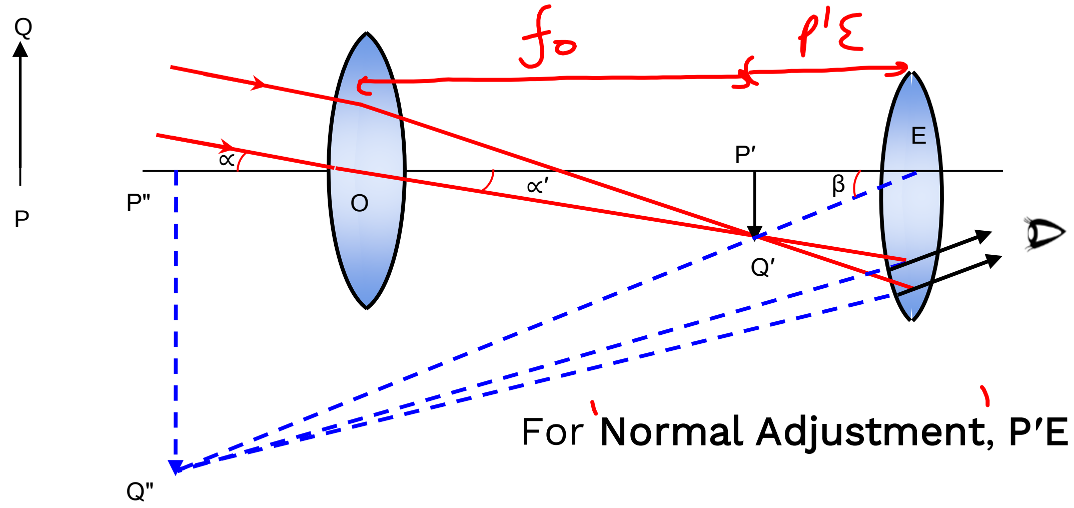
$$= -\frac{f_0(f_e + D)}{f_e D}$$

$$\boxed{= -\frac{f_0}{f_e}\left(1 + \frac{f_e}{D}\right)}$$

– ve denotes final image inverted

Length of Telescope

$$L = OP' + P'E = f_o + P'E$$



For **Normal Adjustment, $P'E = f_e$** so that

$$\boxed{L = f_o + f_e.}$$

For adjustment for **Near Point** vision, we have $P'E = \dfrac{f_e D}{f_e + D}$

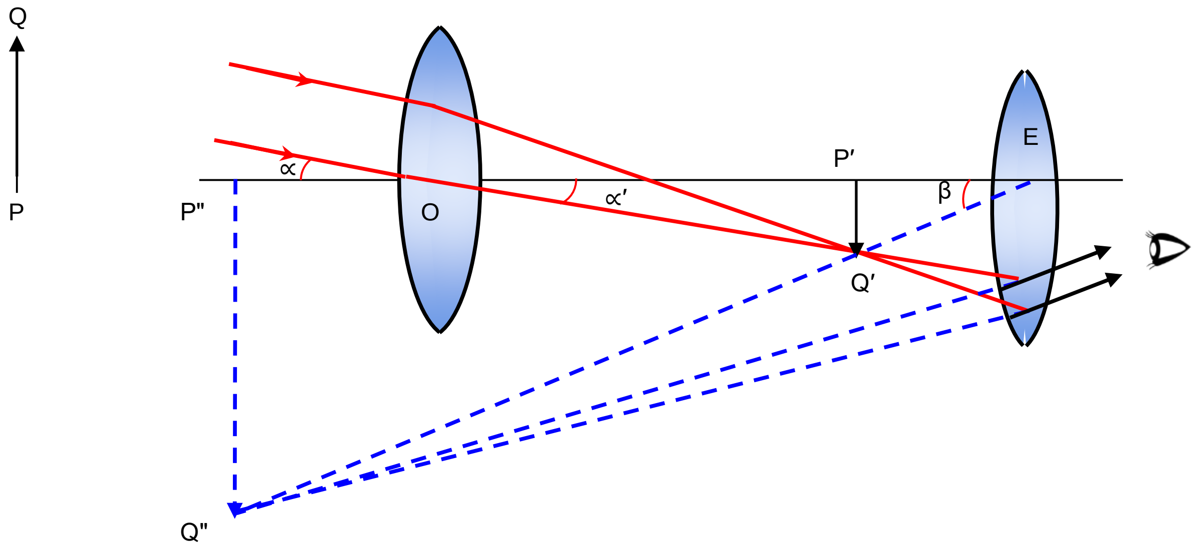
So that the length is $\boxed{L = f_o + \dfrac{f_e D}{f_e + D}}$

2. Terrestrial Telescope

trees, mountains

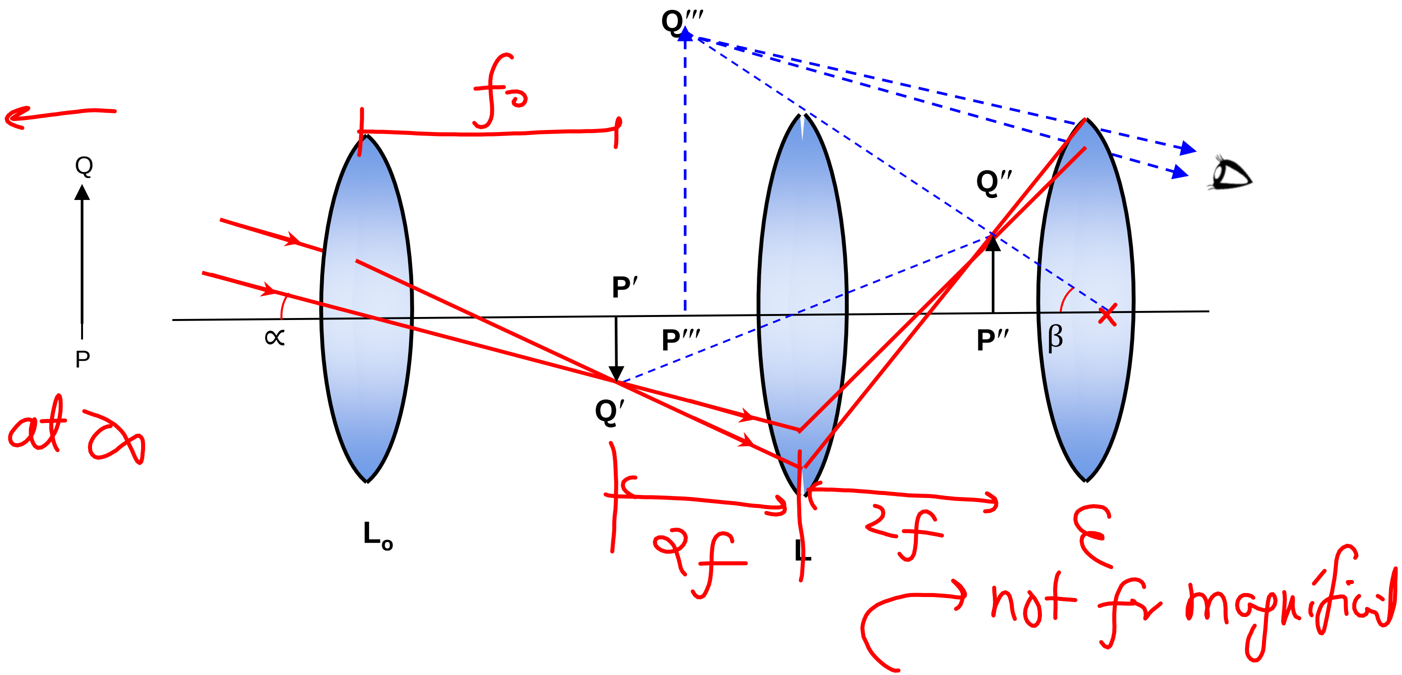
In an **astronomical telescope,**

the **final image is inverted** with respect to the object.



2. Terrestrial Telescope

To remove this difficulty, **a convex lens** of focal length f is **included between the objective and the eyepiece** in such a way that



The role of the **intermediate lens L** is **only to invert the image.**

2. Terrestrial Telescope

for **Normal Adjustment**

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

no -ve sign

final image is upright

And for final image at **Near Point**

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

Length of Telescope

for **Normal Adjustment**

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

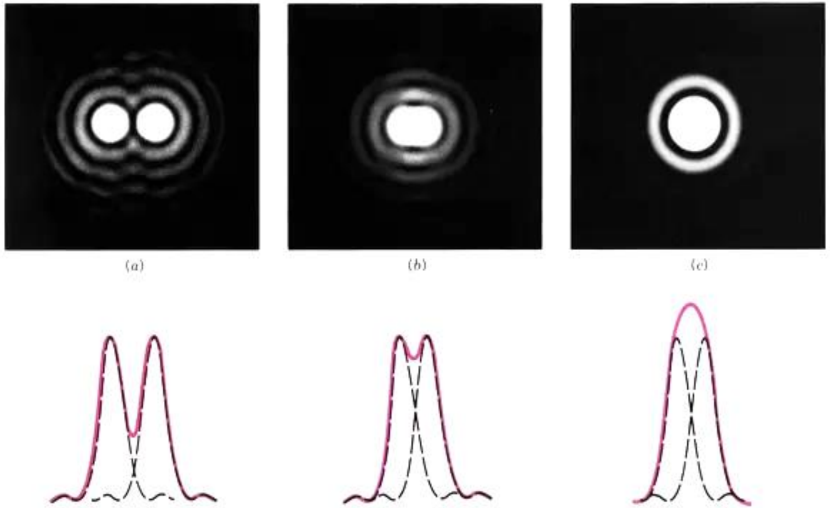
And for final image at **Near Point**

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

Resolving Power of Optical Instruments

Ability of an optical instrument
to separate two objects,
that are close together, into individual images.

R.P. high



Low R P

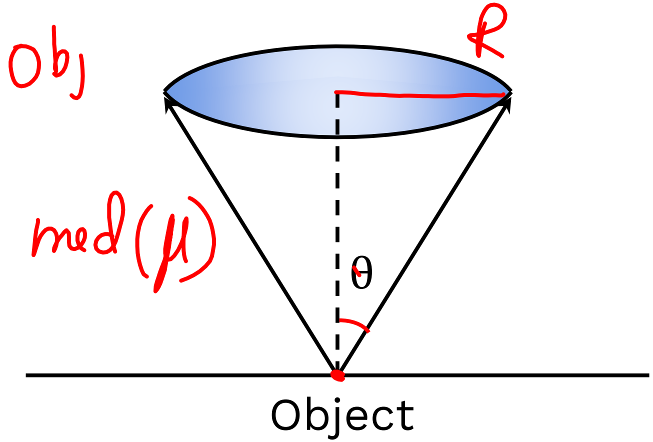
Resolving power is the **ability of an imaging device to separate** (i.e., to see as distinct) points of **an object** that are located at a small angular distance

Resolving Power of a Microscope

It is the **reciprocal of the distance** between two objects **which can be just resolved** when seen through the microscope.

O_1 Δd O_2

$$\boxed{R = \frac{1}{\Delta d} = \frac{2\mu \sin\theta}{\lambda}}$$



Depends on the

Wavelength λ of the light,

Refractive index μ of the medium between the object and the objective of the microscope.

Angle θ subtended by a radius of the objective on the object

Resolving Power of a Microscope

Resolving Power is
inversely proportional to Wavelength λ of the light used,

Light of shorter wavelength like **Blue produces better Resolving Power.**

$$\boxed{R = \frac{1}{\Delta d} = \frac{2\mu \sin\theta}{\lambda}}$$

$\lambda \downarrow$ R.P $\uparrow$

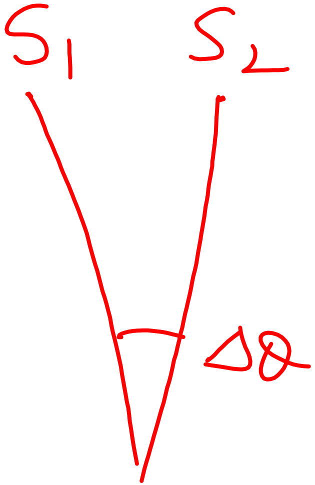
To increase the resolving power,
the objective and the object
are **kept immersed in oil.**
This increases μ and hence **R**.

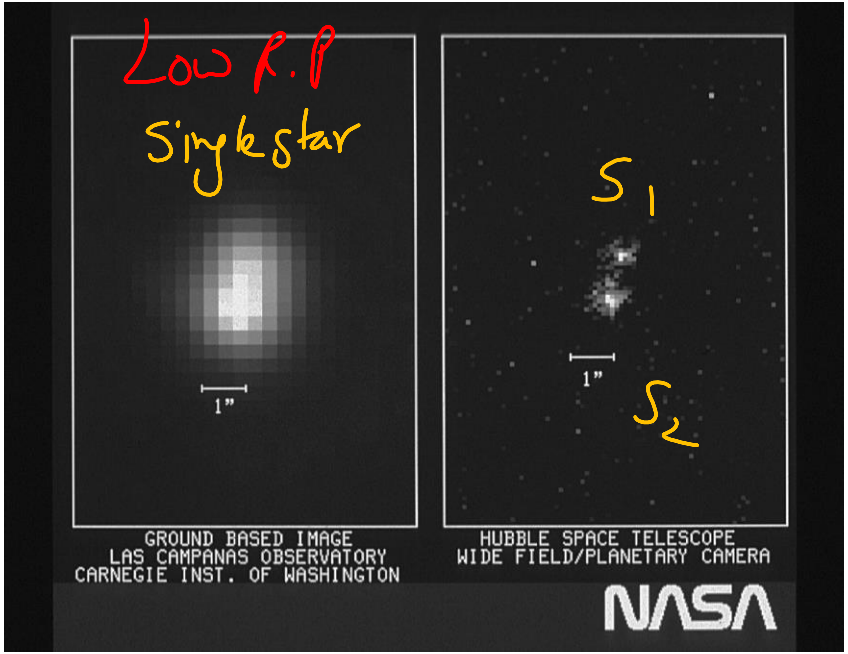
$\mu \uparrow$ R.P $\uparrow$

Resolving Power of a Telescope

Resolving power of a telescope is defined as the

reciprocal of the angular separation between two distant objects which are **just resolved** when viewed through a telescope.





Higher R.P

Resolving Power of a Telescope

jee

Resolving power of a telescope is defined as the **reciprocal of the angular separation between two distant objects** which are **just resolved** when viewed through a telescope.

$$\boxed{R = \frac{1}{\Delta\theta} = \frac{\alpha}{1 \cdot 22\lambda}}$$

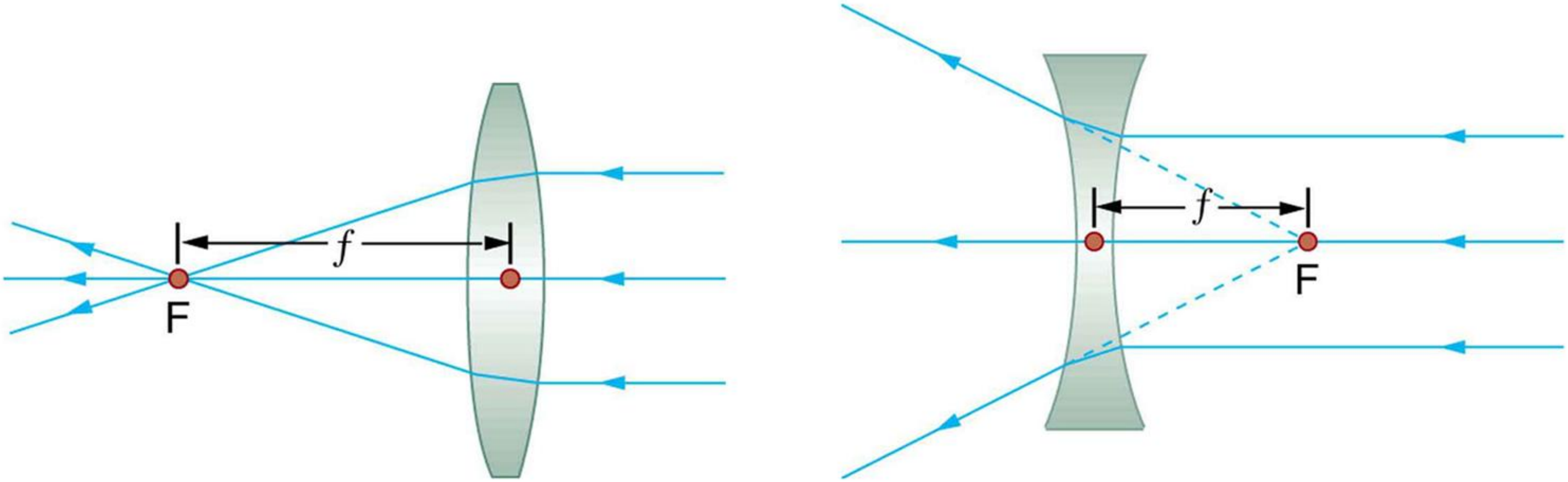
$\alpha \uparrow$ R.P $\uparrow$

$\lambda \downarrow$ R.P $\uparrow$

∝ is the diameter of the objective of the telescope.

The telescopes with larger objective aperture (1m or more) are used in astronomical studies.

Daily Practice Problems



Hi Everyone,

Entire Chapter 19 Optical Instruments from HCV Part 1 is to be done as homework.

Example

In a compound microscope, the focal lengths of objective and eye-lenses are 1.2 cm and 3 cm respectively. If the object is put 1.25 cm away from the objective lens and the final image is formed at infinity, the magnifying power of the microscope is

A. 150 B. 200 C. 250 D. 400

Ans : B

Example

The magnifying power of a simple microscope is given by 1 + D/f, where D is the least distance for clear vision. For farsighted persons, D is greater than the usual. Does it mean that the magnifying power of a simple microscope is greater for a farsighted person as compared to a normal person ? Does it mean that a farsighted person can see an insect more clearly under a microscope than a normal person ?

Ans : Yes, yes

Example

A person has a near point at 100 cm. What power of lens is needed to read at 20 cm if he/she uses

1. Contact lens
2. Spectacles having glasses 2.0 cm separated from the eyes ?

Ans : +4D, + 4.53D

Example

Magnification produced by astronomical telescope for normal adjustment is 10 and length of telescope is 1.1 m. The magnification when the image is formed at least distance of distinct vision (D = 25 cm) is

A. 14 B. 6 C. 16 D. 18

Ans : A

Example

An astronomical telescope has a converging eye-piece of focal length 5 cm and objective of focal length 80 cm. When the final image is formed at the least distance of distinct vision (25 cm), the separation between the two lenses is

A. 75.0 cm B. 80.0 cm C. 84.2 cm D. 85.0 cm

Ans : C

Example

A telescope of objective lens diameter 2m uses light of wavelength 5000 Å for viewing stars. The minimum angular separation between two stars whose image is just resolved by their telescope is

A. 4×10^{-4} rad

B. 0.25×10^{-6} rad

C. 0.31×10^{-6} rad

D. 5×10^{-3} rad

Ans : C

Example

An eye can distinguish between two points of an object if they are separated by more than 0.22 mm when the object is placed at 25 cm from the eye. The object is now seen by a compound microscope having a 20 D objective and 10 D eyepiece separated by a distance of 20 cm. The final image is formed at 25 cm from the eye.

What is the minimum separation between two points of the object which can now be distinguished ?

Ans : 0.04mm

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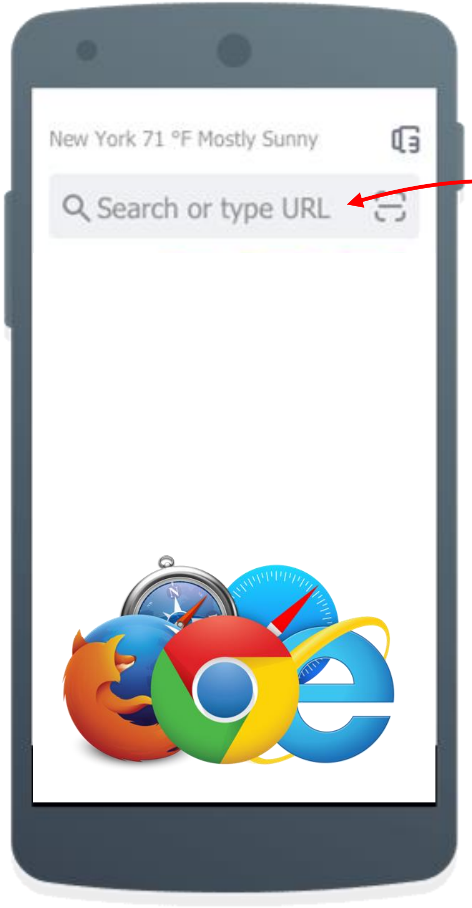

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