



HKALE Physics

Notes	
	Wave motion – Optical instruments (1/1)
1.	Basic knowledge of lens
2.	Basic knowledge of eye focusing
3.	Angular Magnification with optical instrument
4.	Optical instrument: Magnifying glass
5.	Optical instrument: Compound microscope
6.	Optical instrument: Refracting telescope
7.	Eye ring
8.	Chapter Summary



Do you know what the difference between linear magnification and angular magnification is?




HKALE Physics Syllabus

Section B: Wave motion

Section B: Wave motion		
Syllabus	Notes	Suggested Experimental Work
2.5 Optical instruments	Formation of images by lenses. Use of the equation $1/u + 1/v = 1/f$ for a single, thin lens. Qualitative understanding of how optical instruments work (using simple ray diagrams only).	E18. Measurement of focal length of lenses.
Magnifying glass	Magnifying powers of magnifying glass, microscope and refracting telescope considered as ratio of visual angles subtended by the image and the object (as obtained from simple ray diagrams).	
Microscope	Two-lens type only. Formation of image at least distance of vision.	
Refracting telescope	Two-lens type only. Formation of image at infinity.	

I. Basic knowledge of lens

Beams (Light rays)

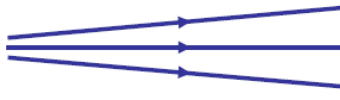
Andy wants to point out  :

1. There are three types of beams (Light rays):

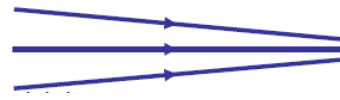
- i. Parallel Beams
- ii. Divergent beams
- iii. Convergent beams



Parallel Beams

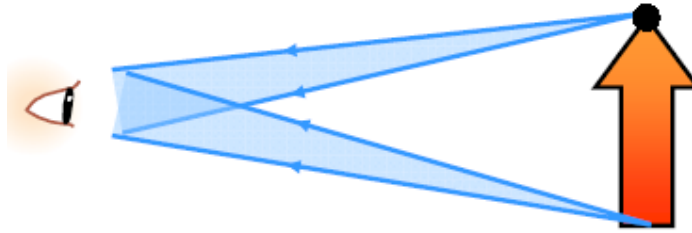


Divergent Beams

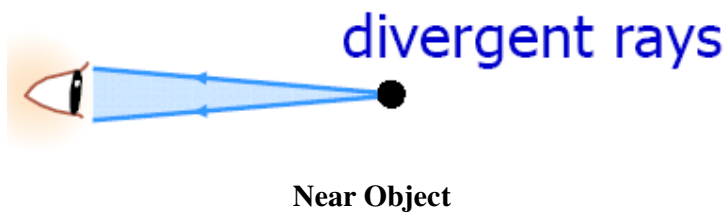


Convergent Beams

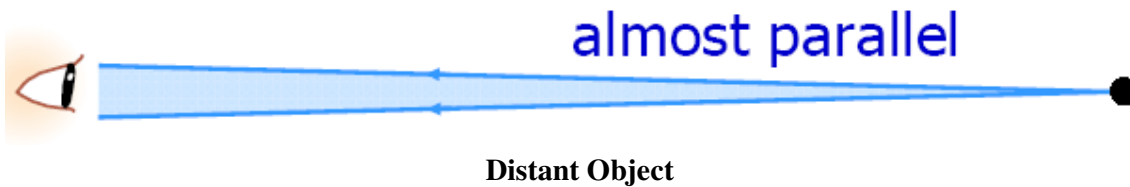
2. Cones of Rays: No need to draw all the rays!!!



3. Light rays of objects at a near point and distant point:



Near Object



Distant Object

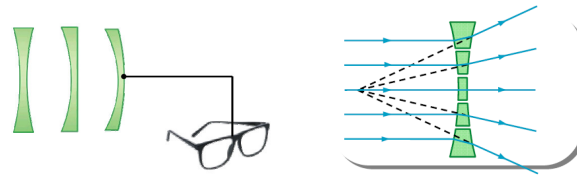
Types of Lenses

Andy wants to point out  :


1. **Convex Lens: Thicker at the centre than at the edge**
Convergent Lens: Bend the light rays inwards



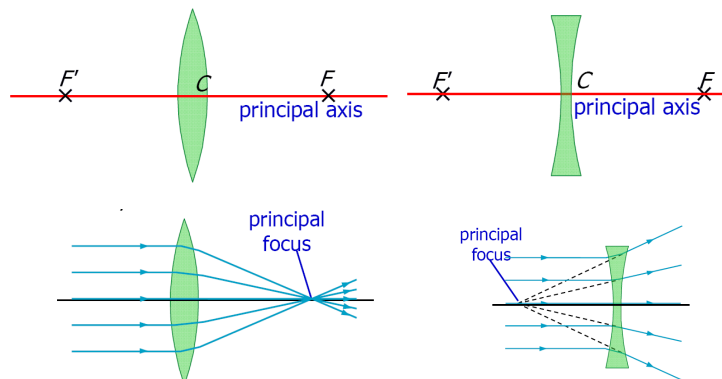
2. **Concave Lens: Thinner at the centre than at the edge**
Divergent Lens: Bend the light rays outwards




Features of Lenses

Andy wants to point out  :

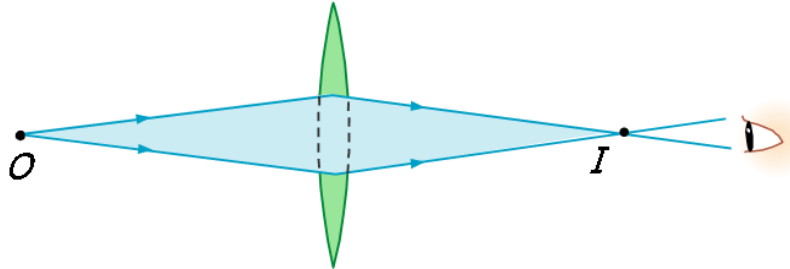
1. **There are four features of lenses:**
 - i. **Two Principal foci (F): Parallel rays are refracted and meet at this point.**
 - ii. **Optical centre (C): Centre of lens which light ray will pass through without bending**
 - iii. **Focal length: Distance of F from C**
 - iv. **Principal axis: The line through the optical centre and 2 foci.**



Real Images Vs Virtual Images

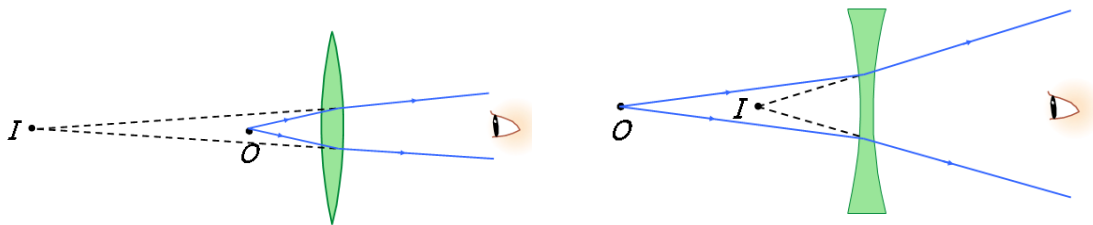
Andy wants to point out  :

1. **Real Images: Images can be formed on a screen. (if available)**




Convex Lens Only

2. **Virtual Images: Images cannot be formed on a screen.**

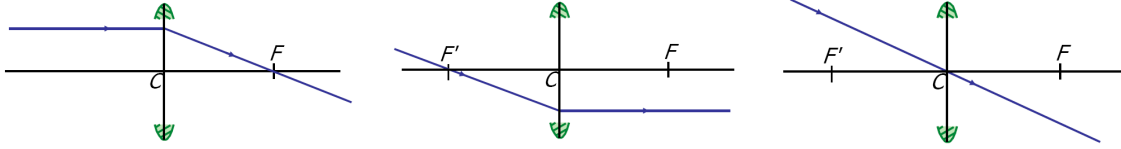


Convex Lens / Concave Lens

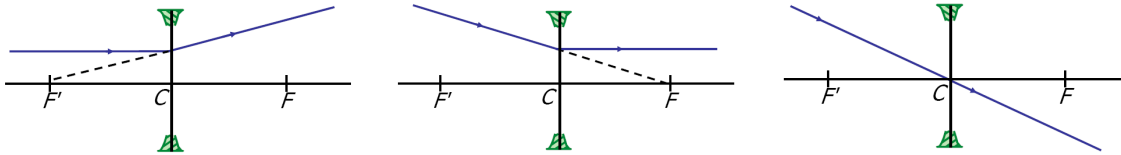
Ray diagrams for lenses

Andy wants to point out  :

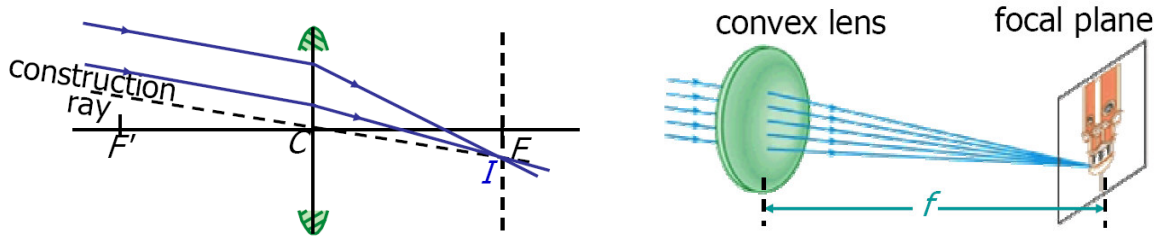
1. Construction rules for Convex Lens:



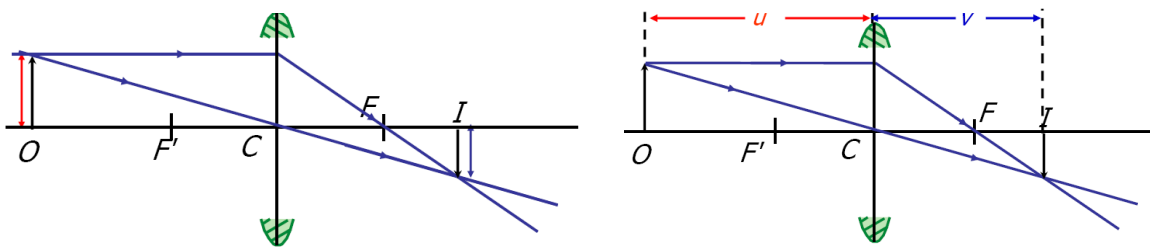
2. Construction rules for Concave Lens:



3. Construction Line: Parallel Light ray \Rightarrow Image formed on Focal Plane!!!



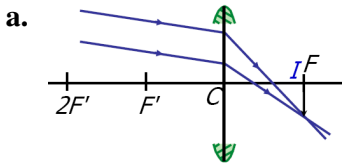
4. Linear Magnification of objects, $m = \frac{\text{Image Size}}{\text{Object Size}} = \frac{\text{Image Distance}}{\text{Object Distance}} = \frac{v}{u}$



Images formed by lenses: Ray diagrams

Andy wants to point out  :

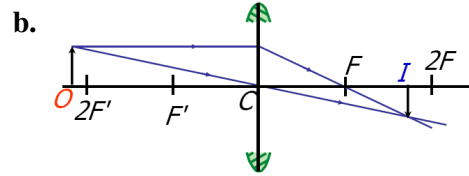
1. Images formed by Convex lens:



Object: $u = \infty$

Image: $v = F$, Real, Inverted, Diminished

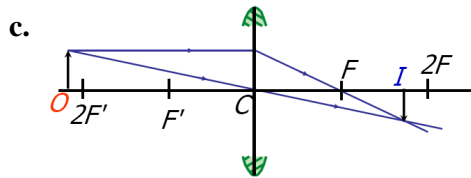
Usage: Measurement of focal length



Object: $u > 2F$

Image: $F < v < 2F$, Real, inverted, Diminished

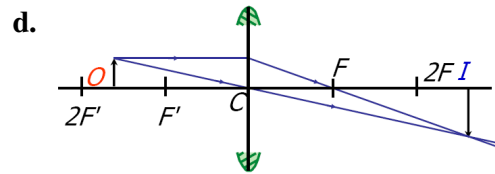
Usage: Projection of Large object on a small screen



Object: $u = 2F$

Image: $v = 2F$, Real, Inverted, Same Size

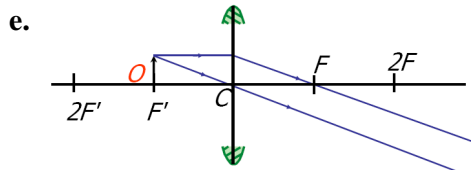
Usage: Erecting lens in refracting telescope



Object: $F < u < 2F$

Image: $v > 2F$, Real, Inverted, Magnified

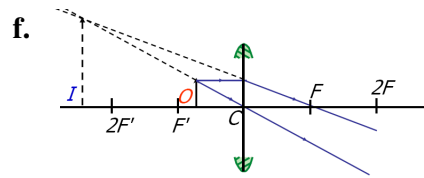
Usage: Projection of small object on a large screen



Object: $u = F$

Image: $v = \infty$ (Image at infinity!)

Usage: eyepiece of a refracting telescope

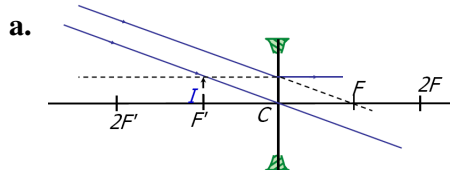


Object: $u < F$

Image: $v > u$, Virtual, Erect, Magnified

Usage: Magnifying glass

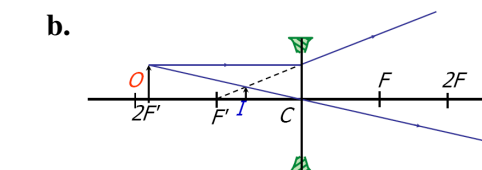
2. Image formed by Concave lens:



Object: $u = \infty$ (Object at infinity!)

Image: $v = F'$, Virtual, Erect, Diminished

Usage: lens in short-sighted glass



Object: $u < \infty$

Image: $F < v < 2F$, Virtual, erect, Diminished

Usage: i. Peephole in front door,

ii. Lens in short-sighted glass

Images formed by lenses: Lens Formula:

1. lens formula: $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

u : object distance **v** : image distance **f** : focal length

2. When applying the formula, we should use the real-is-positive convention.

- i. **u** and **v** are positive for real object and image.
- ii. **u** and **v** are negative for virtual object and image.
- iii. **f** is positive for concave mirror and convex lens.
- iv. **f** is negative for convex mirror and concave lens.

II. Basic knowledge of eye focusing

Basic principle of our eye focusing

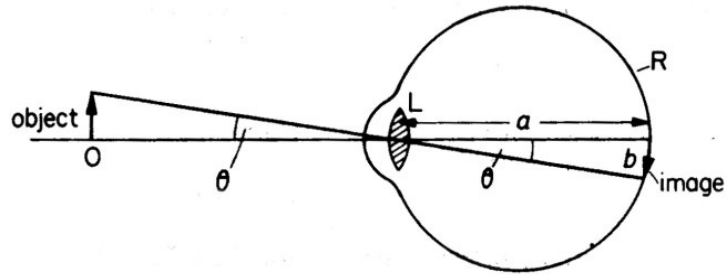
黎 Sir 提提你  :

1. **Near point:** The position of the nearest object that can be focused both clearly and without strain by the unaided eye.
2. **Far point:** the position of the farthest object that can be focused by the unaided eye (i.e. eye without the help of optical instruments).
3. **For an normal eye:**
 - i. **Near point:** about 25cm from the eye. i.e. Least distance of distinct vision. (D)
 - ii. **Far point:** At infinity.
4. **When the eye sees the object, the image formed on the retina must be real.**
5. **The thicker the lens, the shorter the focal length.**

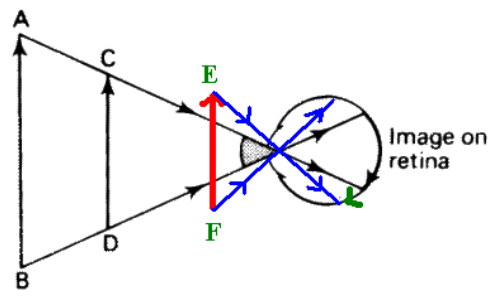
Visual angle

黎 Sir 提提你 :

1. Since the image distance is fixed (the distance of the eye ball is fixed!), the size of the image is determined by the angle θ subtended by the object at the eye, which is so-called visual angle of the object.
2. Visual angle, θ , of an object: the angle subtended by the object at the eye.



3. \uparrow Visual angle $\theta \Rightarrow \uparrow$ size of the object!
4. The observation of AB, CD and EF of the eye are as follows:
 - i. The size of AB and CD are not the same, but their images on the retina are the same since they have same size of visual angle.
 - ii. The size of EF is the smallest among them. However, its image on the retina is the largest since its visual angle is the largest.



5. For small visual angle,

$$\frac{\text{Object Height}}{\text{Distance from eye to object}} = \frac{\text{Image height on the retina}}{\text{Distance from the eye lens to the retina}}$$

6. The closer the object to the eye, the larger the apparent size! So the greatest angle subtended by an object at an unaided eye is the angle subtended at the Near Point.

III. Angular Magnification with optical instrument

Angular Magnification

黎 Sir 提提你  :

1. Angular magnification (magnifying power), $M = \frac{\beta}{\alpha}$

β : Angle subtended at the eye by the image formed when using the instrument.

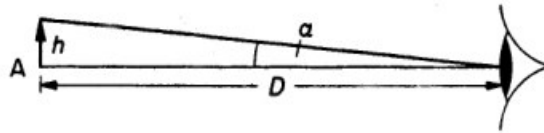
α : Angle subtended at the unaided eye at some stated distance.

M: Ratio of the apparent sizes of image and object (or visual angles)

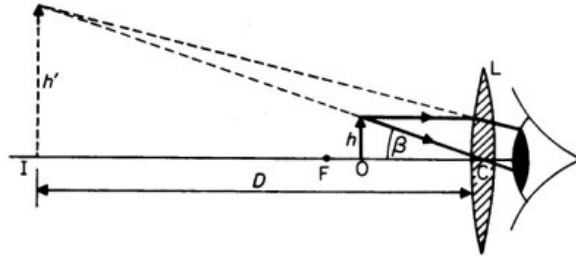
m: Ratio of the actual sizes of image and object.

2. For an unaided eye, $\therefore \theta$ is small, $\tan \alpha \approx \alpha$

$$\therefore \tan \alpha = \alpha = \frac{h}{D} \quad (D: \text{least distance of distinct vision})$$



3. For an eye with optical instrument, e.g. magnifying glass, $\beta = \frac{h_1}{D}$



4. \therefore Angular magnification, $M = \frac{\beta}{\alpha} = \frac{\frac{h_1}{D}}{\frac{h}{D}} = \frac{h_1}{h}$.

5. Normal adjustment: An optical instrument is in normal adjustment when the final image is formed in a specified position.

i. For a magnifying glass or a compound microscope with normal adjustment: The image at the near point, so that maximum angular magnification is obtained.

ii. For a telescope with normal adjustment: The image is at infinity, so that the eye is most relaxed.

IV. Optical instrument: Magnifying glass

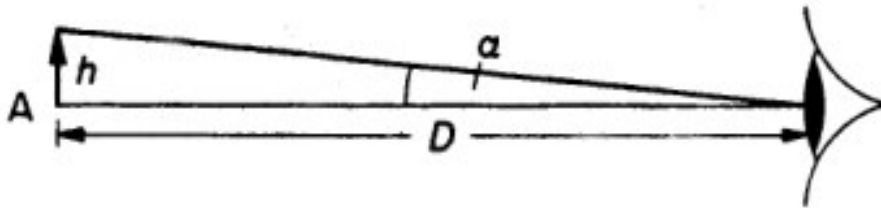
Magnifying glass (Simple Microscope)

黎 Sir 提提你  :

1. A converging lens forming a virtual, upright and magnified image of an object placed inside its principal focus.

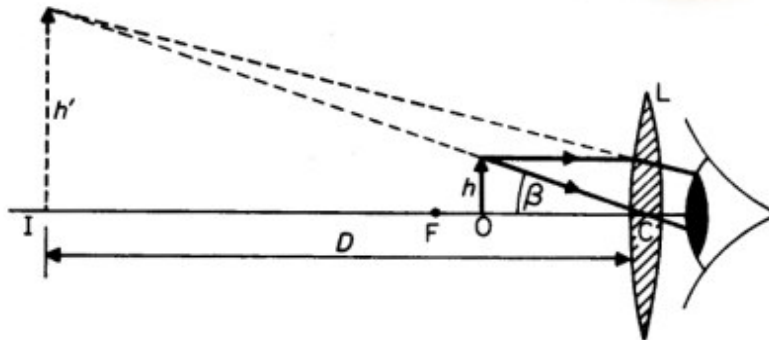
2. For an unaided eye, $\because \theta$ is small, $\tan \alpha \approx \alpha$

$$\therefore \tan \alpha = \alpha = \frac{h}{D} \quad (D: \text{least distance of distinct vision})$$



3. For an eye with magnifying glass with Normal adjustment,

i.e. final image at near point, $\beta = \frac{h_1}{D}$



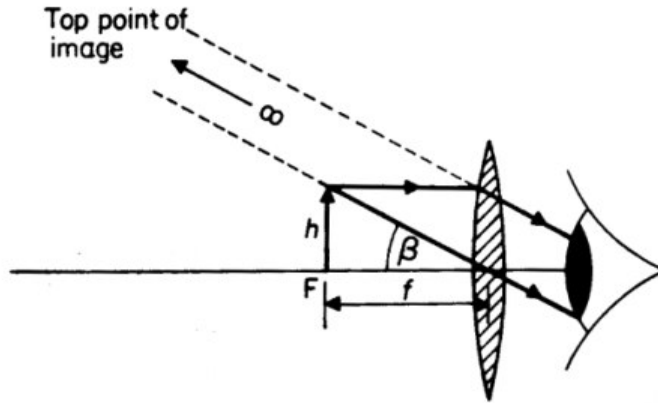
$$\therefore \text{Angular magnification, } M = \frac{\beta}{\alpha} = \frac{\frac{h_1}{D}}{\frac{h}{D}} = \frac{h_1}{h} = \frac{v}{u}$$

$$\therefore \text{By lens formula, } \frac{1}{u} + \frac{1}{v} = \frac{1}{f} \Rightarrow \frac{v}{u} = \frac{v}{f} - 1 \Rightarrow M = \frac{v}{f} - 1 \text{ or } M = \left| \frac{v}{f} \right| + 1$$

e.g. $f = 5 \text{ cm}$, $v = -D = -25 \text{ cm}$, If $v = D$, $M = \left| \frac{-25}{5} - 1 \right| = |-6|$, i.e. Magnifying power = 6.

4. For an eye with magnifying glass and image at infinity, $\beta = \frac{h_1}{\infty} = \frac{h}{f}$ (Similar triangle!)

Then $M = \frac{\beta}{\alpha} = \frac{\frac{h}{f}}{\frac{h}{D}} = \left| \frac{D}{f} \right|$. e.g. $f = 5 \text{ cm}$, $v = -\infty$, then $u = f$, so Magnifying power = 5.



5. Range of angular magnification of a magnifying glass:

- i. For an eye with magnifying glass with Normal adjustment (Final image at near point)

$M = \left| \frac{D}{f} \right| + 1 \Rightarrow$ Largest Angular Magnification but eye feel very tired!

- ii. For an eye with magnifying glass and image at infinity,

$M = \frac{\beta}{\alpha} = \frac{\frac{h}{f}}{\frac{h}{D}} = \left| \frac{D}{f} \right| \Rightarrow$ Least Angular Magnification but the eye feels most relaxed!

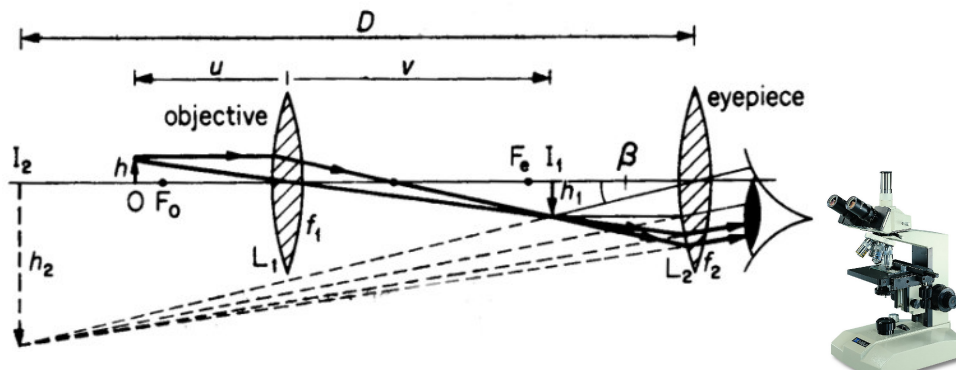
- iii. Conclusion: $\left| \frac{D}{f} \right| \leq M \leq \left| \frac{D}{f} \right| + 1$

V. Optical instrument: Compound microscope

Compound microscope

黎 Sir 提提你  :

1. Aim: Produce an image on the retina larger than that obtainable by placing a small accessible object at the near point.
2. Two converging lens (short focal lengths)
 - I. Objective L_1 (near to the object)
 - i. Forms a real, magnified and inverted image I_1 just outside its principal focus F_o .
 - ii. I_1 is just on or inside the principal focus F_e of the second lens.
 - II. Eyepiece L_2
 - i. I_1 produces a magnified and virtual image I_2 .



3. Normal adjustment: I_2 is at the near point.

$$\alpha = \frac{h}{D} \text{ and } \beta = \frac{h_2}{D}, \text{ Therefore, } M = \frac{\beta}{\alpha} = \frac{\frac{h_2}{D}}{\frac{h}{D}} = \frac{h_2}{h} = \frac{h_2}{h_1} \times \frac{h_1}{h} = m_e \times m_o$$

m_e : linear magnification of eyepiece m_o : linear magnification of objective.

$$m_e = \frac{v}{f_2} - 1 = \left| \frac{D}{f_2} \right| + 1 \text{ and } m_o = \left| \frac{v}{f_1} \right| + 1,$$

Therefore, $M = m_e \times m_o = \left(\left| \frac{D}{f_2} \right| + 1 \right) \left(\left| \frac{v}{f_1} \right| + 1 \right)$, i.e. M is large if f_1 and f_2 are small.

4. It is more restful for the eye to view the final image I_2 at infinity but the magnifying power is slightly less.

VI. Optical instrument: Refracting telescope

Refraction telescope

黎 Sir 提提你  :

1. Aim: Produce an enlarged retinal image of a distant inaccessible object.
2. For a distant object which cannot be brought close to the eye, the angle subtended at the unaided eye by the object can be taken as the angle subtended at the objective lens.

i.e. $\alpha = \frac{h_1}{f_o}$

3. Two converging lens:

I. Objective L_1

i. forms a real and inverted image I_1 of a distant object at principal focus F_o .

II. Eyepiece L_2

i. forms a magnified and inverted image of I_1 at infinity.

ii. F_o and F_e coincide.

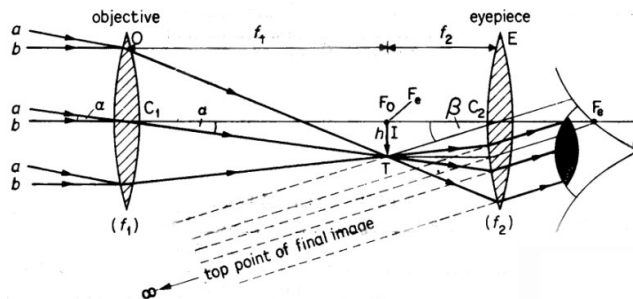
4. Normal adjustment: I_2 is at infinity.

$$\alpha = \frac{h_1}{f_o} \quad \text{and} \quad \beta = \frac{h_1}{f_e} \Rightarrow M = \frac{\beta}{\alpha} = \frac{f_o}{f_e}$$



5. For high magnifying power, the objective should have large focal length and the eyepiece has small focal length.

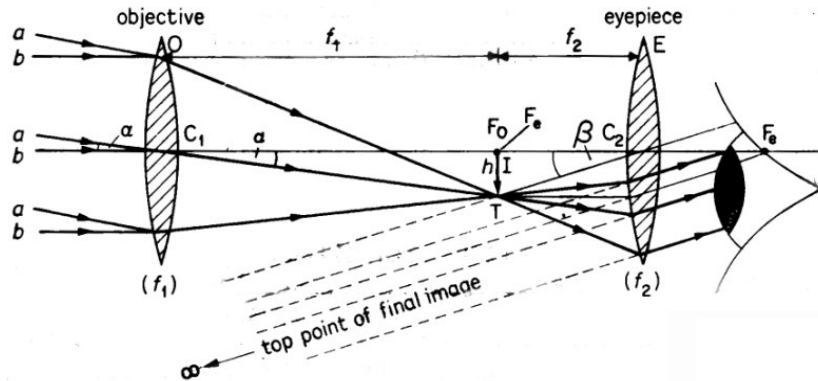
6. When normal adjustment, the separation of the objective and eyepiece is $(f_o + f_e)$.



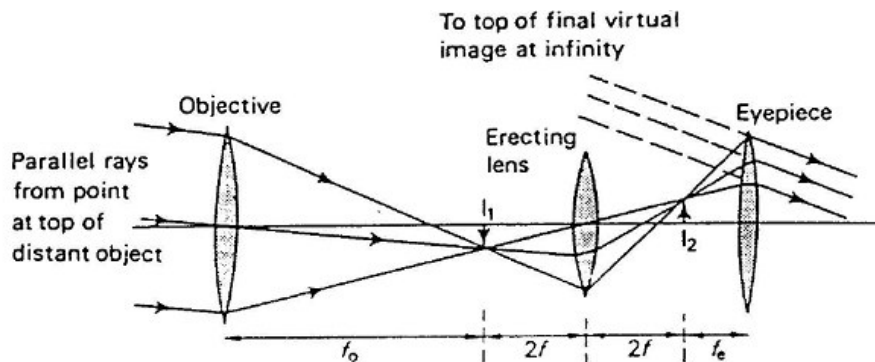
Refracting telescope with erecting lens

黎 Sir 提提你  :

1. With the diagram shown below, One major disadvantage is that the final image observed by the refracting telescope is inverted!



2. To solve the problem of inverted image, we can use an erecting lens for an additional inversion of the intermediate image I_1 .
3. In the figure below, the erecting lens which is a convex lens with focal length f is placed between the intermediate image I_1 and the eyepiece. The distance between the erecting lens and the intermediate image I_1 is $2f$.
4. The produced image I_2 is the same size as I_1 but I_2 is erect. Moreover, the distance between I_2 and the eyepiece is f_e , it makes the final image is also formed at infinity but the final image is Erect!.



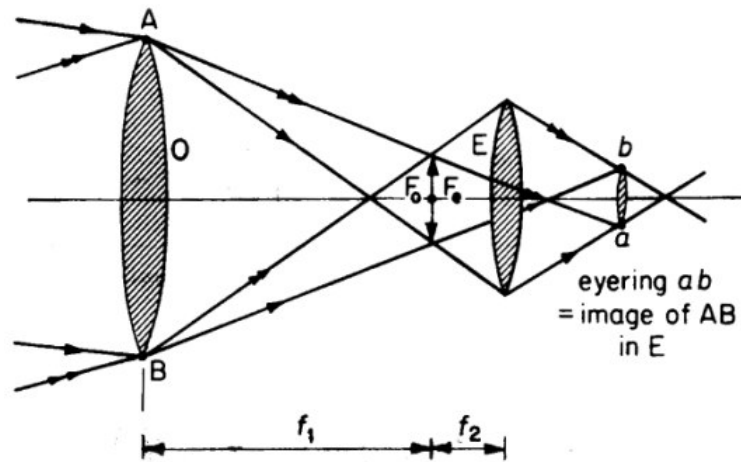
5. Other limitation of refracting telescope: Dispersion of light.

VII. Eye ring

Eye ring

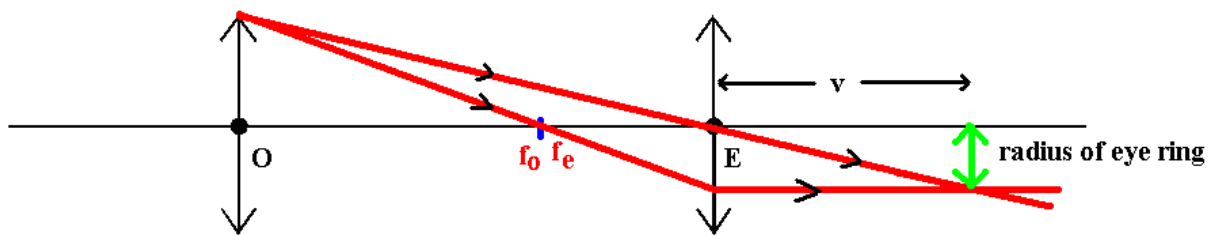
黎 Sir 提提你  :

1. The best position to place the eye.
2. Gathers most light from that passing through the objective.



3. Position of eye-ring = Image distance of the objective lens formed by the eyepiece.

Image distance (v) of the objective lens formed by the eyepiece = Position of eye-ring



4. Diameter of eye-ring = 2 x Radius of eye-ring.

VIII. Chapter summarySummary of Optical instruments黎 Sir 提提你 :

1. **Real image:** Image can be formed on a screen.
2. **Virtual image:** Image cannot be formed on a screen.
3. **lens formula:** $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$, (Real is positive, convex lens: $+f$, concave lens: $-f$)
4. **Near point:** Least distance of distinct vision (D), for normal eye ≈ 25 cm!
5. **Far point:** Farthest distance of distinct vision, for normal eye: At infinity
6. **Visual angle, θ , of an object:** the angle subtended by the object at the eye.
7. \uparrow Visual angle $\theta \Rightarrow \uparrow$ size of the object.
8. **Greatest visual angle of an unaided eye:** Object at near point!
9. **Normal adjustment:** Optical instrument with final image formed in a specified position.
10. **For a magnifying glass and a microscope with normal adjustment:** Image at near point
11. **For a telescope with normal adjustment:** Image is at infinity
12. **Linear magnification (Ratio of actual size of image and object):** $m = \frac{v}{u}$
13. **Angular magnification (magnifying power):** $M = \frac{\beta}{\alpha}$
14. **Magnifying power of**
 - i. **Magnifying glass:** $\left| \frac{D}{f} \right| \leq M \leq \left| \frac{D}{f} \right| + 1$
 - ii. **Compound microscope with normal adjustment:** $M = \left(\left| \frac{D}{f_2} \right| + 1 \right) \left(\left| \frac{v}{f_1} \right| + 1 \right)$
 - iii. **Refracting telescope with normal adjustment:** $M = \frac{f_o}{f_e}$
15. **Eye ring:** Position of eye to gather most light from that passing through objective lens
16. **Position of eye-ring = Image distance of the objective lens formed by the eyepiece.**
17. **Limitation of refracting telescope: Inverted final image, Compensation: Erecting lens.**

The end.

