SPECTROMETER

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Aim: To familarise with the working and setting of spectrometer.

Construction:

(A) The knob at A is used to clamp the telescope in place so that it can not be moved. It should always be loosened when large adjustments do the position of telescope are made.

(B) The knob at B is finely used to adjust telescope. Knob A must be clamped before to make fine adjustments.

(C) The knobs at C can be used to level the prism table with respect to optical axes.

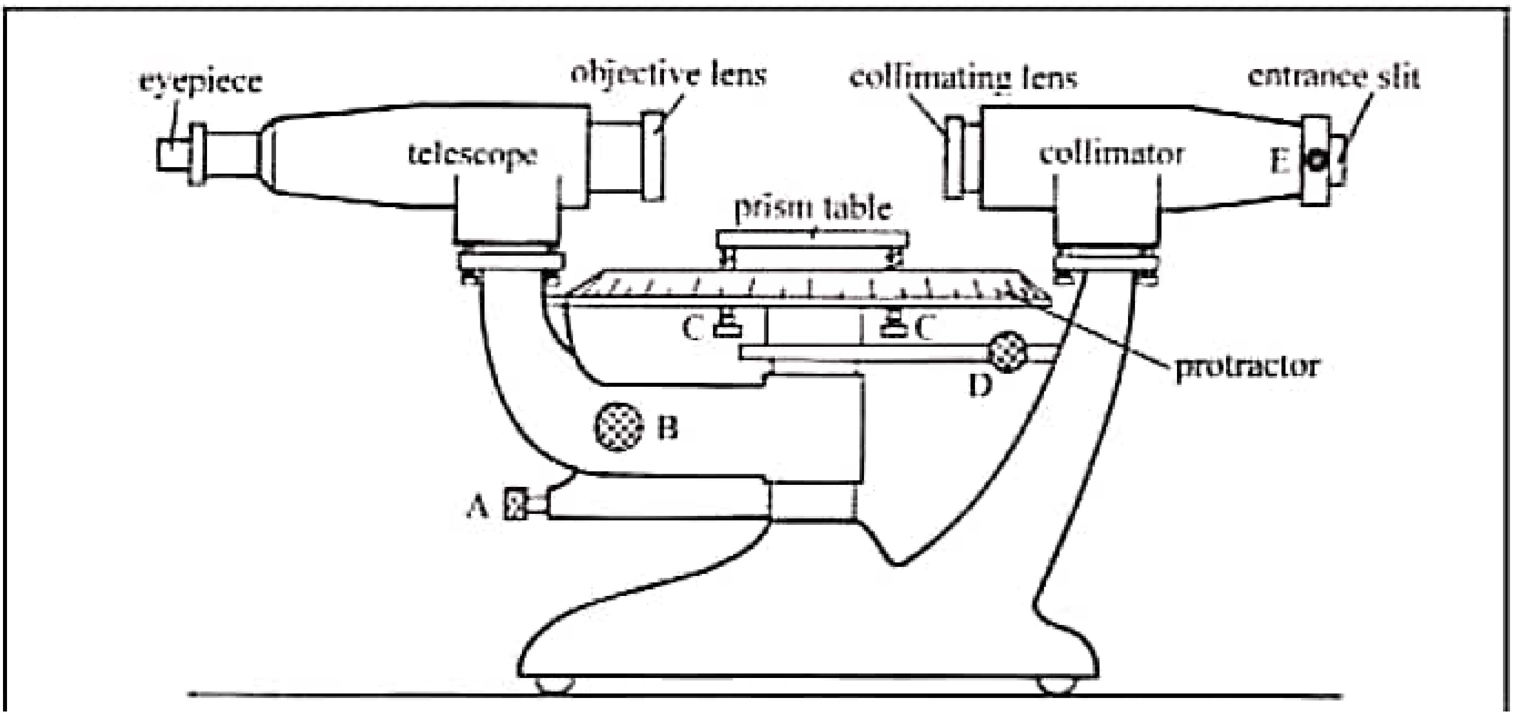
(D) The knob at D is used to clamp protactor as well as prism and grating table It must be clamped when angular readings are taken with the combination of the protactor and vernier scales.

(E) The knob at E is used to adjust the width of the slit at the front of the collimator. One edge of the stilt remains fixed on the optical axis, the other edge is adjustable.

Working:

When a source of light is kept in front of spectrometer, image of the slit obtained will be blurred which shows a parallax To rectify this, the prism spectrometer has to be set in three steps which include :- (a) setting the telescope
(b) setting the collimator
(c) setting the prism table

(a) setting the telescope :- the telescope has to be set for parallel rays. The telescope is turned towards the distant vertical object and eye piece is moved in and out with Rack and Pinion Arrangement of the telescope. This is carried out till


eyepiece
objective lens
collimating lens
entrance slit
telescope
collimator
E
prism table
C
C
protractor
D
B
A

Page No.:
Date:
YOUVA

the image of the distant object is well-focused. The telescope is now set for parallel rays. This setting remains undisturbed throughout the experiment.

(b) setting the collimator :- the telescope is turned so as to bring it in line with collimator. The slit of the collimator is now illuminated using a source of white light. Initially the height and width of slit are adjusted to obtain a fine slit to minimise any error in measurement. In the collimator, the distance between the slit and the collimator lens is adjusted, so that a clear image of slit is seen through the telescope. The collimator is now ready to provide a parallel beam of light. These light rays fall on the objective of the telescope. A real, inverted, highly diminished is formed at principal focus of objective lens and this goes through the principal focus of eyepiece lens. Here, the cross-wires are fixed and thus final magnified image is obtained on eyepiece of telescope. The image of slit now obtained is without parallax. The spectrometer reading thus obtained for "direct rays" is taken as (δ_1).

(c) setting the prism table :- the spectrometer experiments are always done by keeping prism at minimum angle of deviation (this is the position at which light is deviated least by the prism).
To obtain this position, white light incident on one phase of prism emerges out of the other face. This white light comes from collimator. Now, telescope is turned towards refracting face till image of spectrum is seen through eyepiece.
On rotating prism table gradually, the spectral lines also turn. This is because on rotating prism table, the angle of incidence and hence angle of minimum deviation (δ) change. During its rotation, for a particular position of the prism, the spectral lines become stationary.
On rotating the prism table further in the same direction,

the spectral lines start moving in the opposite direction. The prism table is rotated back to position. Now, telescope and vernier table are clamped. Now using tangential screw, a particular spectral line is made to coincide with cross-wires. This is the position of "minimum deviation". The spectrometer reading taken for this position is (δ_2).

The difference of two readings ($\delta_1 - \delta_2$) gives the angle of minimum deviation (δm).

The angle of minimum deviation is different for different colors ($\delta_b > \delta_y > \delta_r$).

Adjustments:

To obtain satisfactory results, the spectrometer requires some initial adjustments before the desired measurements can be performed. Great care must be taken in adjusting spectrometer so that telescope is focused at infinity and collimator is set to give an accurately parallel beam. It is particularly important to ensure that the cross-hairs of the telescope are sharply visible and that no parallax exists between them and the spectral line images.

...(for details go to 'Points to be addressed' part (f))

Applications:

(i) It is used to measure angle of a prism.
(ii) It is used to measure angle of minimum deviation.
(iii) It is used to measure refracting index of prism material.
(iv) It is used to measure unknown wavelength.

Points to be addressed!

Page No.:
Date: 21/04/21

(a) Achromatic Lens

Achromat is a lens that is designed to limit the effects of chromatic and spherical aberration.

Achromatic lenses are corrected to bring two wavelengths (typically red and blue) into focus on the same plane.
As, chromatic aberration of a single lens causes different wavelengths of light to have differing focal lengths. So, achromatic doublet brings red and blue light to the same focus.
Achromatic doublet is made of two individual lenses which are made of glasses with different amounts of dispersion. One element is concave made of flint glass with high dispersion and second element is convex made of crown glass with low dispersion. Setting of both lenses are done in such a way such that chromatic aberration of one is counterbalanced by other.

In case of prisms, two prisms are cemented such that their refracting angles are in opposite directions.
With a convex lens, blue rays of light come to focus at a point nearer the lens.
With a concave lens, red rays of light meet the axis at a point nearer the lens.

Let μ_b, μ_r and μ'_b, μ'_r be the refracting indices for blue, red light rays for two materials and f_b, f, f_r and f'_b, f', f'_r are corresponding focal lengths of two lenses and ω and ω' are the dispersive powers for convex and concave lenses.

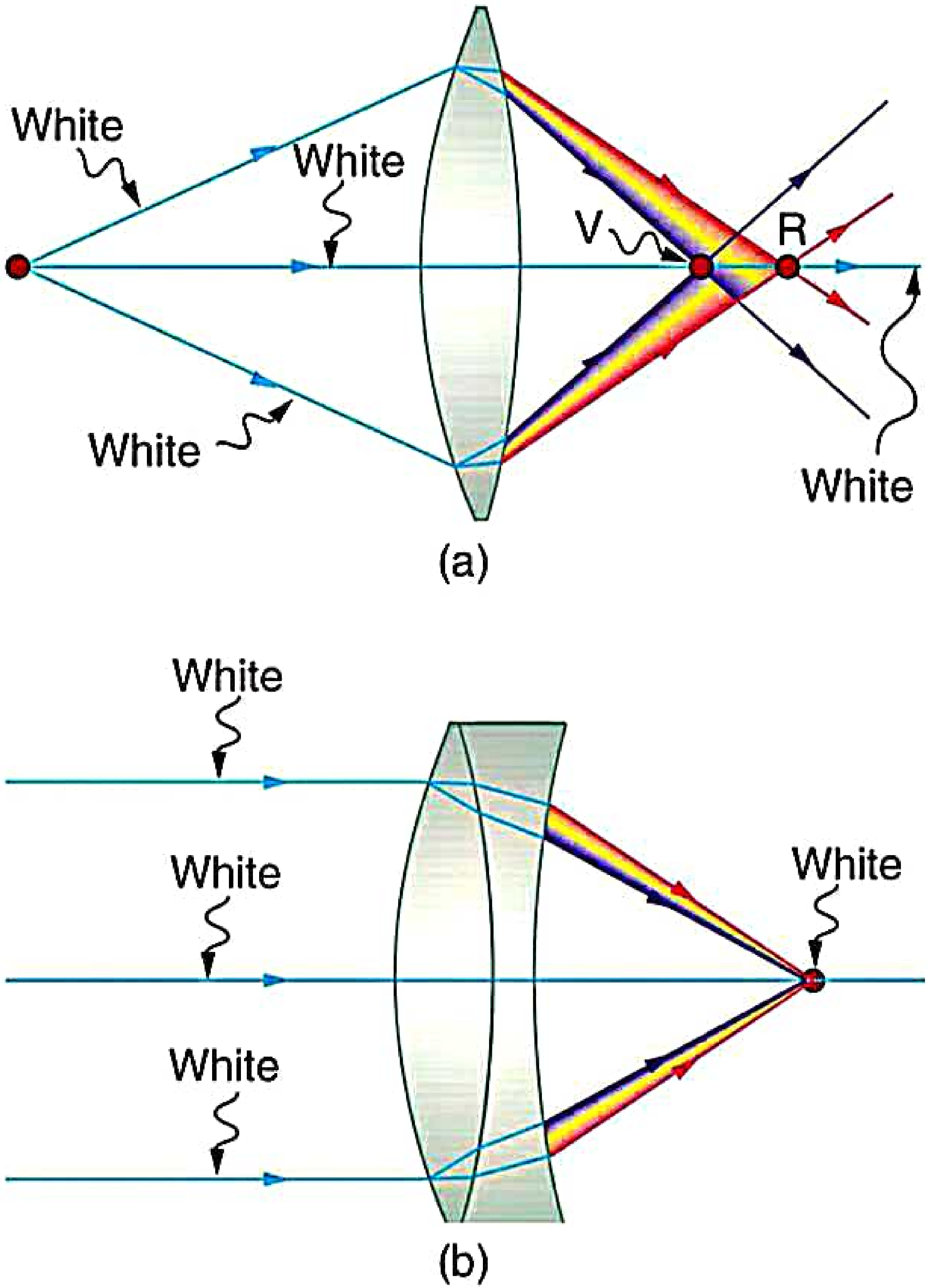
$$\frac{1}{f} = (\mu-1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad \text{and} \quad \frac{1}{f'} = (\mu'-1)\left(\frac{1}{R'_1} - \frac{1}{R'_2}\right)$$

So, $\frac{1}{f^b} = (\mu_b - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$ and $\frac{1}{f^r} = (\mu_r - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$

Also, $\frac{1}{f'^b} = (\mu'_b - 1)\left(\frac{1}{R'_1} - \frac{1}{R'_2}\right)$ and $\frac{1}{f'^r} = (\mu'_r - 1)\left(\frac{1}{R'_1} - \frac{1}{R'_2}\right)$

it is also known :- $\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = \frac{1}{(\mu-1)f}$ and $\left(\frac{1}{R'_1} - \frac{1}{R'_2}\right) = \frac{1}{(\mu'-1)f'}$

$\therefore \frac{1}{f^b} = \frac{(\mu_b - 1)}{(\mu-1)f}$, $\frac{1}{f^r} = \frac{(\mu_r - 1)}{(\mu-1)f}$ and $\frac{1}{f'^b} = \frac{(\mu'_b - 1)}{(\mu'-1)f'}$, $\frac{1}{f'^r} = \frac{(\mu'_r - 1)}{(\mu'-1)f'}$


White
White
V
R
White
White
(a)
White
White
White
White
(b)

(b) Cardinal Points

Cardinal points consist of three pairs of points located on the optical axis of a rotationally symmetric, focal, optical system.
These are the focal points, principal points and nodal points.

→ for ideal systems, basic imaging properties (image size, location, orientation) are completely determined by the location of cardinal points.
Here, only four points are sufficient which must include two focal points and either two principal points or nodal points.

→ Cardinal points are widely used to determine behaviour of real optical systems. Cardinal points give a way to analytically simplify any system with many components.
So, imaging characteristics are approximately determined with just simple calculations.

HISTORICAL BACKGROUND :-

In case of refraction through thin lenses, thickness of lenses gets neglected in calculating many formulae. So, it is very less significant that from which point of the lens, the distances are measured.

In case of refraction through thick lens or combination of two lenses separated by a finite distance, thickness of len can not be neglected in calculating formulae. Thus, method of evaluating the distance of image with consideration of refraction at each surface is tedious.

To overcome this difficulty, Gauss in 1841 proved that any number of co-axial refracting systems can be treated as one unit and simple formulae for thin lenses can be applied, given the distances are measured from two theoritical planes, fixed with reference to the refracting system.

The points of intersection of these planes are called the Principal or Gauss points.
Actually, there are six points in all (two principal points, two foci, two nodal points). These six points are known as cardinal points of an optical system.

(c) Combination of Thin Lenses in Contact

In various optical instruments, two or more lenses are often combined to :
(i) increase magnification of the image
(ii) make the final image erect w.r.t. the object
(iii) reduce certain aberrations

We first find the image of object formed by first lens. This image acts as an object for second lens and we locate its image. The image formed by second lens serves as the object for the third lens and so on.

Focal Length of Equivalent Lens

(a) both lenses are convex :-
C_1 and C_2 are the optical centres of two thin convex lens L_1 and L_2 held co-axially in contact with each other in air. (f_1) and (f_2) be their respective focal lengths.
$OC_1 = u$ and L_1 forms image I' on its alone and $C_1I' = v'$
lens formula says, $\frac{1}{v'} - \frac{1}{u} = \frac{1}{f_1}$

I' acts as a virtual object for L_2. L_2 forms final image at I and $C_2I = v$.
lenses are thin, $C_2I' = u \approx C_1I' = v'$
lens formula says, $\frac{1}{v} - \frac{1}{v'} = \frac{1}{f_2}$

adding above two equations :- $\frac{1}{v} - \frac{1}{u} = \frac{1}{f_1} + \frac{1}{f_2}$

Replace two lenses by a single lens of focal length F which forms image I at distance (v) of object at distance (u) from lens. So,
$\frac{1}{v} - \frac{1}{u} = \frac{1}{F}$

$$\Rightarrow \frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} \Rightarrow F = \frac{f_1 \times f_2}{f_1 + f_2}$$

(b) one lens is convex and other is concave :-

(f_1) be focal length of convex lens, (f_2) be focal length of concave lens.

So,
$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{(-f_2)} = \frac{1}{f_1} - \frac{1}{f_2}$$

$$\Rightarrow F = \frac{f_1 f_2}{f_2 - f_1}$$

three cases arise :-

(i) ($f_1 = f_2$) $\therefore$ $F = \infty$ and combination behaves as plane mirror

(ii) ($f_1 > f_2$) $\therefore$ $F = -ve$ and combination behaves as concave lens

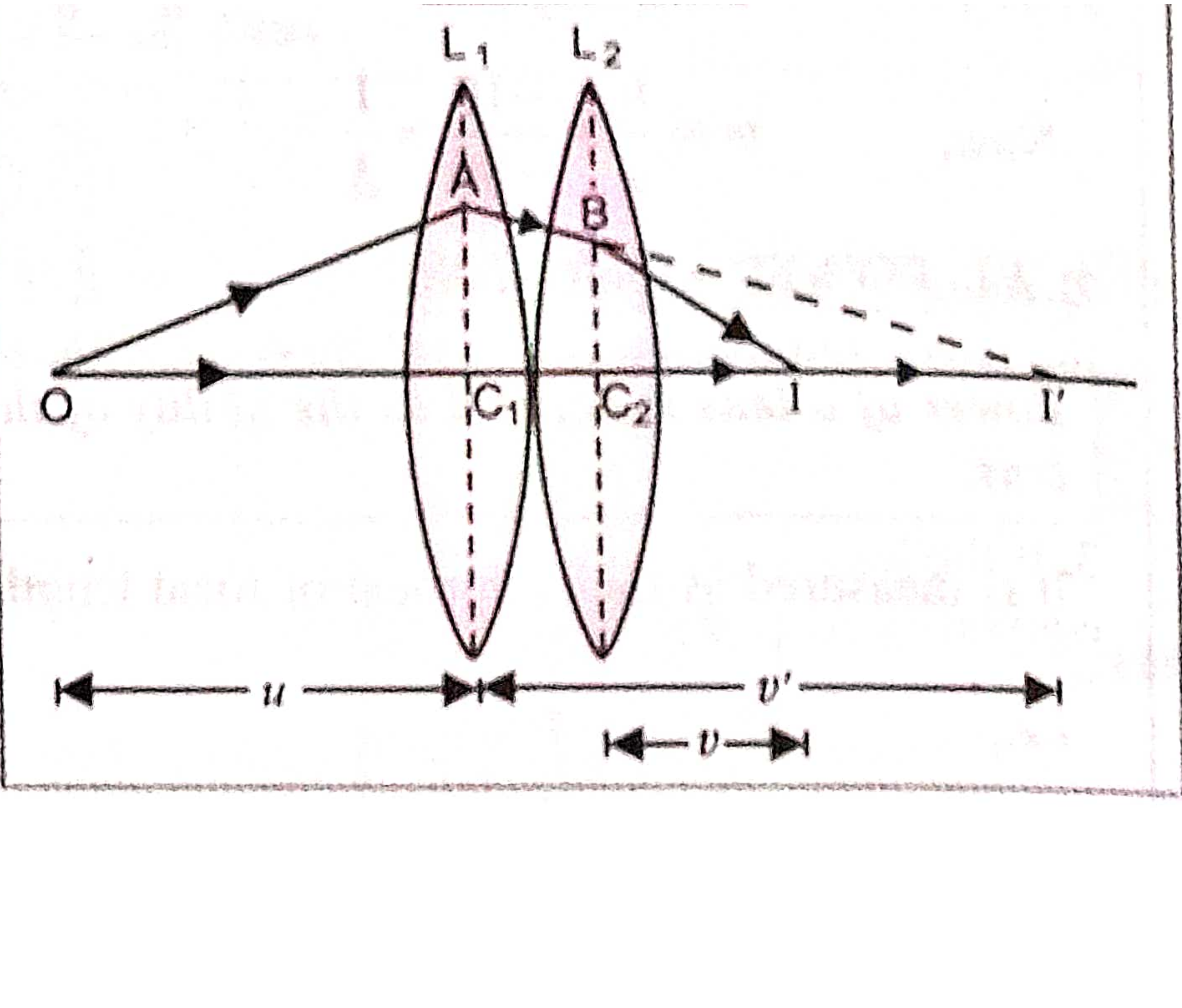
(iii) ($f_1 < f_2$) $\therefore$ $F = +ve$ and combination behaves as convex lens

→ above derivation carried for several thin lenses of focal lengths $f_1, f_2, f_3 \ldots$ in contact. Effective focal length (f) is :-

$$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} + \frac{1}{f_3} + \ldots$$

→ if lenses of focal lengths (f_1) and (f_2) are separated by a finite distance (d), the focal length (F) of equivalent lens is :-

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2}$$



L1
L2
A
B
O
C1
C2
I
I'
u
v'
v

Page No.:
Date
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(d) Simple Microscope

It is used for observing magnified images of tiny objects.
A virtual, erect, magnified image of object is formed at the least distance of distinct vision from eye hold close to lens. So, simple microscope is also called magnifying glass.

F, F are two principal foci and C is the optical centre of convex lens. Object AB is held between C and F and AB is perpendicular to the principal axis.
A virtual, erect, magnified image A'B' is formed.
Eye is held close to lens and CB' = d = least distance of distinct vision for normal eye.

Angular Magnification of a simple microscope is the ratio of angle subtended at the eye by final image to the angle subtended at the eye by object when both final image and object are situated at least distance of distinct vision from the eye.

$\angle A'CB' = \beta$ and let object AB is displaced to A_1B' at distance (d) $\therefore \angle A_1CB' = \alpha$

Magnifying Power $= m = \beta/\alpha$

for small angles, $\tan\theta \approx \theta$ $\therefore \tan\alpha \approx \alpha$, $\tan\beta \approx \beta$ ... (θ in radians)

$\Rightarrow m = \dfrac{\tan\beta}{\tan\alpha}$

$\tan\beta = \dfrac{AB}{CB}$ (in ΔABC), $\tan\alpha = \dfrac{A_1B'}{CB'} = \dfrac{AB}{CB'}$ (in $\Delta A_1B'C$)

$\Rightarrow m = \dfrac{AB}{CB} \times \dfrac{CB'}{AB} = \dfrac{CB'}{CB} = \dfrac{-v}{-u} = \dfrac{v}{u} \Rightarrow m = \dfrac{v}{u}$;

$-v$ = distance of image from lens, $-u$ = distance of object from lens

lens formula :- $\dfrac{1}{v} - \dfrac{1}{u} = \dfrac{1}{f} \Rightarrow 1 - \dfrac{v}{u} = \dfrac{v}{f} \Rightarrow 1 - m = \dfrac{v}{f} \Rightarrow m = 1 - \dfrac{v}{f}$

but $v = -d \Rightarrow m = \left(1 + \dfrac{d}{f}\right)$

as (f) decreases, (m) increases

Use of a simple microscope :-

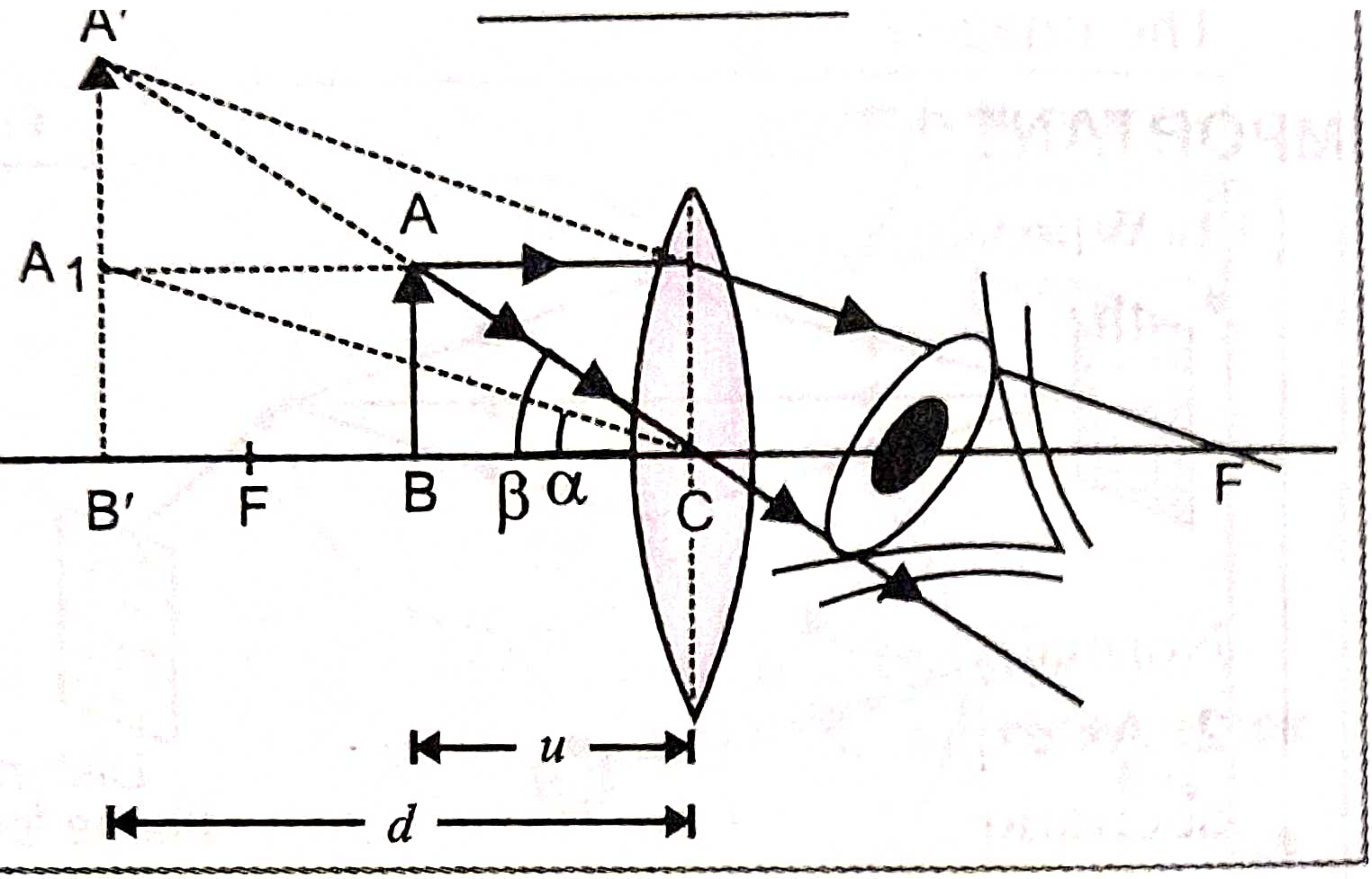
(i) by watch makers and jewellers to see magnified view of tiny parts of watch and fine jewellery work

(ii) by students in Science Laboratories for vernier scales etc.

→ here, image is very bright and sharp because object is held close to the lens.

→ when object is at focus i.e. $u = f$ ∴ $(m = d/f)$
normally, magnifying power of a simple microscope is ≤ 10.

→ A single lens suffers from defects of spherical abberation and chromatic aberration. So, image formed by a single lens is often blurred and coloured. Thus, to get sharp and bright image from a simple microscope, a suitable lens combination is used.


A′
A
A1
B′
F
B
β
α
C
F
u
d

Compound Microscope

It is an optical instrument used for observing highly magnified images of tiny objects.

Construction :- It consists of two converging lenses. Objective lens O is of very small focal length and short aperture. Eye piece E is of moderate focal length and large aperture.
Two lenses are held co-axially at free ends of a tube at a suitable fixed distance from each other.

AB object is held perpendicular to common principal axis in front of objective lens beyond its principal focus F_o. A real, inverted, enlarged image A'B' of this object is formed by the objective lens.

A'B' acts as a object for eye lens and position of A'B' is adjusted such that A'B' lies between optical centre C_2 of eye lens and principal focus F_e. A virtual, magnified image A''B'' is formed by eye lens. A''B'' is erect w.r.t. A'B' but A''B'' is inverted w.r.t. AB.

Final image A''B'' is seen by eye held close to lens.
Adjustment is done such that A''B'' is at least distance of distinct vision from eye i.e. $C^2B'' = d$.

Angular Magnification of a compound microscope is the ratio of angle subtended at the eye by final image to the angle subtended at the eye by object when both final image and object are situated at least distance of distinct vision from eye.

$\angle A_1C_2B'' = \alpha$ (AB is shifted to A_1B'' so that it is at (d) distance from eye)
$\angle A''C_2B'' = \beta$
Magnifying power $= m = \frac{\beta}{\alpha}$

$\alpha \approx \tan\alpha$, $\beta \approx \tan\beta$ (α and β are small angles in radians)

$\Rightarrow m = \frac{\tan\beta}{\tan\alpha}$

$\tan\beta = \frac{A''B''}{C_2B''}$ (in $\Delta A''B''C_2$), $\tan\alpha = \frac{A_1B''}{C_2B''} = \frac{AB}{C_2B''}$ (in $\Delta A_1B''C_2$)

$\Rightarrow m = \frac{A''B''}{C_2B''} \times \frac{C_2B''}{AB} = \frac{A''B''}{AB} = \frac{A''B''}{A'B'} \times \frac{A'B'}{AB} \Rightarrow$ $m = m_e \times m_o$

but $m_e = \left(1+\frac{d}{f_e}\right) \rightarrow$ derived in simple microscope

$m_o = \frac{A'B'}{AB} = \frac{\text{distance of } A'B' \text{ from } C_1}{\text{distance of } AB \text{ from } C_1} = \frac{C_1B'}{C_1B} = \frac{v_o}{-u_o}$

$\Rightarrow m = \frac{v_o}{-u_o}\left(1+\frac{d}{f_e}\right) = \frac{v_o}{|u_o|}\left(1+\frac{d}{f_e}\right)$

$u_o = C_1B \approx C_1F_o = f_o$ = focal length of objective lens...[because AB lies very close to F_o]

$v_o = C_1B' \approx C_1C_2 = L$ = length of microscope tube...[because A'B' lies close to eye lens whose focal length is also short]

$\Rightarrow m = \frac{L}{-f_o}\left(1+\frac{d}{f_e}\right) = \frac{L}{|f_o|}\left(1+\frac{d}{f_e}\right) = m$

also lens formula says:- $\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{f_o} \Rightarrow 1 - \frac{v_o}{u_o} = \frac{v_o}{f_o} \Rightarrow \frac{v_o}{u_o} = \left(1 - \frac{v_o}{f_o}\right)$

$\Rightarrow$ $m = \left(1-\frac{v_o}{f_o}\right)\left(1+\frac{d}{f_e}\right)$

Magnifying Power of Compound Microscope when final image is at ∞ :-

$m_o = \frac{v_o}{u_o}$, $m_e = \frac{d}{f_e}$ $\therefore m = m_o \times m_e = \frac{v_o}{u_o} \times \frac{d}{f_e}$

Normal Adjustment :-

When object is very close to principal focus of objective lens and image is formed is very close to the eye lens.

$u_o \approx f_o$, $v_o \approx L$ = length of microscope tube

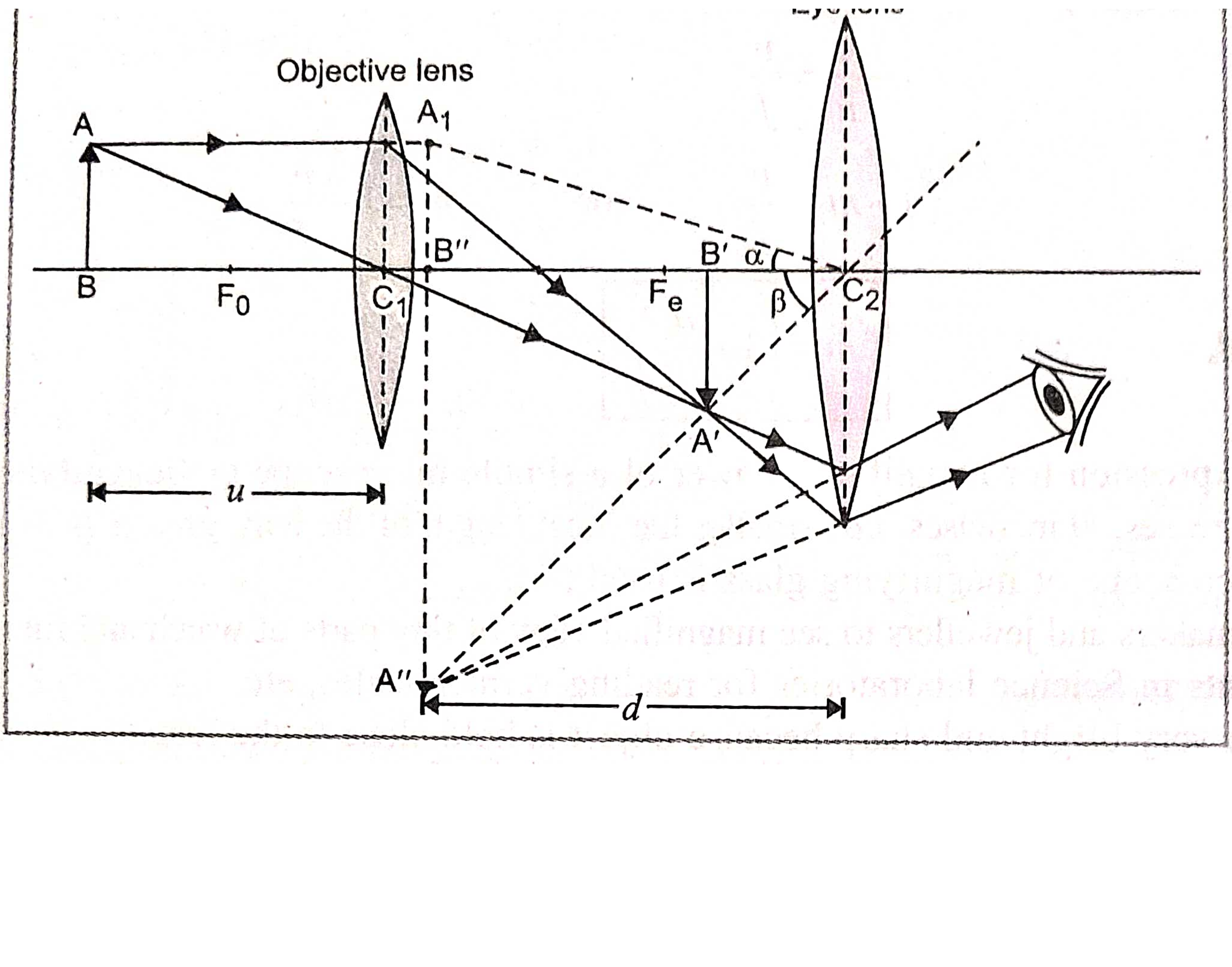
$\therefore m = m_o \times m_e = \frac{-L}{f_o} \times \frac{d}{f_e}$

→ (m) is -ve ∴ image seen in microscope is always inverted w.r.t. object

→ to increase (m), both (f_o) and (f_e) have to be small and (f_o) < (f_e) to increase field of view.

→ as aperture of both lenses in a microscope is small, spherical abberation is minimised.

→ in compound microscope, objective lens and eye lens are fixed distance apart, so to focus an object, distance between object and objective lens is adjusted.


Objective lens
A
A1
B″
B′
α
β
B
F0
C1
Fe
C2
A′
u
A″
d

Astronomical Telescope

It is an optical instrument which is used to observe distinct images of heavenly bodies like stars, planets, etc.

Construction :- It consist of two lenses. Objective lens is of large focal length and large aperture. Eye lens is of small focal length and small aperture. Two lenses are mounted co-axially at the free ends of two tubes. Distance between these lenses can be adjusted.

A parallel beam of light from an astronomical object (at ∞) is made to fall on the objective lens of telescope. It forms a real, inverted, diminished image A'B' of object.

Eye piece is adjusted such that A'B' lies just at the focus of eye piece. So, a highly magnified image is formed at infinity.

Final image is erect w.r.t. A'B' and inverted w.r.t. object and this doesn't matter because astronomical objects are usually spherical.

Angular Magnification of astronomical telescope in normal adjustment is the ratio of angle subtended at the eye by final image to the angle subtended at the eye by object directly when final image and object both lie at infinite distance from eye.

In normal adjustment, final image is at infinity.

As object lies at very huge distance, so angle made by it at C_2 is same as the angle made by it at C_1 (because C_1 is much close to C_2 in comparison with object distance from lens).

$\angle A'C_1B' = \alpha$, $\angle A'C_2B' = \beta$ = angle made by rays coming from final image

$m = \frac{\beta}{\alpha}$ = Magnifying power

$\alpha \approx \tan\alpha$, $\beta \approx \tan\beta$ (α and β are small angles in radians)

$\Rightarrow m = \frac{\tan\beta}{\tan\alpha}$

$\tan\beta = \frac{A'B'}{B'C_2}$ (in $\Delta A'B'C_2$), $\tan\alpha = \frac{A'B'}{B'C_1}$

$\Rightarrow m = \frac{A'B'}{B'C_2} \times \frac{B'C_1}{A'B'} = \frac{C_1B'}{C_2B'} \rightarrow m = \frac{f_o}{-f_e}$

→ negative sign of (m) indicates that final image is inverted w.r.t. object.

→ to increase (m) in normal adjustment, (f_o) should be large and (f_e) should be small.

Angular Magnification of astronomical telescope is ratio of angle subtended at the eye by final image at least distance of distinct vision to the angle subtended at the eye by object at infinity when seen directly.

Object is very far off. C_1 and C_2 are closer than that distance. So, angle made by object on eye at C_2 is equal to angle made by it at C_1.
$\angle A'C_1B' = \alpha$, $\angle A''C_2B'' = \beta$ and $C_2B'' = d$ = least dis. of distinct vision

Magnifying power $= m = \frac{\beta}{\alpha}$

$\tan\alpha \approx \alpha$, $\tan\beta \approx \beta$ (α and β are small angles in radians)

$\Rightarrow m = \frac{\tan\beta}{\tan\alpha}$

$\tan\beta = \frac{A'B'}{C_2B'}$ (in $\Delta A'B'C_2$), $\tan\alpha = \frac{A'B'}{C_1B'}$ (in $\Delta A'B'C_1$)

Page No.
Date

$\Rightarrow m = \frac{A'B'}{C_1B'} \times \frac{C_1B'}{A'B'} = \frac{C_1B'}{C_2B'} = \frac{-f_o}{-u_e}$

now, for eye lens :- $\frac{1}{v_e} - \frac{1}{(-u_e)} = \frac{1}{f_e}$ and $v_e = -d$, $-u_e = -u_e$; $\frac{-1}{d} + \frac{1}{u_e} = \frac{1}{f_e}$

$\Rightarrow \frac{1}{u_e} = \frac{1}{f_e} + \frac{1}{d} = \frac{1}{f_e}\left(1 + \frac{f_e}{d}\right)$

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

→ As (m) is negative, final image is inverted.

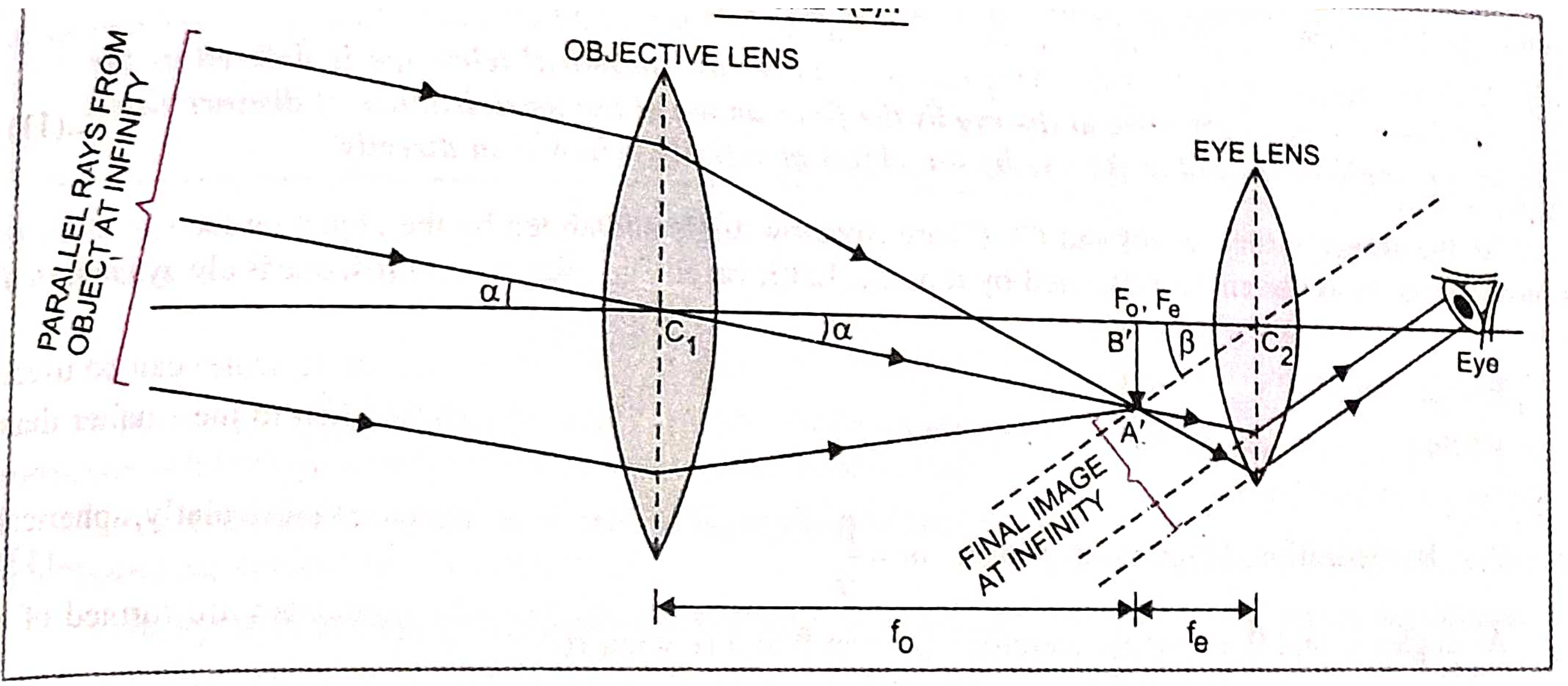
→ In normal setting, final image is at infinity and magnifying power is least.
$m_{min.} = -\left(\frac{f_o}{f_e}\right)$

→ The largest lens objective in use has a diameter of (102) cm. This telescope is at the Yorkes Observatory in Wisconsin (U.S.A.)

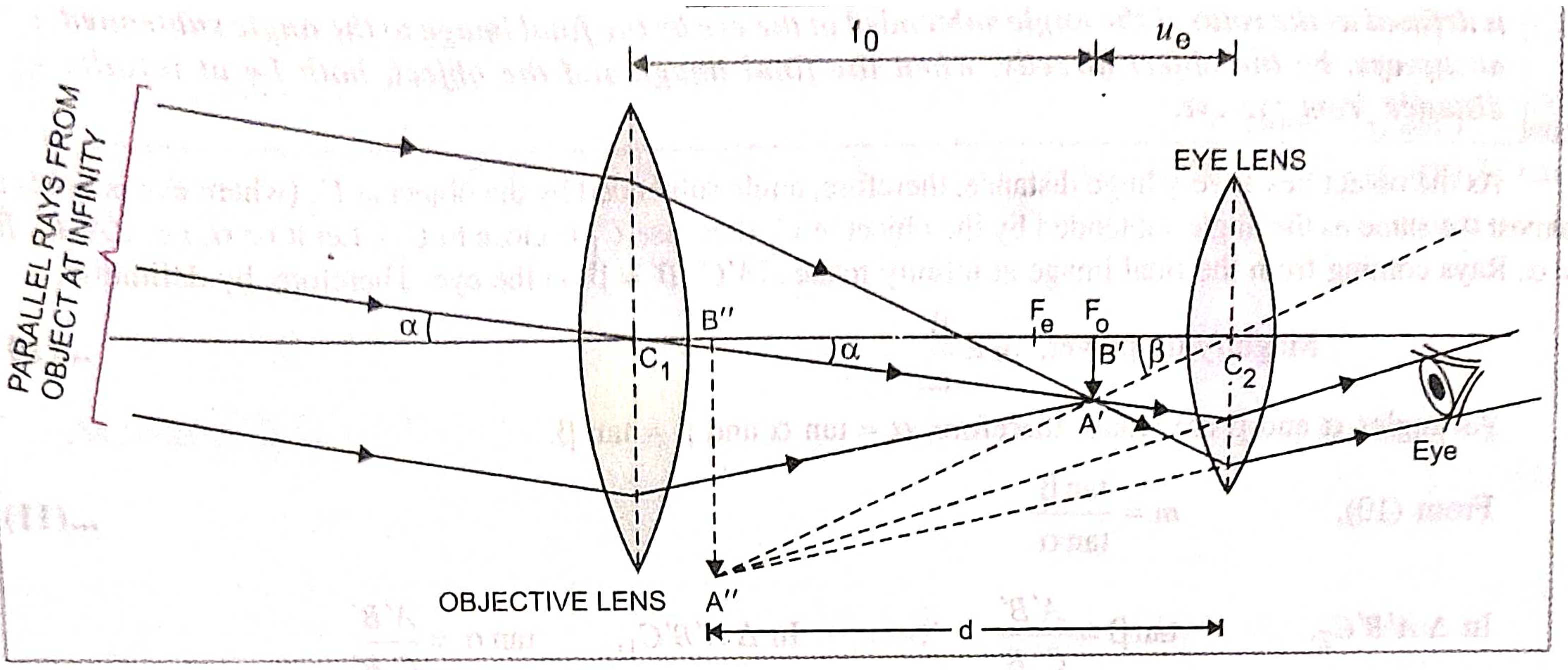
Limitations of refracting type telescope :-

(i) Defects of spherical and chromatic aberrations in single lenses used as objective and eye piece.

(ii) Objective lenses of very large aperture are difficult to manufacture and handle.



PARALLEL RAYS FROM OBJECT AT INFINITY
OBJECTIVE LENS
EYE LENS
α
α
C_1
F_o, F_e
B′
β
C_2
A′
Eye
FINAL IMAGE AT INFINITY
f_o
f_e



PARALLEL RAYS FROM OBJECT AT INFINITY
f_0
u_e
EYE LENS
α
B''
α
F_e
F_o
B'
β
C_1
C_2
A'
Eye
OBJECTIVE LENS
A''
d

Reflecting Type Telescope / Cassegrainian Telescopic

It is an improvement over refracting type astronomical telescope. Here, objective lens gets replaced by a concave parabolic mirror of large aperture which is free from chromatic and spherical aberrations. Image formed is much brighter. This telescope has high resolving power.

Newton designed it initially to observe distant stars.
Guillaume Cassegrain designed Cassegrainian type telescope.

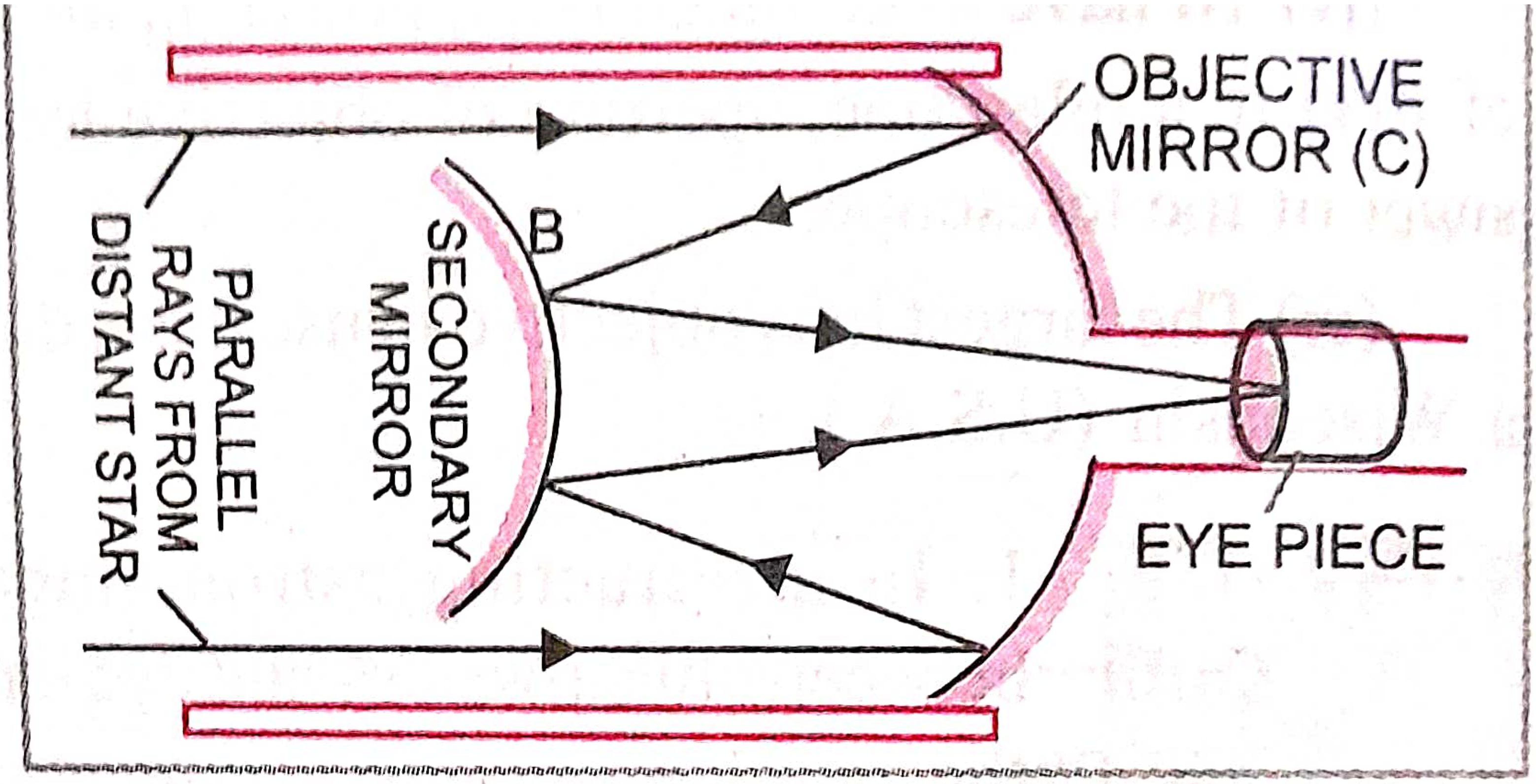
C is a parabolic concave reflector of about 200 inch aperture with a narrow hole at the centre. Parallel rays from a distant star entering the telescope in a direction parallel to principal axis of mirror tend to collect at focus of mirror. But these reflected rays encounter a secondary convex mirror B before metting at focus.
The convex mirror reflects them onto eye piece.
Final image is seen through eye piece.
Final image is inverted w.r.t. the object.

In normal adjustment, magnifying power $= m = \frac{f_o}{f_e} = \frac{(R/2)}{f_e}$ and

R is the radius of curvature of concave reflector.

→ The largest reflecting type cassegranian telescope in India is in Kavalur, Tamil Nadu. The diameter of objective concave mirror is 2.34 m.

→ The largest reflecting type telescope in the world is in Hawaii, USA. The concave mirror used in each of the pair of telescopes has a diameter of 10 m.


OBJECTIVE
MIRROR (C)
B
SECONDARY
MIRROR
PARALLEL
RAYS FROM
DISTANT STAR
EYE PIECE

Newtonian Reflecting Type Telescope:

The parallel beam of light coming from the distant star is reflected by large parabolic concave reflector C on to a plane mirror M. This mirror is inclined at an angle of 45° to the axis of C. The plane mirror reflects the beam forming a real image I in front of eye piece E.

The eye piece acts as a magnifier and the final, virtual, magnified image of the star is distinctly seen by the eye.

Advantages of Reflecting Type Telescope:

(i) There is no chromatic aberration as the objective is mirror.

(ii) Spherical aberration is reduced using objective mirror in paraboloid form.

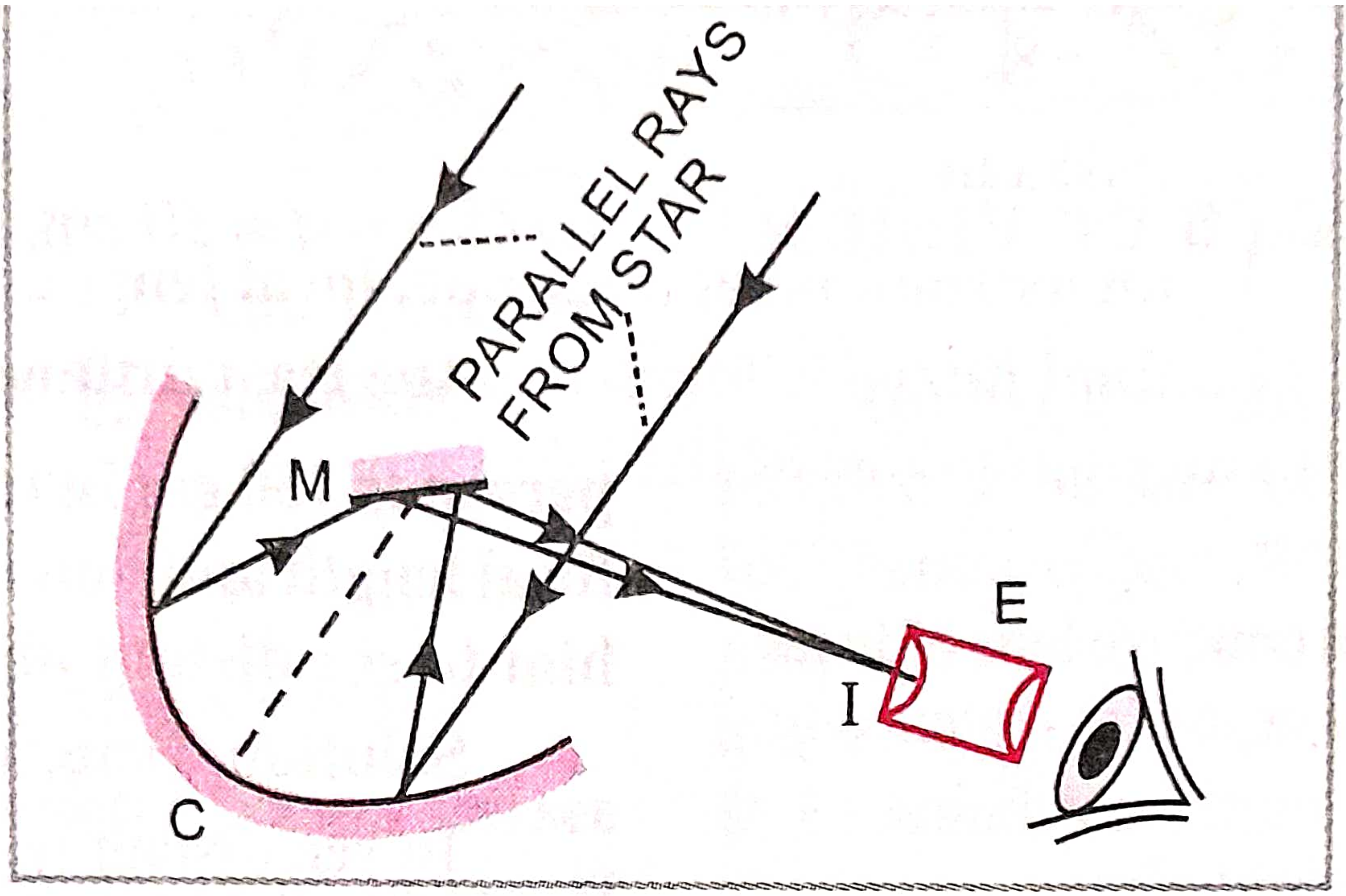
(iii) Image is brighter compared to that in refracting type telescope.

(iv) Mirror requires grinding and polishing of only one side.

(v) High resolution is achieved by using a mirror of large aperture.

(vi) A mirror weighs much less than a lens of equivalent optical quality. So, mechanical support of mirror is much less of a problem.

(vii) Mirror can be supported over its entire back surface unlike a lens which is supported over the rim only.



PARALLEL RAYS
FROM STAR
M
E
I
C

(e) Eyepieces

The image formed by a single lens form two main defects:-
(i) chromatic aberration (ii) spherical aberration

Chromatic aberration is caused by differences in refractive index for different wavelengths of light.

Spherical aberration occurs when light rays pass through a spherical lens near the edge.
Spherical aberration can be reduced by reducing the aperture of lens but at the same time field of view is reduced. In order to increase the field of view and to reduce chromatic and spherical aberrations, an eyepiece is used.

Eye piece consists of two convex lenses separated by a certain distance. So, eye piece is primarily a magnifier designed to give more perfect image than obtained by a single lens.

The lens towards the object is known as field lens. It has large aperture to increase field of view. The lens which is towards the eye is known as eye lens. It mainly magnifies the image.
To reduce the spherical aberration, the lenses taken are plano-convex lenses. Commonly two eyepieces are used.

Ramsden's Eyepiece

It consists of two plano - convex lenses each of focal length (f) separated by a distance equal to (2f/3).

The conditions of minimum chromatic and spherical aberrations are not satisfied but spherical aberration is reduced by taking plano convex lenses and placing their convex surfaces facing each other.

Focal length be F of equivalent lens.

$$\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f_2} - \frac{d}{f_1 f_2} \Rightarrow \frac{1}{F} = \frac{1}{f} + \frac{1}{f} - \frac{2f}{3(f \times f)}$$

$$\Rightarrow \frac{1}{F} = \frac{2}{f} - \frac{2}{3f} = \frac{4}{3f} \Rightarrow \boxed{F = \frac{3}{4}f}$$

Gaussian Eyepiece

It is a modification of Ramsden's Eyepiece.
It has a field lens and eye lens having equal focal length (f) separated by a distance equal to ($2/3 f$). A thin glass plate G inclined at angle (45°) to the axis of lens system is placed between the field lens and eye lens to illuminate the field of view.

Light from source S enters the tube from opening and reflects from glass plate G along the axis towards objective of telescope and illuminates field of view. Cross wire C is kept at a distance ($f/4$) in front of field lens like Ramsden's eyepiece.

Uses :-

The eye piece is often used in spectrometer telescopes and helps to focus the telescope and collimator of spectrometer for parallel rays and adjusting the axis of telescope and microscope perpendicular to the axis of the instrument.

(f) Optical Levelling And Focusing of Spectrometer For Emitting And Receiving Parallel Rays

1. FOCUSING THE TELESCOPE :-

Focus the telescope for parallel rays from distant object by sliding eyepiece looking through telescope in and out, until a sharp image of object is seen.

2. LEVELLING THE COLLIMATOR :-

Place the spirit level on the collimator tube with its axis parallel to axis of tube. If the bubble in the collimator is found to be displaced from its central position, turn the levelling screws provided with the collimator tube, in the same direction to bring the bubble back to its central position. This makes the axis of collimator tube horizontal.

3. LEVELLING OF PRISM TABLE :-

There are three levelling screws just below the prism table for levelling. There are parallel lines drawn on prism table parallel to the line joining two of the screws. Place the spirit level parallel to these lines and bring the bubble to central position by turning these two screws equally in opposite directions.

Now place the spirit level perpendicular to these lines. If the bubble is not in central position, then turn that remaining third screw alone to bring bubble in central position.

Continue above process a few times until bubble is in centre in both positions. This will make table vertical to axis of rotation.

4. FOCUSING THE COLLIMATOR :-

Place a discharge lamp in front of spectrometer and turn the telescope until it is in line with and pointing directly at the collimator. Looking through the telescope and adjusting position of focusing screw on collimator until a sharp image of slit is observed in telescope. Collimator gives parallel rays to fall on prism.

(g) Constant Deviation Spectrometer

The collimator and telescope are fixed and axes are perpendicular to each other. The prism table can be rotated about the vertical axis using a drum which is attached to the table. The head of the drum is calibrated for the wavelength and thus wavelength can be measured directly.
When light is incident on the prism, the prism table can be rotated till angles of incidence and emergence are equal. The pointer seen in field of view of telescope can be used for measurement. After clamping the prism, the drumhead is rotated to rotate the prism table and desired wavelength is measured.

Benefit :- An ordinary prism and a spectrometer can be used for this task, but the process will be time consuming. The adjustment of minimum deviation and if it is disturbed, resetting is troublesome.
So, in case of constant deviation spectrometer, if the prism is disturbed it can easily get reset by using a source of known wavelength.

Prism Formula

In fig 6(c).2, ABC is principal section of a prism with angle of prism = A
KL light is incident on AB face at ($\angle i_1$).
It reflects along LM at ($\angle r_1$) bending towards normal N_1O.
Refracted ray LM is incident at ($\angle r_2$) on AC face. It bends away from normal N_2O and emerges along MN at ($\angle i_2$)
$\angle QPN = \delta$ = angle of deviation

Deviation on face AB = $\delta_1 = i_1 - r_1$ (clockwise)
Deviation on face AC = $\delta_2 = i_2 - r_2$ (clockwise)
Total deviation = $\delta = \delta_1 + \delta_2 = (i_1 + i_2) - (r_1 + r_2)$
in ΔALM :- $A + (90° - r_1) + (90° - r_2) = 180° \Rightarrow A = (r_1 + r_2)$

$\therefore \delta = (i_1 + i_2) - A$

Snell's Law at L :- $\frac{\sin i_1}{\sin r_1} = (\mu)$; Snell's Law at M :- $\frac{\sin r_2}{\sin i_2} = \frac{1}{\mu}$

μ = refractive index of material

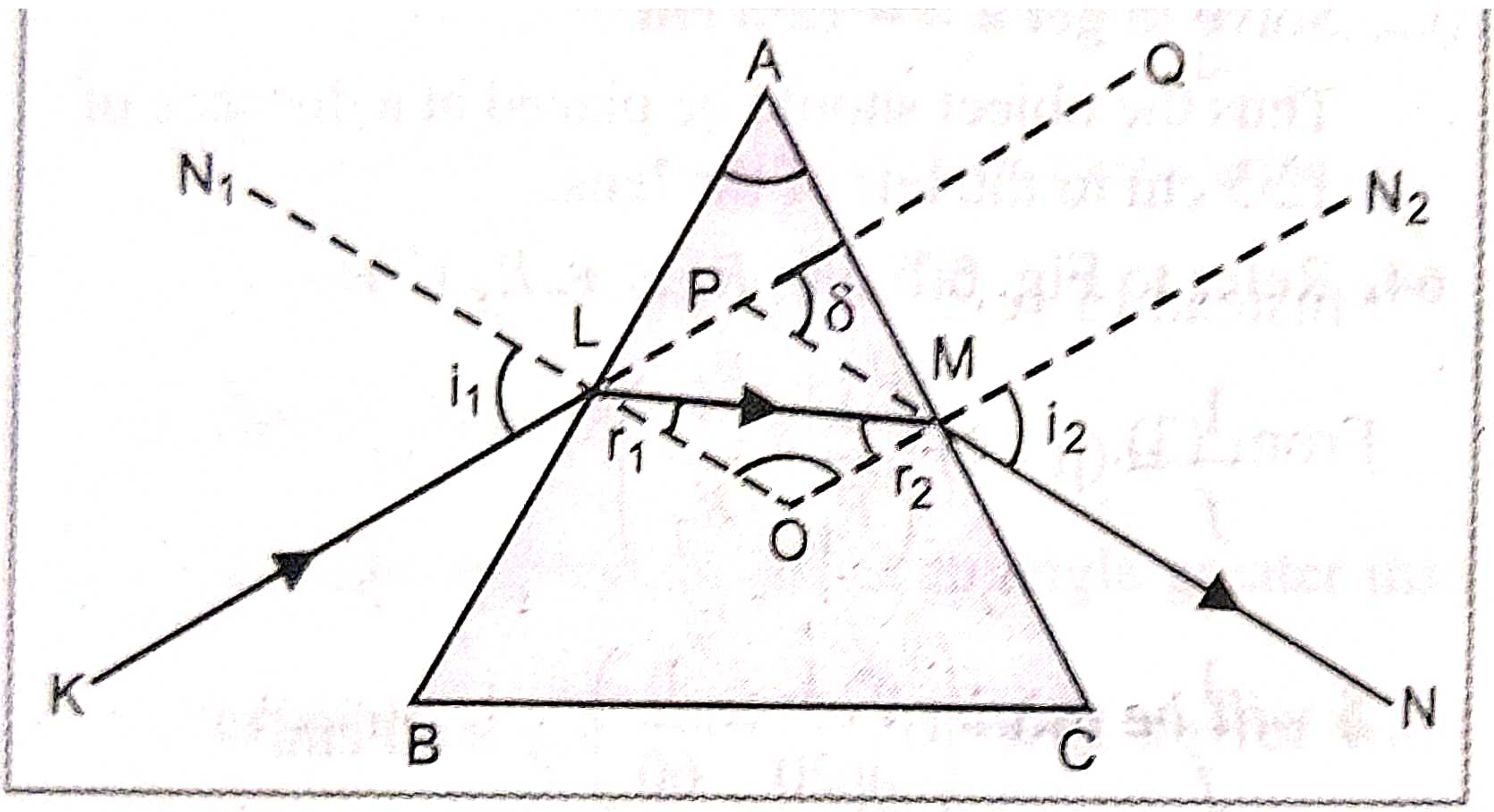
At minimum deviation, there is only one angle of incidence :-
$\delta = \delta_{min}$ and $\angle i_1 = \angle i_2 = \angle i$

$\therefore \frac{\sin i_1}{\sin r_1} = \mu = \frac{\sin i_2}{\sin r_2} \Rightarrow \angle r_1 = \angle r_2 = \angle r$

$\therefore A = r + r = 2r \Rightarrow r = (A/2)$

$\therefore \delta_{min} = 2i - A \Rightarrow i = \frac{\delta_{min} + A}{2}$ and $\mu = \frac{\sin i}{\sin r}$

$$\therefore \mu = \frac{\sin\left(\frac{A + \delta_{min}}{2}\right)}{\sin(A/2)}$$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