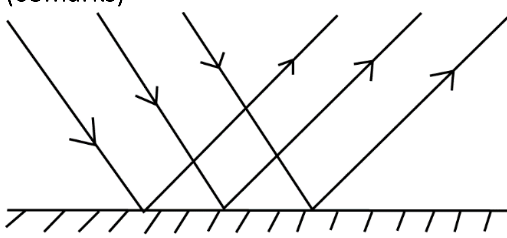
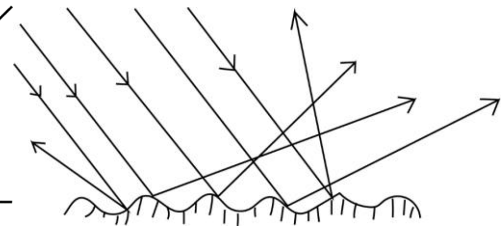
1. (a) (i) With the ais of digrams, differentiatebetween regular and irregular refelection (03marks)



Regular reflection



Irregular reflection

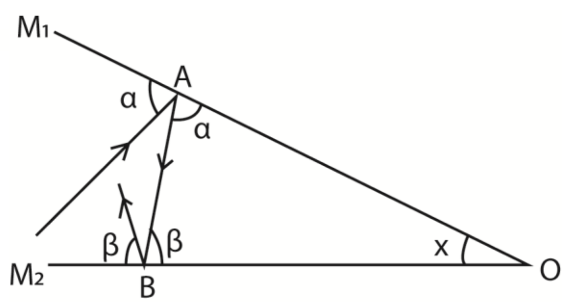
Differences between regular and irregular reflection

Regular reflection	Irregular reflection
Occurs on smooth surface	Occurs on a rough surface
Parallel incident beam is reflected parallel	Parallel incident beam is scattered after reflection
Reflected beam is very bright	Reflected beam is dull

(ii) Show that if two plane mirrors are inclined at an angle, x, then the total deviation of a light ray produced is 2x after reflection once in each mirror. (03 marks)

Deviation by successive reflections at two inclined mirrors

Consider an incident ray of light reflected successively from two mirrors M_1 and M_2 inclined at an angle x to each other at O as shown



Let the glancing angle at and B be α and β respectively

Deviation by $M_1 = 2\alpha$ (clockwise direction)

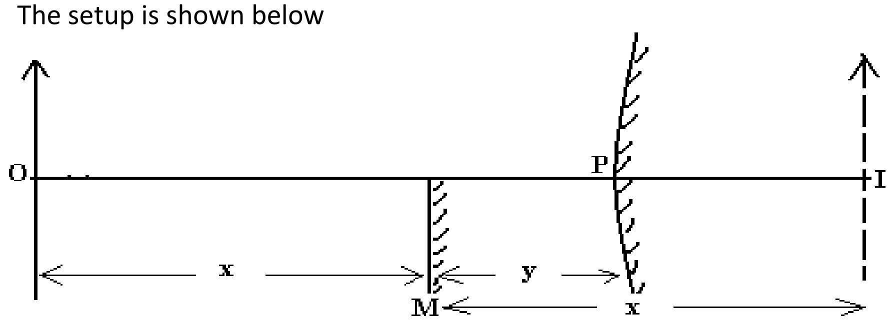
Deviation by $M_2 = 2\beta$ (clockwise direction)
Total deviation $= 2\alpha + 2\beta$
$= 2(\alpha + \beta)$ …………………. (i)
But $\alpha + \beta + x = 180$ (Angle sum of a triangle)
$\alpha + \beta = 180 - x$ ……………………..(ii)
Combining (i) and (ii)
Total deviation = $2(180 - x)$ (clockwise)
$= 360 - 2x$ (clockwise)

$= 2x$ (anticlockwise)

Thus, the deviation produced by two inclined mirrors is twice the angle between the mirrors when a ray under goes two successive reflections.

(b) Describe an experiment to determine the focal length of a convex mirror using a plane mirror and a pin. (04marks)

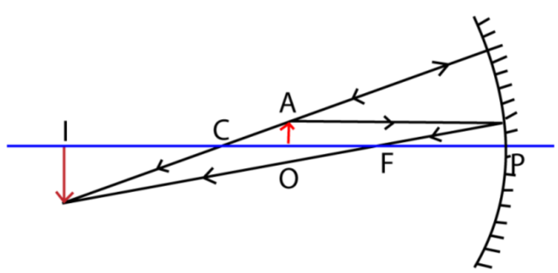
The setup is shown below



(i) An object pin **O** is placed in front of a convex mirror as shown in the diagram above
(ii) A virtual diminished image is formed at **I**.
(iii) A plane mirror **M** is placed between **O** and **P** so as to intercept half the field of view of the convex mirror.
(iv) Mirror **M** is adjusted until its own image of **O** coincides with **I** by no parallax method.
(v) Measure the distances **x** and **y.**
(vi) The focal length of the mirror is calculated from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Where u = (x + y) and v = (y-x)

(c) (i) Sketch a ray diagram to show how a concave mirror forms a magnified real image of a real object. (02marks)



Note that the object is between F and C while the image is real and inverted beyond C

(ii) A concave mirror of radius of curvanture 48cm produces a real image whose size is three times that of the object,. Determine the position of th object.m(02marks)

$\frac{u}{f} = 1 + \frac{1}{m}$

⇨ $\frac{u}{24} = 1 + \frac{1}{3}$

⇨ u = 32cm

Or

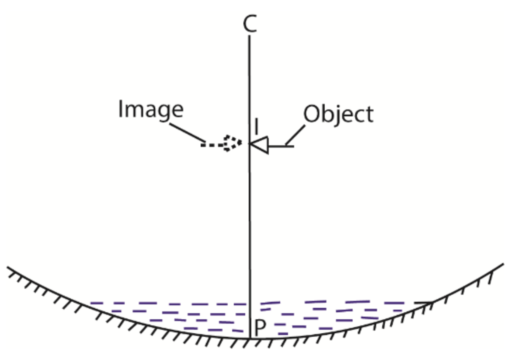
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

⇨ $\frac{1}{24} = \frac{1}{u} + \frac{1}{3u}$

⇨ u = 32cm

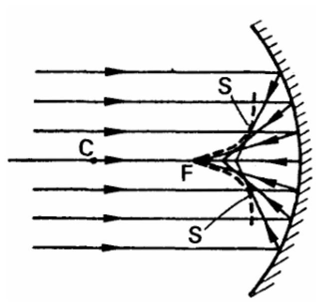
(d) Describe an experiment to determine the refractive index of a liuid using a concave mirror. (04marks)

An experiment to determine refractive index of a liquid using a concave mirror



- A concave mirror is placed on a horizontal table with its reflecting surface facing upwards.
- A clamped pin with its tip along the principal axis above the concave mirror is coincided with its image at C and distance PC is measured
- A small quantity of the liquid under test is poured into a concave mirror and a new point I at which the object pin coincides with its image is obtained.
- Distance IP is measured.
- The required refractive index of a liquid, $\boldsymbol{n_l} = \frac{\boldsymbol{PC}}{\boldsymbol{IP}}$

(e) Explain the meaning of a caustic curve. (02 marks)
When a wide parallel beam of light is incident on a converging mirror, the reflected rays converge at different points along the axis of the mirror. A curve, S, called a caustic curve, with an apex or cusp at principal focus, F is formed which passes through the points of intersection of the reflected and incident rays.



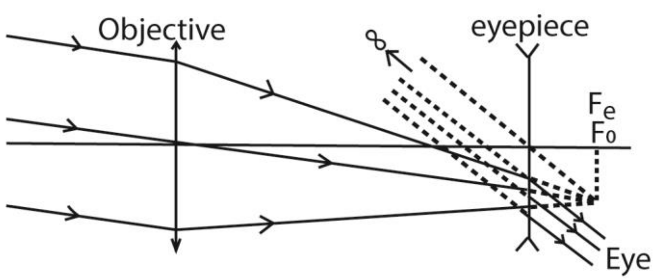
2. (a)(i) What is meant by visual angle? (01 mark)

Visual angle is the angle subtended by an object or image at the eye.

(ii) An observer viewa a series of electric poles in a straight line. Explain why the pole nearer the observer appears taller than the rest. (03marks)

The apparent size of an object or image is proportiona to thevisual angle. An object nearer the eye subtends a larger angle at the eye than a distant one, hence a nearer pole appears taller.

(b)(i) With the aid of a ray-diagram, describe how a telescope consisting of a convex lens and a concave lens can be adjusted to form a final imageat infinity. (05 marks)



The objective lens is arranged with the eyepiece such that their principal foci coincide. The objective foorms a realimage of a distant object on their common focal point Or at its principal focus, and the eyepiece forms a final virtual image at infinity.

(ii) What are the advantages and limitations of a telescope in (b)(i) (02marks)

Advantages

- It forms an upright image
- It is short and portable.

Limitation

- Has virtual eye ring
- Has a narrow field of view
- Form less bright and less clear image

(c)(i) Describe how you can modify an astronomical telescope to produce an erect image at infinity.(02marks)

A convex lens isinserted between the objective and eyepiece such that it fo +2f from objective and fe + 2f from the eyepiece.

(ii) Give two majr disadvantages of the modification. (01marks)

- It decreases the brightness of the final image
- It make the telescope long and bulky
- It gives a narrow field of view.

(d) The objective of an astronomical telescope in normal adjustment has a diameter of 20cm and a focal length of 200cm. The eye-piece has a focal length of 2cm. Calculate the;

(i) magnifying power of the telescope (02marks)

$m = \frac{f_0}{f_e} = \frac{200}{2} = 100$

(ii) position of the eye-ring (02marks)

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

$\frac{1}{2} = \frac{1}{202} + \frac{1}{v}$

⇨ v = 2.02cm

(iii) diameter of the eye-ring (02marks)

Linear magnification of eyepiece, $m = \frac{v}{u} = \frac{D_e}{D_o}$

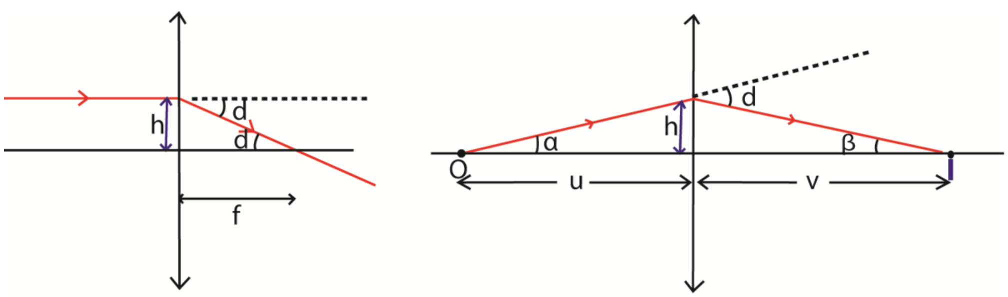
$\frac{2.02}{202} = \frac{D_e}{20}$

De = 0.2cm

3. (a) (i) derive the relationship, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ for convex lens, where u is the object distance, v is the image distance and f is the focal length of the lens. (04marks)

Solution

Consider in each case a ray incident on the same lens at a small height **h** above the principal axis as shown:



(i) (ii)

From Fig (i), the ray parallel and close to principal axis is converged to the focal point **F** and suffer a **small** deviation **d**

where **d** ≈ tan d = $\frac{h}{f}$---------------------------------- (i)

From Fig (ii), the ray from a point object **O** suffers the same small deviation **D** to give rise to a point image **I**.

From geometry, d = α + β where $\alpha \approx \tan\alpha = \frac{h}{u}$ and $\beta \approx \tan\beta = \frac{h}{v}$

$$d = \frac{h}{u} + \frac{h}{v} \quad \text{------------------------------ (ii)}$$

Equating equations (i) and (ii) gives

$$\frac{h}{f} = \frac{h}{u} + \frac{h}{v}$$

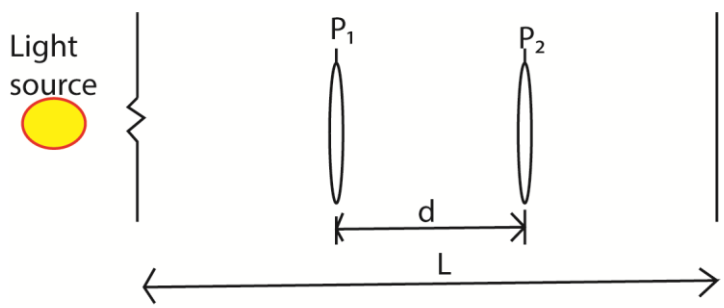
Thus $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

(ii) State three possible reasons under which an image of real object may not be formed by a convex lens on the screen. (03marks)

- When the object is placed between the lens and optical center.
- When the distance between the object and the screen is four times the focal length of the lens
- When the object is at the principal focus
- When the screen is between the lens and its principal focus.
-

(b) Describe an experiment to determine the focal length of a convex lens fixed inside a short cylindrical tube (05marks)

Solution
Illustration



- The tube is placed between an illuminated object and a screen a distance l slightly more than 4 times the approximate focal length of a lens to form a clear magnified image at the screen. The position of the front part P_1 is noted

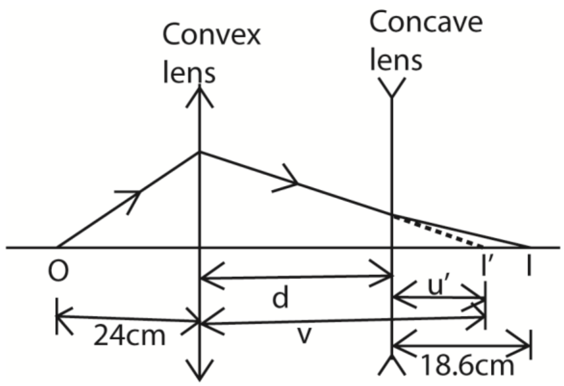
- The tube is moved towards the screen until a clear diminished image is formed on the screen and position P_2 of the front part is noted

- The displacement, $d = P_2 - P_1$ is noted

  The focal length, f of the lens = $\frac{l^2-d^2}{4l}$

(c) A convex lens of focal length 10cm is arranged coaxially with a concave lens of focal length 18cm. the lens system is used to focus an object placed 24cm from the convex lens on the side remote from the concave lens. the final image is formed on a screen placed 18.6cm from the concave lens. Calculate the;

(i) separation between the lenses. (05marks)



Let the separation between the lenses be d.

For convex lens

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

$\frac{1}{10} = \frac{1}{24} + \frac{1}{v}$; v = 17.14cm

For concave lens

$\frac{1}{-18} = \frac{1}{u'} + \frac{1}{18.6}$, u' = -9.15cm (-ve because object is virtual)

Separation, d = v-u' = 17.14 – 9.15 = 7.99cm

(ii) Magnification (03marks)

$M = M_1 \times M_2$

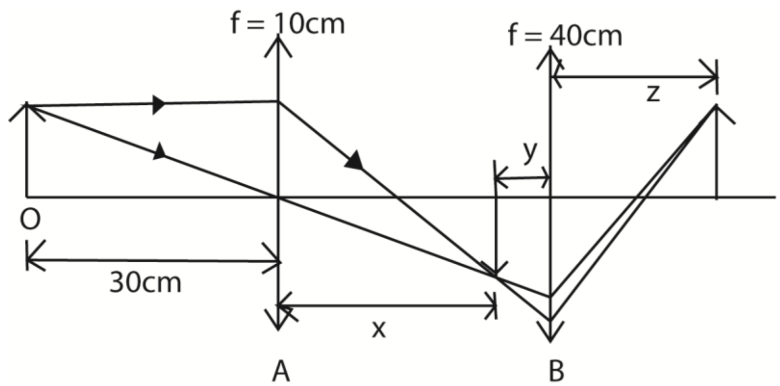
$= \frac{v}{u} x \frac{V'}{u'}$

$= \frac{17.14}{24} x \frac{18.6}{9.15}$ = 1.45

4. (a) (i) State the laws of refraction of light. (02marks)
   - The incident ray, refracted ray and the normal at the point of incidence all lie in the same plane
   - The ratio of the angle of incidence to the sine of angle of refraction is constant for a given pair of media.

   (ii) A small object is placed at a distance of 30.0cm from a converging lens of focal length 10.0cm. Calculate the distance from the first lens where a second converging lens of focal length

40.0cm must be placed in order to produce an erect image of the same size as the object. (05marks)



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

$\frac{1}{10} = \frac{1}{30} + \frac{1}{x}$; x = 15cm

Magnification, $M_1 = \frac{v}{u} = \frac{15}{30} = \frac{1}{2}$

Magnification, $M_2 = \frac{z}{y}$

But m = M_1 x M_2

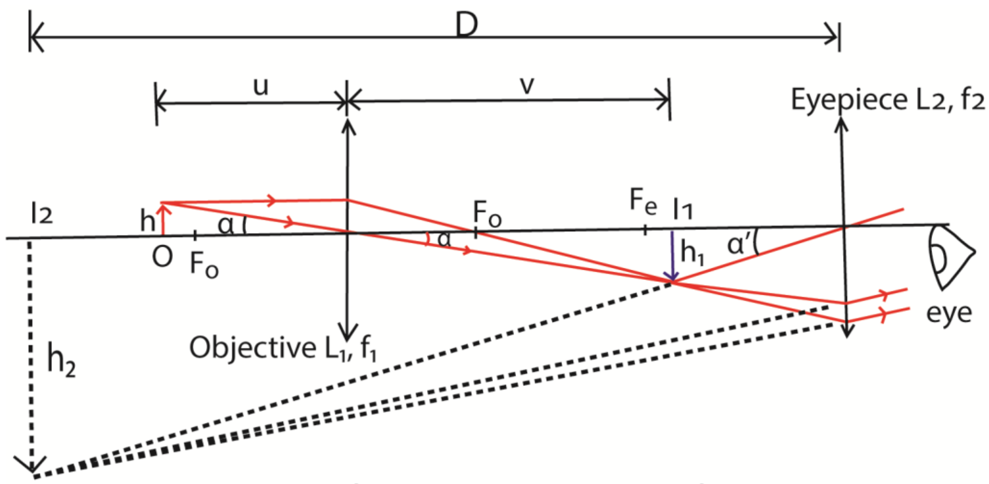
$1 = \frac{1}{2} x \frac{z}{y}$; z = 2y

Action of second lens

$\frac{1}{40} = \frac{1}{y} + \frac{1}{2y}$; y =60cm

Position = x + y= 15 + 60 = 75cm from the first lens

(b) (i) Draw a diagram to show the formation of an image by a compound microscope in normal adjustment and use it to derive an expression for the magnifying power. (06marks)



Compound microscope in normal use

Linear magnification can also be expressed as, m = $\frac{h_2}{h} x \frac{h}{h_1}$ = m_e x m_o.

Where, m_e and m_o are linear magnifications of the eye piece and objective lenses respectively.

$m_o = \frac{v}{f_0} - 1$ and me = $\frac{-D}{fe} - 1$

$m = (\frac{-D}{fe} - 1)\ (\frac{v}{f_0} - 1)$

(ii) A microscope has an objective of focal length 10.0cm and eye piece of focal length 20.0cm. If the distance between the objective and eye piece is 20 cm, calculate the magnifying power of the microscope. (03marks)

Given, f_0 = 10cm, f_e = 20, D = -25cm

$v_0 + v_e$ = 20.0cm

Using eye piece lens;

$\frac{1}{fe} = \frac{1}{u_e} + \frac{1}{D}$

$\frac{1}{20} = \frac{1}{u_e} + \frac{1}{-25}$

$u_e = 11.11$

$v_o + u_e = 20$

v_0 = 20 – 11.11 = 8.89cm

Using m = $(\frac{-D}{fe} - 1)\ (\frac{v}{f_0} - 1) = \left(\frac{-25}{20} - 1\right)\left(\frac{8.89}{10} - 1\right)$ = 0.2475

(c) What is meant by the following:

(i) total internal reflection (01mark)

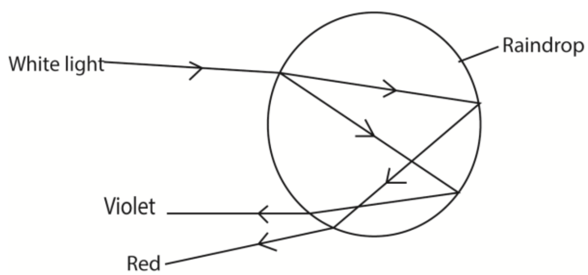
Total internal reflection is the bouncing back of all incident light into the more dense medium when the angle of incidence exceeds the critical angle for a ray originally travelling from the more dense to a lens dense medium.

(ii) critical angle (01mark)

Critical angle is the angle of incidence in more optically denser medium for which the angle of refraction in the less dense medium is 90^0.

(d) Briefly explain why an observer sees a spectrum of colors through rain drops when it is raining on a sunny day. (02marks)

White light from the sun undergoes dispersion as it enter into the rain drops of water in the sky. Total internal reflection takes place at the opposite side of the rain drop and different colors emerge from the raindrop after refraction. Hence the observer sees a spectrum of colors through raindrops when it is raining on sunny day.



5. (a) Define the following as applied to telescope

(i) Eye-ring (01marks)

Eye-ring of a telescope is the image of objective formed by the eyepiece.

(ii) Magnifying power(01mark)

Magnifying power is the ratio of the angle subtended by the final image at the eye when using the telescope to the angle subtended by the object at unaided eye.

(b) What is the significance of the eye-ring of an astronomical telescope? (01mark)

It is the best position for best view in a telescope

(c) State two advantages of a reflecting telescope over a refracting telescope (02marks)

- there is no chromatic aberration
- there is no spherical aberration
- it is relatively cheap since only one face of the objective needs grinding
- Has high resolving power since the objective may have a high field of view.
- The image is brighter.

(d) The figure below shows an optical system consisting of two thin converging lenses arranged coaxially. Lens A has a focal length of 40mm and lens B has a focal length of 375mm. an object O of height 5mm is placed 50mm from A. I_1 is the real image of O and I_2 is the virtual image of I_1 in B and is 250mm from B.

(i) Determine the value of distance, Y of image I_1 from lens A (02marks)

Using $\frac{1}{f} = \frac{1}{u} + \frac{1}{V}$

⇨ $\frac{1}{40} - \frac{1}{50} = \frac{1}{y}$; y = 200mm

(ii) Calculate the distance, x, between the images I_1 and I_2. (02marks)

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

$= \frac{1}{375} - \frac{1}{(-250)}$

u = 150mm

distance x = v-u = 250 – 150 = 100mm

(iii) Find the linear magnification produced by the lens system. (02marks)

$M = M_1 \times M_2 = \frac{200}{50} x \frac{250}{150} = 6.7$

(e) Name one defect of the image formed by a lens and explain how the defect is minimized in practice. (03marks)

(i) Chromatic aberration can be minimized by placing the eye very close to the lens. This insures that images due to different colors subtend the same angle at the eye. Or by use of chromatic doublet in which the dispersion produced by one lens is reversed by another.

Or

(ii) Spherical aberration can be minimized by using a stopper which allows only central rays to form a sharp image. Or by grinding the lens to suitable shape. Or using a narrow aperture

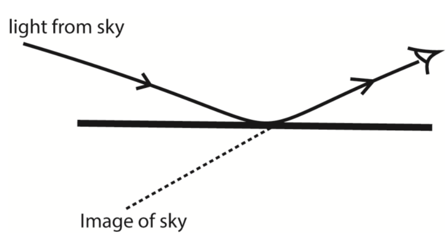
(f) Explain the following

(i) total internal reflection (03marks)

If a ray of light is incident from a denser to less dense medium, there is partial reflection and partial refraction. When the angle of incidence exceeds the critical angle, all the incident light is reflected back into the denser medium. This is called total internal reflection.

(ii) Formation of mirages (03marks)

On a hot day, layer on air near the ground are hotter and lens dense than layers above. This leads to total internal reflection of rays of light from the sky. And mirage is the image of the sky to the eye by total internal reflection

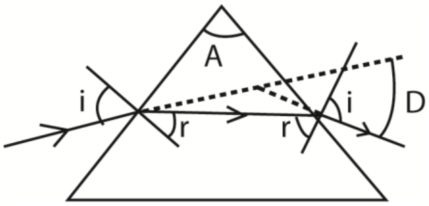


6. (a) State the laws of refraction of light. (02marks)

- The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane

- The ratio of the sine of angle incidence to the angle of refraction is constant for a given pair of the media.

(b) Derive an expression for refractive index of a prism in terms of the refractive angle A and the angle of minimum deviation D. (05marks)



Minimum deviation, D, occurs when a ray passes symmetrically through the prism when the angle of incidence, i, is equal to the angle of emergence as shown above.

D = 2i -2r

But 2r = A, hence, r = $^{A}/_{2}$

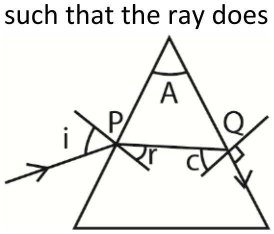
∴ D = 2i – A

⇨ $i = \frac{D+A}{2}$

From Snell's law, n = $\frac{\sin i}{\sin r}$

$$n = \frac{\sin\frac{D+A}{2}}{\sin\frac{A}{2}}$$

(c) A ray of light is refracted through a prism in a plane perpendicular to its edge. The angle of incidence is 30^0 and the refractive index of the prism is 1.50. Calculate the angle of the prism such that the ray does not emerge when it strikes the second face. (05marks)



At P

r = $\sin^{-1}(\frac{\sin 30}{1.5})$ = 19.5^0

At Q

c = sin-1 $(\frac{1}{1.5})$ = 41.8^0

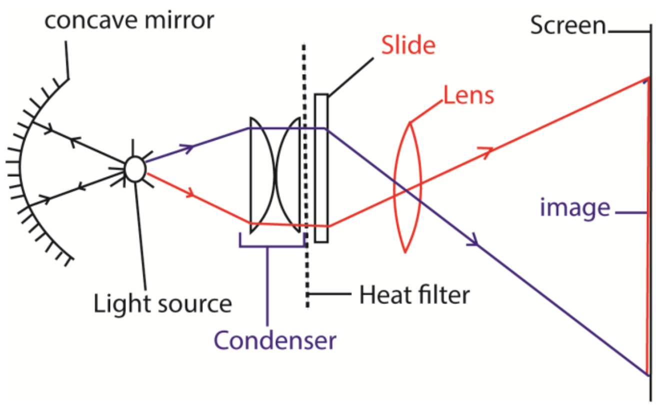
Angle of the prism = c + r = 19.5 + 41.8 = 61.3^0

(d) (i) Describe with the aid of a labelled diagram, the structure and operation of projection lantern. (04marks)

Projection lantern

A **projector** is an instrument used to produce a large image of a small object.

- The slide, or film, is placed behind the **projector** lens outside its focal length and is illuminated buy a small but powerful source of light from concave reflector through condensing lenses.
- A magnified, real and inverted image on the screen



Area magnification = $\frac{Area\ of\ the\ image}{Area\ of\ the\ object}$

(ii) A projector produces an image of area $2m^2$ on a screen placed 5m from the projection lens. If the area of the object slide is $8cm^2$, calculate the focal length of the projection lens. (02marks)

Area magnification = $\frac{Area\ of\ the\ image}{Area\ of\ the\ object} = \frac{2}{8\ x\ 10^{-4}}$ = 2500

Linear magnification = $\sqrt{2500}$ = 50

From M = $\frac{v}{f} - 1$

$50 = \frac{5}{f} - 1$

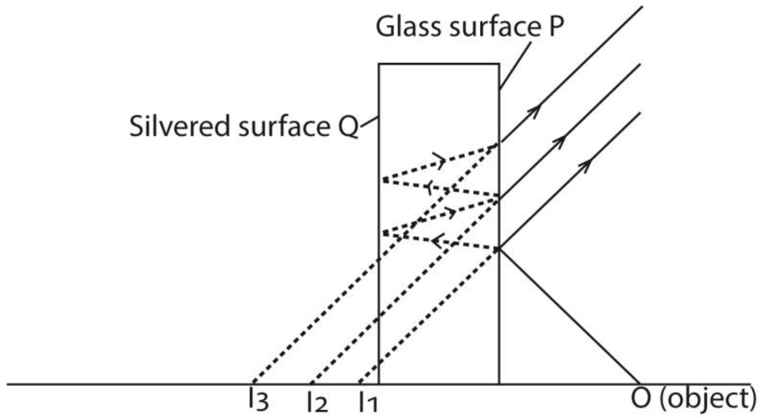
f = $\frac{5}{51}$ = 0.098m = 9.8cm

7. (a) (i) State two differences between real and virtual images (02marks)

A real image is formed by actual intersection of rays and can be formed on a screen while virtual image is formed by apparent intersection of rays and cannot be formed on a screen.

(ii) Explain with the aid of a diagram how thick plane mirror forms multiple images (04marks)

Formation of multiple images in thick plane mirror



Multiple images are formed due to partial reflection and refraction at the non-silvered surface of the mirror.

- İmage I_1 is formed by reflection on the glass surface P
- The image I_2 (the brightest is formed by reflection of the most light on the silvered surface Q
- Others by partial refraction

(b) A convex mirror forms a real image which is three times the linear size of the object. When the object is displaced though a distance y, the real mage formed is four times the linear size of he object. If the distance between the two image positions is 20 cm, find the

(i) focal length of the mirror (03marks)

$M_1 = \frac{v_1}{f} - 1$ and $M_2 = \frac{v_2}{f} - 1$

$M_2 - M_1 = \frac{v_2 - v_1}{f}$

$4 - 3 = \frac{20}{f}$

f = 20cm

(ii) distance, y. (03marks)

Also $\frac{1}{M} = \frac{u}{f} - 1$

$\frac{1}{3} = \frac{u_1}{f} - 1$

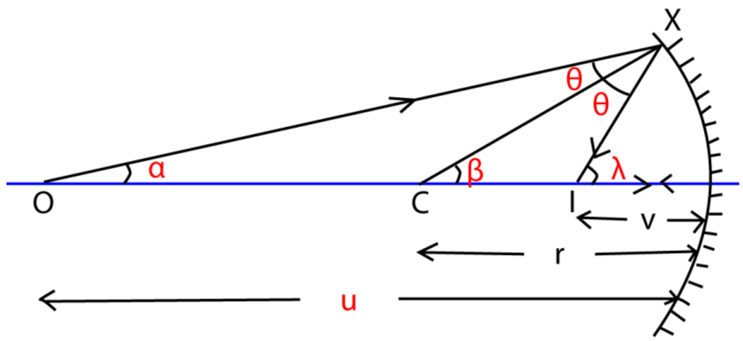
$\frac{1}{4} = \frac{u_2}{f} - 1$

$\frac{1}{3} - \frac{1}{4} = \frac{u_1 - u_2}{f} = \frac{y}{20}$

y = 1.67cm

(c) Use a geometrical ray diagram to derive the relation, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$ for concave mirror. (05marks)

Consider the incidence of ray **OX** on to a concave mirror from a point object **O** placed along the principal axis and then suddenly reflected in the direction XI making an angle ⍰ with the normal CX.



Ray OP strikes the mirror incident normally at P and thus reflected back along its own path. The point of intersection **I** of the two reflected rays is the image position.

From Δ OXC, α + θ = β ………………. (i)

From Δ CXI β + θ = λ ………………… (ii)

Eliminating θ from eqn. (i) and eqn. (ii)

α + λ = 2β ………………………………….. (iii)

If X is very close to P, then

α ≈ tan α = $\frac{XP}{u}$, β ≈ tan β = $\frac{XP}{r}$, λ ≈ tan λ= $\frac{XP}{v}$Equation (a) becomes = $\frac{XP}{u} + \frac{XP}{v} = \frac{2XP}{r}$

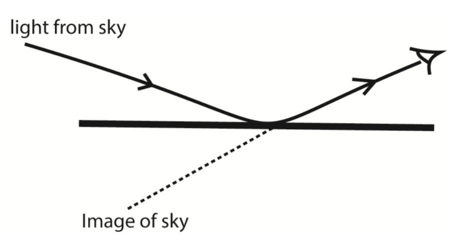
= $\frac{1}{u} + \frac{1}{v} = \frac{2}{r}$

But 2 = 2f

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

(d) Explain how mirage is formed. (03marks)

On a hot day, layer on air near the ground are hotter and lens dense than layers above. This leads to total internal reflection of rays of light from the sky. And mirage is the image of the sky to the eye by total internal reflection



8. (a) Define the following as applied to a converging lens;

(i) Principal focus (01mark)

The principal focus of converging lens is the point on the principal axis to which paraxial rays converge after refraction from the lens.

(ii) center of curvature (01mark)

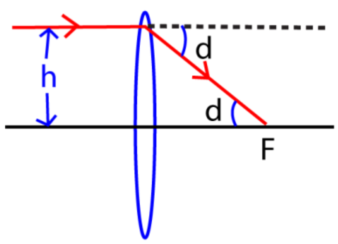
The center of curvature of lens is the center of the sphere of which one of the spherical surfaces of the lens form part.

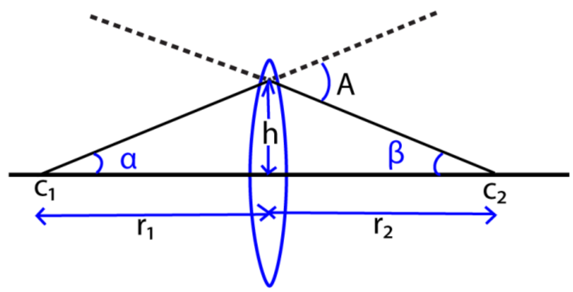
(b) Find the power of a lens of focal length 15 cm (02marks)

Power of lens = $\frac{1}{f(m)} = \frac{1}{0.15}$=6.67D

(c) Derive an expression for focal length of a lens in terms of the radii of curvature of its surfaces and refractive index (05marks)

Consider a ray parallel to the principal axis, incident at height, h.





tan d = $\frac{h}{f}$ d is small in radian, d = $\frac{h}{f}$……………………………….(i)

For small angle prisms d = (n-l)A ………………………. (ii)

From the diagram above, α + β =A ……………………. (iii)

For small angle

$\alpha \approx \tan\alpha = \frac{h}{r_1}$ and $\beta \approx \tan\beta = \frac{h}{r_2}$

Substitution α and β in equation (iii)

$\left(\frac{h}{r_1} + \frac{h}{r_2}\right)$ = A ……………………………………………………… (iv)

Substituting equation (i) and (iv) in equation (ii)

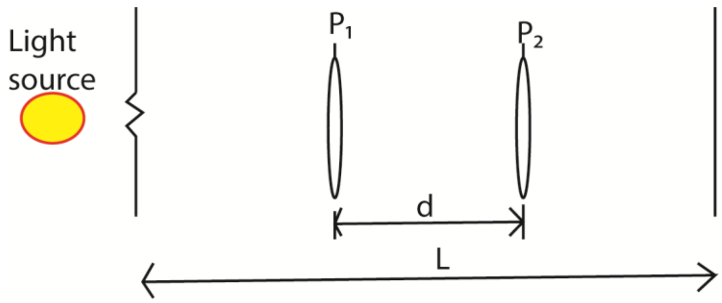
$\frac{h}{f} = (n-1)\left(\frac{h}{r_1} + \frac{h}{r_2}\right)$

Dividing by h

$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$

(d) Describe an experiment to determine the focal length of a thin converging lens mounted inside a short cylindrical tube. (05marks)

Illustration



- The tube is placed between an illuminated object and a screen a distance l slightly more than 4 times the approximate focal length of a lens to form a clear magnified image at the screen. The position of the front part P_1 is noted

- The tube is moved towards the screen until a clear diminished image is formed on the screen and position P_2 of the front part is noted

- The displacement, $d = P_2 – P_1$ is noted

  The focal length, f of the lens $= \frac{l^2 - d^2}{4l}$

(e) A compound microscope consists of two thin lenses, an objective of focal length 1.0cm and eye piece of focal length 5.0cm. The objective forms an image of an object placed in front of it at a point 16.0cm away. If the final image is formed at the near point of the eye, calculate the

(i) Separation of the lenses (03marks)

Consider the eyepiece lens, using $\frac{1}{f} = \frac{1}{u} + \frac{1}{V}$

$\frac{1}{5} = \frac{1}{u_e} + \frac{1}{-25}$; u_e = 4.17m

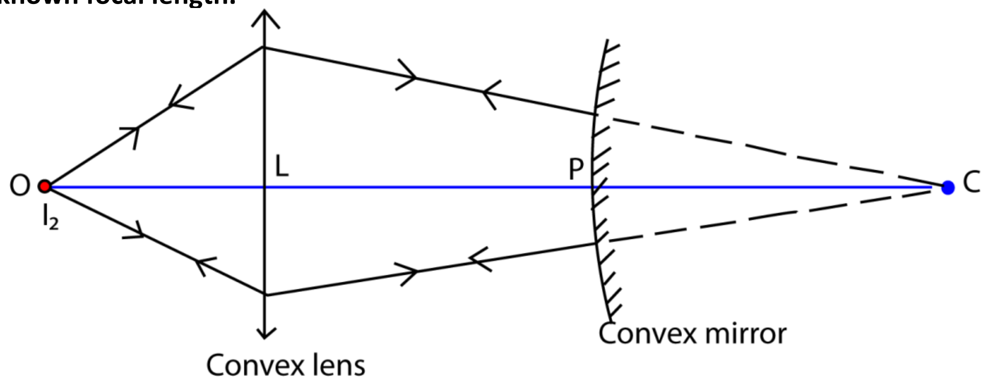
Separation of lenses = $v_0 + u_e$ = 16.0 + 4.17 = 20.17cm

(ii) magnifying power of the instrument (03marks)

M = $\left(\frac{-D}{fe} – 1\right)\left(\frac{v}{f_0} – 1\right) = \left(\frac{-25}{5} – 1\right)\left(\frac{1}{1} – 1\right)$ = -90

9. (a) (i) Describe how the focal length of a convex mirror can be measured using a convex lens of known focal length. (04marks)

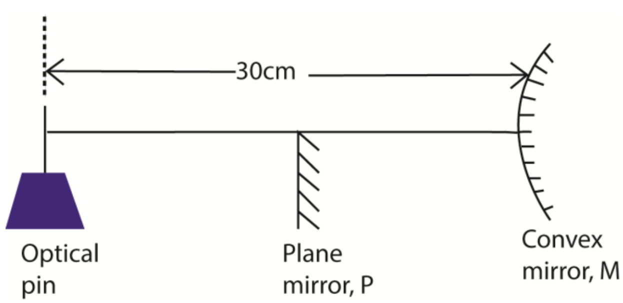
Determination of the focal length of a convex mirror can be measured using a convex lens of known focal length.



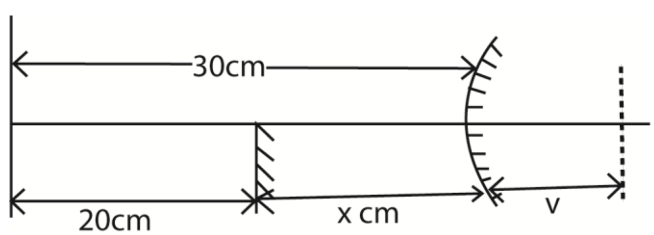
- The apparatus is arranged as shown above
- An object, O is placed in front of a convex lens L and its image formed at C
- The distance LC is measured and recorded.
- The convex mirror whose focal length, f, is required is placed is placed between L and C with its reflecting surface facing the lens.
- The lens is then moved along the axis, OC until a converging beam incident normally on the mirror forms its image at O
- Distance LP is measured

  PC = LC – LP thus, f can be determined from f = $\frac{PC}{2}$

(ii) The plane mirror, P, in the figure below is adjusted to a position20cm from optical pin, the image of the pin in P coincides with its image in M.



Calculate the focal length of the convex mirror. (04marks)



v = 20 – x

= 20 – (30-20) = 10cm

Using $\frac{1}{f} = \frac{1}{u} + \frac{1}{V}$

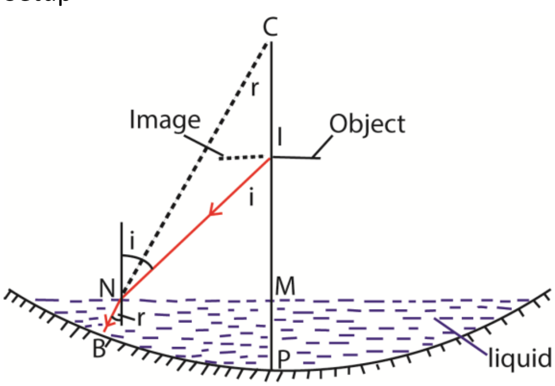
= $\frac{1}{30} + \frac{1}{-10}$

f = 15cm

(b) A pin is clamped horizontally above a concave mirror with its tip along the principal axis. When the pin is adjusted, it coincides with its image at a distance R from the mirror. When a small liquid of refractive index, n, is put on the mirror, the pin again coincides with its image at a distance R' from the mirror. Show that the refractive index, n, is given by

n = $\frac{R}{R'}$ (04marks)

Setup



From n = $\frac{\sin i}{\sin r}$

From the diagram,

sin i = $\frac{NM}{NI}$ and sin r = $\frac{NM}{NC}$

n = $\frac{NM}{NI} \div \frac{NM}{NC} = \frac{NM}{NI} x \frac{NC}{NM} = \frac{NC}{NI}$

For small angle, i, and small liquid

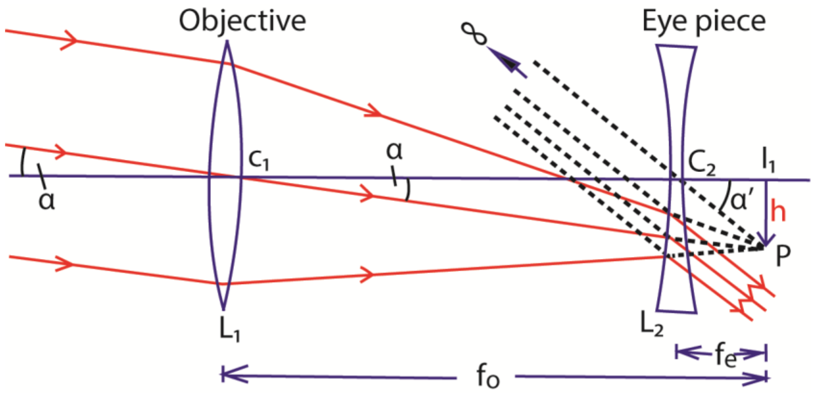
NC $\approx PC = R$ and NI $\approx PI = R'$

Thus, n = $\frac{R}{R'}$

(c)(i) Explain the term eye-ring as applied to the telescope. (02marks)

The eye-ring is the image of objective lens in eyepiece

(ii) Draw a ray diagram to show the formation of final image in Galilean telescope in normal adjustment. (03marks)



Galilean telescope in normal adjustment

(iii) Explain two advantages and one disadvantage of the telescope in (c)(ii) above. (03marks)

Advantages of a Galilean telescope

It forms a final erect image.

It is shorter than the terrestrial and astronomical telescopes because the separation of lenses is

f_0-f_e.

Disadvantages of a Galilean telescope

It has a small field of view.

It has a virtual eye ring not accessible to the observer

10. (a)(i) When does light pass through a prism symmetrically? (01marks)

Light is said to pass through a prism symmetrically when the angle of incidence is equal to the angle of emergence or when minimum deviation occurs.

(ii) Find the angle of incidence, i, on an equilateral prism of refractive index 1.5 placed in air, when light passes through it symmetrically. (03marks)

From Snell's law, $1.5 = \frac{sini}{\sin r}$

But, $r = \frac{A}{2} = \frac{60}{2} = 30^0$

$\text{Sin } i = 1.5\sin 30^0$

$i = 48.6^0$

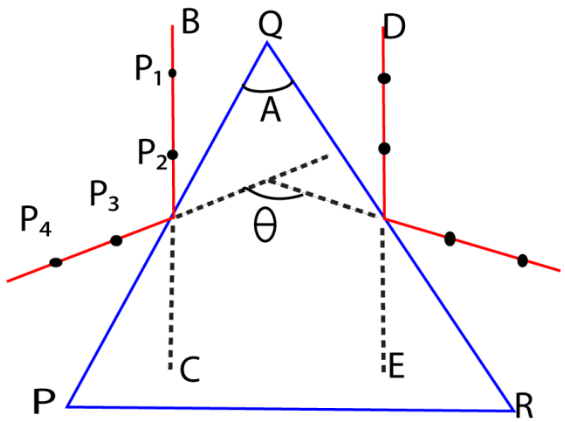
(iii) Describe what happens to the deviation of light passing through a prism in (a) (ii) when the angle of incidence is increased from a value less than i to a value greater than i. (02marks)

Angle of deviation increases when either angle i is increased or decreased.

(b) Describe how the refractive angle of a prism can be determined using optical pins. (05marks)

Using optical pins

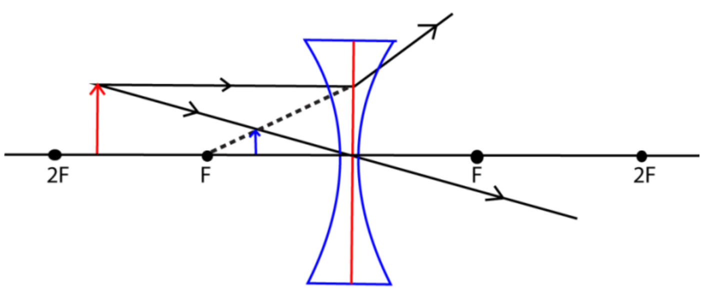
A white paper is stuck to the soft board using top-headed pins. Two parallel lines AB and DC are drawn on the paper and the prism is placed with its apex as shown.



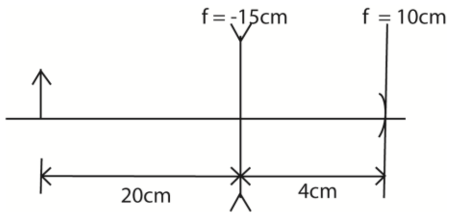
- Two optical pins **P_1** and **P_2** are placed along AB and pins **P_3** and **P_4** are placed such that they appear to be in line with the images of P_1 and **P_2** as seen by reflection from face PQ.
- The procedure is repeated for face QR. The prism is removed and angle θ is measured.

The required refracting angle **A** $= \frac{\theta}{2}$

(c) (i) Draw a sketch ray diagram showing formation of the image of a finite size real object by a concave lens. (02marks)



(ii) A concave lens of focal length 15.0cm is arranged coaxially with a concave mirror of focal length 10.0cm, a distance of 4.0cm apart. An object is placed 20.0cm in from of the lens on the side remote from the mirror. Find the distance of the final image from the lens. (04marks)



Action of concave lens

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{-15} - \frac{1}{20}$

v = $\frac{-60}{7}$ = -8.6cm

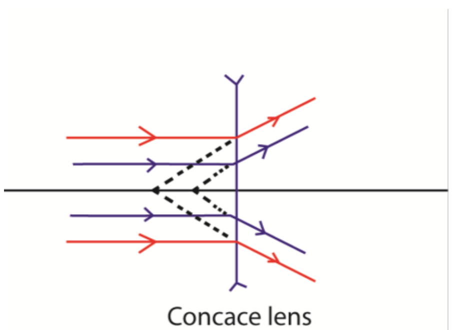
Action of concave mirror

u = 8.6 + 4 = 12.6cm, f = 10

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{1}{10} - \frac{1}{12.6}$; u = 48.5cm

Distance of image from the lens = 48.5- (20 + 4) =24.5 cm on the side remote to the mirror

(d) With the aid of a sketch ray diagram explain spherical aberration in a concave lens, and state how it is minimized. (03marks)

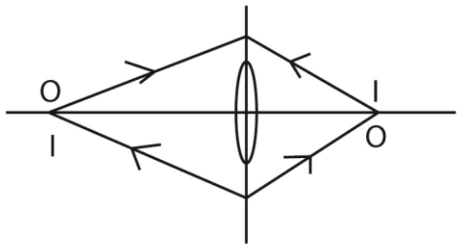


When a wide beam of light falls on the lens, marginal rays are refracted and appear to come from a point different from that of the central rays.

The image formed is thus blurred (distorted). This is called spherical aberration. It is minimized by using an opaque disc with central hole to allow only central rays to pass through

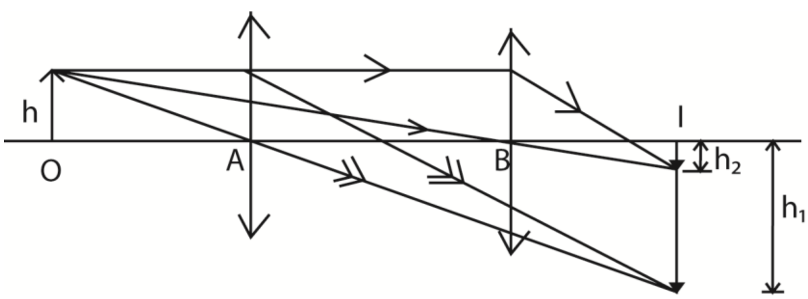
11. (a) Explain what is meant by conjugate points. (02marks)

These are two points, O and I. each on the opposite side of a convex lens such that an object and its image at these points are interchangeable.



(b) A converging lens forms an image of height, h_1 on a screen of an object O of height, h. When the lens is displaced towards the screen, an image of height, h_2 is formed on the screen.

(i) Sketch a ray diagram to show the formation of the images on the screen. (02marks)



(ii) Show that h = $\sqrt{h_1h_2}$ (04marks)

O and I are conjugate points with respect to the lens

OB = AI and OA = BI

At point A, linear magnification, Ma = $\frac{AI}{OA} = \frac{h_1}{h}$ …………………. (i)

At point B, linear magnification, Mb = $\frac{BI}{OB} = \frac{h_2}{h}$ …………………. (ii)

But AI = OB

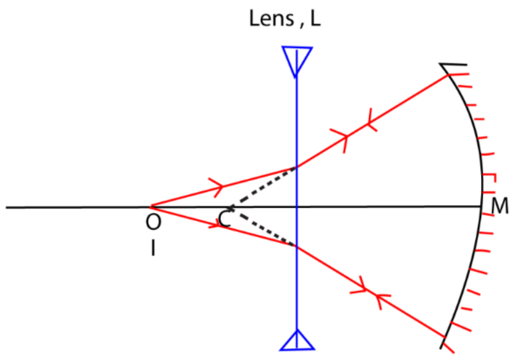
$\frac{h}{h_1} = \frac{h_2}{h}$

$h^2 = h_1h_2$

h =$\sqrt{h_1h_2}$

(c) Describe an experiment to determine focal length of a diverging lens using a concave mirror of known focal length.

Determination of focal length of concave lens using concave mirror.



(i) An illuminated object is placed beyond the center of curvature of a concave mirror of known radius of curvature, r.

(ii) A diverging less L is placed between O and M and its position is adjusted until a clear image I is formed besides O.

(iii) Distance LI and LM are measured and recorded.

(iv) For the lens, object distance, u = -CL = - (r-LM); image distance, v =LI or LO

The focal length, f, is calculated from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

(d) The objective of astronomical telescope in normal adjustment has a diameter of 150mm and focal length of 3.0m. The eyepiece has focal length of 25.0mm. Calculate

(i) the position of the eye ring (03marks)

$u = f_0 + f_e = 3000 + 25 = 3025$mm

$f = f_e = 25$mm

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{25} = \frac{1}{3025} + \frac{1}{v}$; v = 25.2mm

∴ position of eye-ring = 25.2mm

(ii) diameter of the eye-ring (03marks)

Angular magnification, M = $\frac{diameter\ of\ objective}{diameter\ of\ eye-ring} = \frac{f_e}{f_0}$

$$\frac{150}{D_e} = \frac{3000}{25}$$

$D_e = 1.25$mm

(c) Give one advantage of placing the eye at the eye-ring (01mark)

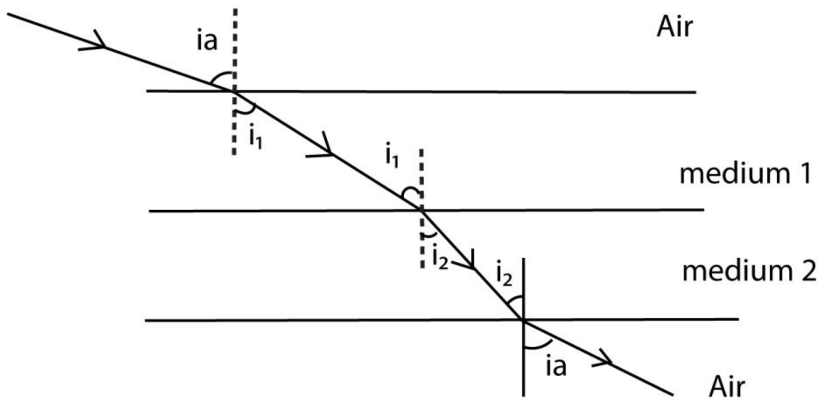
A clearest image is observed.

12. (a) show that for a ray of light passing through layers of transparent media separated by parallel boundaries,

nsini = a

where a is a constant and n is the refractive index of the medium containing angle i. (04marks)

Consider a ray of light moving from air through a series of media **1, 2** and then finally emerge into air as shown.



At air – medium 1 interface, Snell's law gives $\frac{\sin i_a}{\sin i_1} = n_1$

⇨ Sin $i_a = n_1 \sin i_1$ .... (i)

At air – medium 2 interface, Snell's law gives $\frac{\sin i_a}{\sin i_2} = n_2$

⇨ Sin $i_a = n_2 \sin i_2$ .... (ii)

Equating equation (i) and (ii) gives

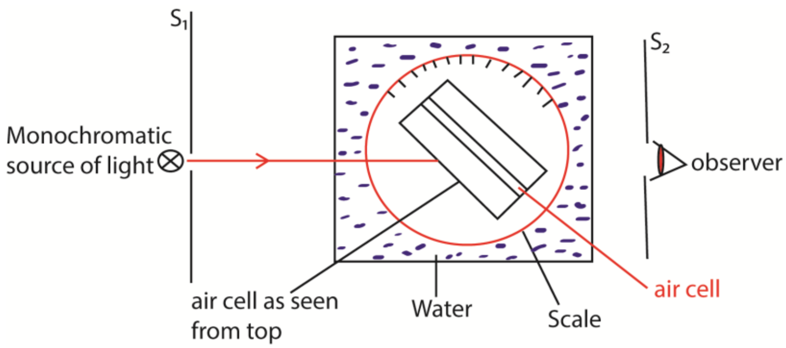
$n_1 \sin i_1 = n_2 \sin i_2$.

∴ **n sin i = a constant.**

(b) (i) What is meant by critical angle? (01mark)

Critical angle is the angle of incidence in a denser medium for which the angle of refraction in a less dense medium is 90^0.

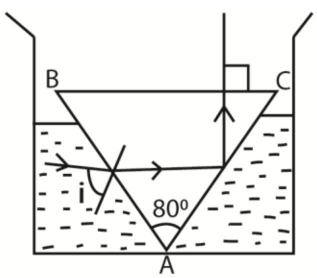
(ii) Describe an experiment to determine the critical angle for a water-air boundary. (05marks)



- The air cell is immersed in water.
- A beam of monochromatic light is directed onto the air cell and then observed through the cell from the opposite side at **E**.
- The cell is then rotated on one side until light is suddenly cut off and the angular position **θ1** is noted.
- The cell is again rotated in the opposite direction until light is suddenly cut off and the angular position **θ2** is noted.

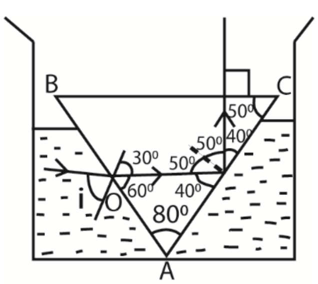
Critical angle, C $=\frac{\theta}{2}$, where **θ** = $\frac{\theta 1+\theta 2}{2}$

(c) The figure below shows an isosceles prism ABC of refractive index 1.51, dipped in a liquid with refractive edge downwards. A ray of light incident on the prism at an angle i = 34.6^0 emerges perpendicularly through the base.



Calculate the refractive index of the liquid (04marks)

Solution



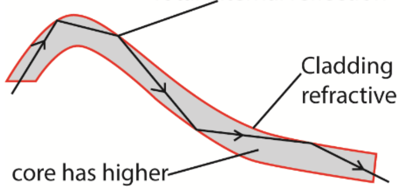
The angles are represented on the diagram above, $r = 30^0$

From nsin i = constant

$n\sin 34.6 = 1.51\sin 30$

$n = 1.33$

(d) Explain how an optical cable transmits light. (03marks)



An optical fiber is made of a transparent material coated with another less optically dense material. Light entering the pipe strikes the boundary of the media at an angle of incidence greater than the critical angle. Total internal reflection thus occurs. This takes place repeatedly in the pipe until the light beam emerges from the pipe.

(e) An optical pin held above a concave mirror containing water of refractive index 1.33, coincides with its image at a distance of 12cm above the mirror. When the water is replaced by a little quantity of a certain liquid, the point of coincidence of the object and the image becomes 13.3cm. Calculate the refractive index of the liquid. (03marks)

Let the radius of curvature of the mirror be r

$\eta_w = \frac{r}{h_w}$ and $\eta_l = \frac{r}{h_l}$

⇨ $\frac{\eta_l}{\eta_w} = \frac{h_w}{h_l}$

⇨ $\frac{\eta_l}{1.33} = \frac{12}{13.3}$

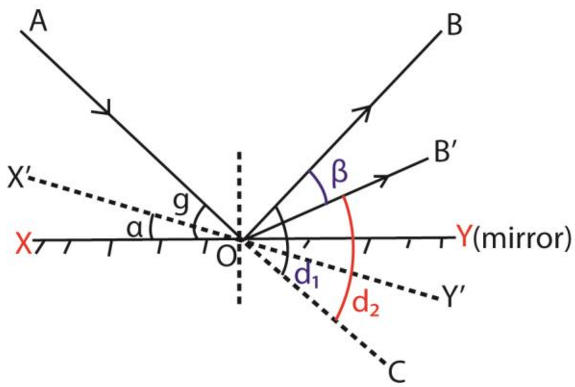
$\eta_l = 1.2$

13. (a) (i) State the laws of reflection of light. (02marks)

- The incident ray, the reflected ray and the normal at the point of incidence all lie in the same plane
- The angle of incidence is equal to the angle of reflection

(ii) A ray of light is incident on a plane mirror. The mirror is then turned through an angle α keeping the direction of the incident ray constant. If a reflected ray turned through angle β, find the relationship between α and β.

Let XY be the initial position of the mirror with ray AO making a glancing angle g. By keeping the direction of the incident ray fixed, the mirror is rotated through an angle **α** to a new position X'Y' as shown.



Case 1 (mirror in position XY)

Glancing angle = g

Deviation d_1 = 2g……… (i)

Case 2**(mirror in position X'Y')**

Glancing angle = (g – α)

Deviation d_2 = 2(g – α) …..(ii)

$\beta = d_1 - d_2$

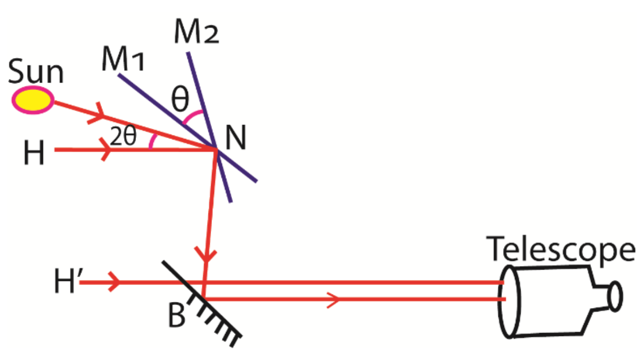
$= 2g - 2(g - \alpha)$

$= 2g - 2g + 2\alpha$

$= 2\alpha$

(b) Describe how a sextant is used to determine the angle of elevation of a star. (05marks)

Setup

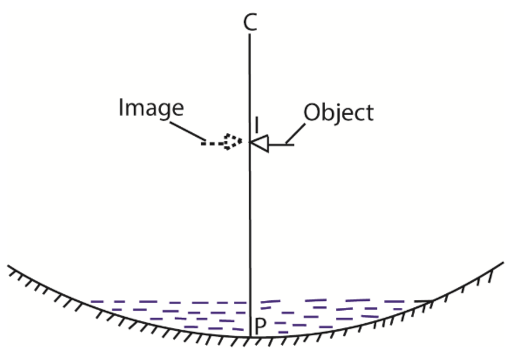


- A sextant consists of a fully silvered mirror M1which can be rotated about a horizontal axis and a fixed half silvered mirror B.
- Mirror M1 is adjusted to become parallel to B by rotating it until the image of the horizon, H' is seen directly through the unsilvered part of mirror B by successive reflection in mirror M_1 and B respectively

- The mirror M_1 is rotated to position M_2 such that the image of the horizon H, and the sun coincides at H'
- The angle of rotation is measured from the scale on the instrument. The elevation of the sun is 2θ.

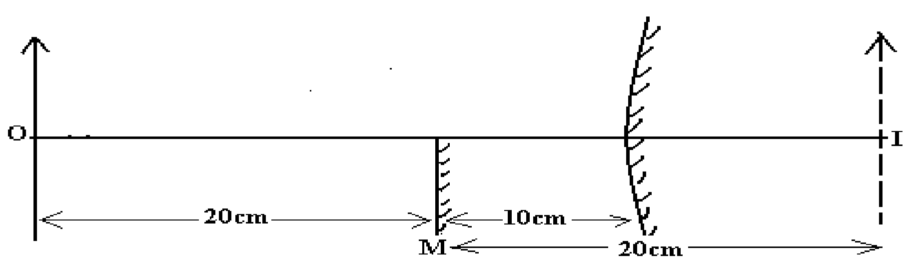
(c) Describe an experiment to determine the refractive index of a small quantity of a liquid using a concave mirror. (05marks)

An experiment to determine refractive index of a liquid using a concave mirror



- A clamped pin with its tip along the principal axis above the concave mirror is coincided with its image at C and distance PC is measured
- A small quantity of the liquid under test is poured into a concave mirror and a new point I at which the object pin coincides with its image is obtained.
- Distance IP is measured.
- The required refractive index of a liquid, $\boldsymbol{n_l} = \frac{\boldsymbol{PC}}{\boldsymbol{IP}}$

(d) A plane mirror is placed 10cmin front of a convex mirror so that it covers about half of the convex mirror surface. A pin placed 20cm in front of the plane mirror gives an image which coincides with that of the pin in the convex mirror. Find the focal length of the convex mirror. (04marks)



Consider the action of a convex mirror

u = 30cm and v = - (20 - 10) = -10cm "The image formed is virtual "

Using the lens formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ give

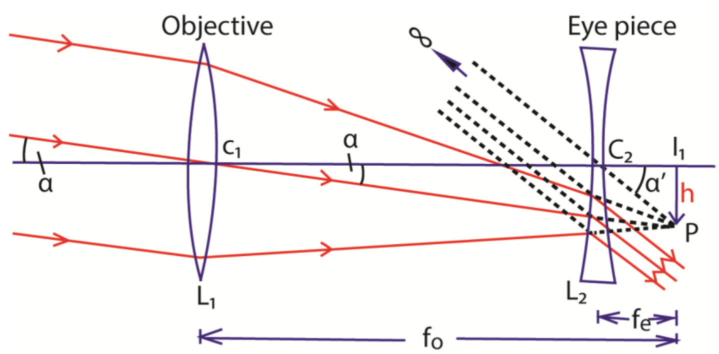
Image distance v of the lens = $\frac{fu}{u-f} = \frac{-10 \, x \, 30}{30-10} = -15cm$

14. (a) Define angular magnification of an optical instrument. (01marks)

This is the ratio of the angle subtended at the eye by the image when using an instrument to the angle subtended at unaided eye by the object.

M = $\frac{\alpha'}{\alpha}$ where α' and α are in radians

(b) (i) Describe with the aid of a ray diagram, the operation of telescope made of a converging lens and a diverging lens when used in normal adjustment. (05mrks)



Galilean telescope in normal adjustment

Light from distant object incident on objective lens is refracted to form real inverted image at its principal focus f_0. In normal adjustment, the principal focuses of both lenses coincide. The eye piece therefore forms the final image of the object at infinity.

To obtain the magnification, m, we assume the eye is very close to the eye piece.

m = $\frac{\alpha'}{\alpha}$

For small angles, α and α' are measured in radians

α ≈ tan α = $\frac{h}{fe}$ and α' ≈ tan α = $\frac{h}{fo}$

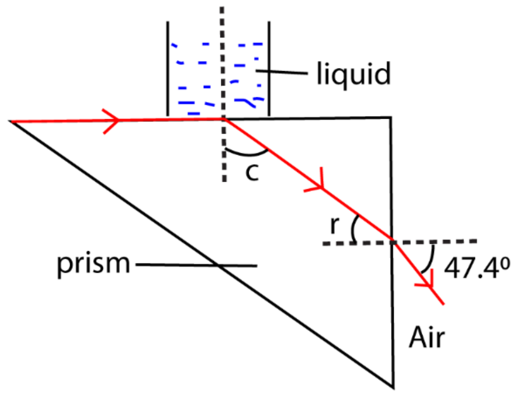
Substituting for α and α'

Magnifying power, m = $\frac{\alpha'}{\alpha} = \frac{h}{fe} \div \frac{h}{fo} = \frac{\boldsymbol{f_0}}{\boldsymbol{f_e}}$

(ii) State two limitations of this type of telescope. (01marks)

- it has virtual eye-ring
- It has a small field of view
- It produces less clear image

(c) The diagram in the figure below shows a path followed by a ray of monochromatic light through a right angled prism of refractive index 1.52. The light emerges in air at an angle of 47.4^0.



Find the refractive index of the liquid. (06marks)

Solution

Note: A ray on the boundary is grazing ray.

Let the refractive index of the liquid and air be and c is the refractive index of glass.

From

n_g sini = na sin 47.6^0

1.52 sin r = 1sin 47.6^0

r = 29^0

r + c = 90^0

c = 61^0

$n_L$sin 90^0 = ng sin c

n_L = 1.52 sin 61^0 = 1.33

(d) Explain the following as applied to lenses.

(i) chromatic aberration (02marks)

It is a failure of a lens to focus all colors to the same point due to different refractive indices for the different color wavelength.

(ii) spherical aberration (02marks)

It is the failure of the lens to focus all rays through the lens to the same point leading blurred image

(e) Explain how chromatic and spherical aberration are minimized in a reflecting telescope (03marks)

Correction of chromatic aberration

- Use **lenses** made of low-dispersion glasses, especially those containing fluorite
- By using combination of lenses of opposite nature (convex & concave) or chromatic doublet such that the dispersion produced by one lens is reversed by another.
- Placing the eye close to the lens such that images due to different colours subtend the same angle at the eye.

Means of reduction of spherical aberration

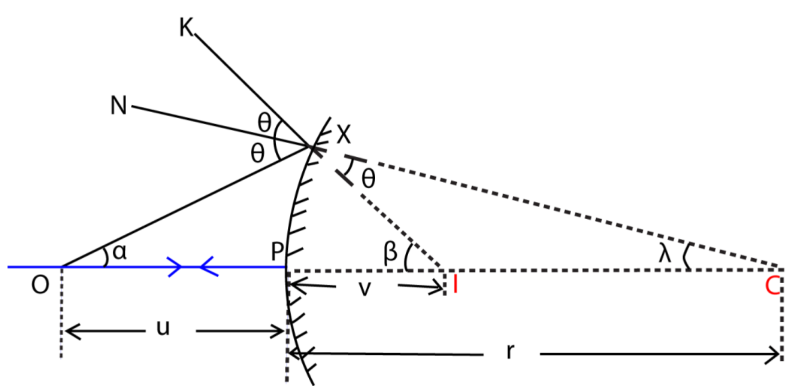
- Using lenses with an aspheric surface
- Using lens of small aperture.
- Using a stopper such that only light incident on the middle of the lens pass, but this method reduces the brightness of the image since it reduces the amount of light energy passing through the lens.

15. (a) Distinguish between a real and virtual image (02marks)

A real image is formed by actual intersection of rays and can be formed on a screen while a virtual image is formed by apparent intersection of rays and cannot be formed on a screen.

(b) Derive an expression relating the focal length, f, of a convex mirror to the object distance, u and image distance, v.

Consider the incidence of ray **OX** on to a convex mirror from a point object **O** placed along the principle axis and then suddenly reflected in the direction **XK** making an angle q with the normal **XN**.



From triangle XIC, $\theta + \lambda = \beta$

⇨ $\theta = \beta - \lambda$ .... (i)

From triangle OXI, $\alpha + \beta = 2\theta$ .... (ii)

Substituting (i) into (ii)

$\alpha + \beta = 2(\beta - \lambda)$

⇨ $\alpha - \beta = -2\lambda$ ………………………………………………… (a)

If X is very close to P. then

$\alpha \approx \tan\alpha = \frac{XP}{u}$, $\beta = \frac{XP}{-v}$ (I is virtual) and $\lambda \approx \tan\lambda = \frac{XP}{-r}$ (C is virtual)

Equation (a) becomes

$$\frac{XP}{u} - \frac{XP}{-v} = \frac{-2XP}{-r}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{2}{r}$$

But 2 = 2f

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

(c) A convex mirror forms an image half the size of the object. The object is then moved towards the mirror until the image is three quarter that of the object. If the image is moved by a distance of 0.6cm, calculate

(i) focal length of the mirror. (03marks)

Using $\frac{v}{f} = m + 1$

Initially, $\frac{v}{f} = \frac{1}{2} + 1 = \frac{3}{2}$ …………………… (i)

When the object was displaced

$\frac{v+0.6}{f} = \frac{3}{4} + 1 = \frac{7}{4}$ …………………………… (ii)

Eqn. (i) and Eqn. (ii)

$\frac{0.6}{f} = \frac{7}{4} - \frac{3}{2} = \frac{1}{4}$; f= 2.4cm

(ii) new potion of the object (03marks)

v + 0.6 = $\frac{7}{4}\, x\, f = \frac{7}{4}\, x\, 2.4$ = 4.2 cm

$$\frac{4.2}{u'} = \frac{3}{4}$$

u' = 5.6cm

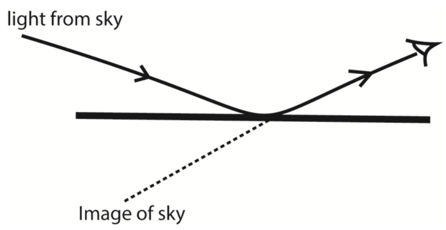
The object is 5.6 cm from the mirror.

(d) (i) What is critical angle? (01mark)

Critical angle is the angle of incidence in the dense medium for which the angle of refraction in the less dense medium is 90^0.

(ii) Explain how mirage is formed (04marks)

On a hot day, layer on air near the ground are hotter and lens dense than layers above. This leads to total internal reflection of rays of light from the sky. And mirage is the image of the sky to the eye by total internal reflection



(e) State four applications of total internal reflection (02marks)

- in radio broadcasting
- determination of refractive index if material
- in optical fiber transmission
- in refracting prisms in binoculars and periscopes

16. (a) State laws of refraction. (02marks)
    - The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane
    - The ratio of the sine of angle incidence to the angle of refraction is constant for a given pair of the media.

(b) (i) The deviation, d, by small angle prism of refractive angle A and refractive index, n, is given by

d = A(n-1)

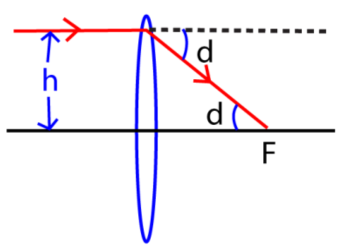
Use this expression to show that the focal length, f, of a thin converging lens of refractive index, n, is given by

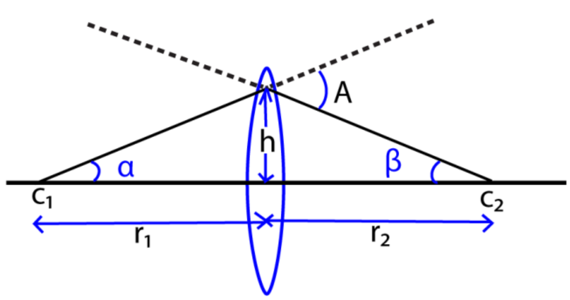
$$\frac{1}{f} = (n-1)\left(\frac{1}{r_1} + \frac{1}{r_2}\right),$$

where r_1 and r_2 are radii of curvature of the lens surfaces (05marks)

Solution

Consider a ray close and parallel to the principal axis, incident at height, h.





tan d = $\frac{h}{f}$ d is small in radian, d = $\frac{h}{f}$......................................(i)

For small angle prisms d = (n-l)A .... (ii)

From the diagram above, α + β =A .... (iii)

For small angle

α ≈ tanα = $\frac{h}{r_1}$ and β≈tanβ =$\frac{h}{r_2}$

Substitution α and β in equation (iii)

$\left(\frac{h}{r_1} + \frac{h}{r_2}\right)$ = A ....(iv)

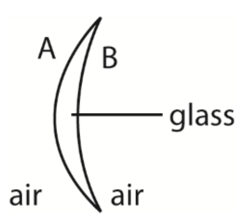
Substituting equation (i) and (iv) in equation (ii)

$\frac{h}{f}$ = (n-1) $\left(\frac{h}{r_1} + \frac{h}{r_2}\right)$

Dividing by h

$\frac{1}{f}$ = (n-1) $\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$

(ii) The figure below is a glass convex lens in air with surfaces A and B having radii of curvature 10cm and 15cm respectively.

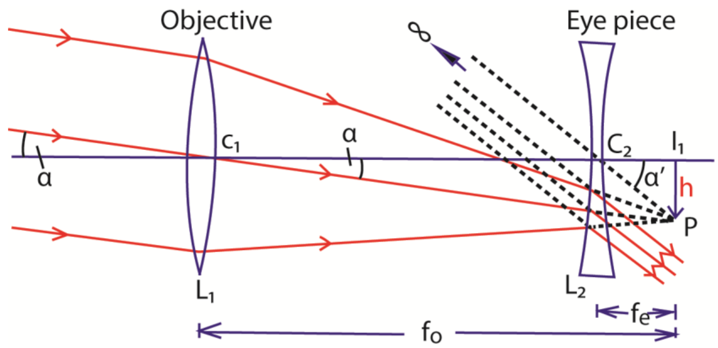


If the refractive index of the glass material is 1.50. Calculate the power of the lens. (03marks)

r_1= 10cm = 0.1m, r_2 = -15cm = -0.15m

Using $\frac{1}{f}$ = (n-1) $\left(\frac{1}{r_1} + \frac{1}{r_2}\right)$ = (1.5 – 1) $(\frac{1}{0.1} + \frac{1}{0.15})$ = 1.67D

(c) (i) with the aid of a ray diagram, describe the structure and action of a Galilean telescope in normal adjustment. (05marks)



Galilean telescope in normal adjustment

Light from distant object incident on objective lens is refracted to form real inverted image at its principal focus f_0. In normal adjustment, the principal focuses of both lenses coincide. The eye piece therefore forms the final image of the object at infinity.

(ii) Derive an expression for angular magnification of the telescope in (c)(i). (03marks)

Magnification, m = $\frac{\alpha'}{\alpha}$

For small angles, α and α' are measured in radians

$\alpha \approx \tan\alpha = \frac{h}{f_e}$ and $\alpha' \approx \tan\alpha = \frac{h}{f_0}$

Substituting for α and α'

Magnifying power, m = $\frac{\alpha'}{\alpha} = \frac{h}{f_e} \div \frac{h}{f_o} = \frac{\boldsymbol{f_0}}{\boldsymbol{f_e}}$

(d) Explain the disadvantage of a Galilean telescope over refracting type. (02marks)

- Eye-ring is virtual
- Image less bright and less clear

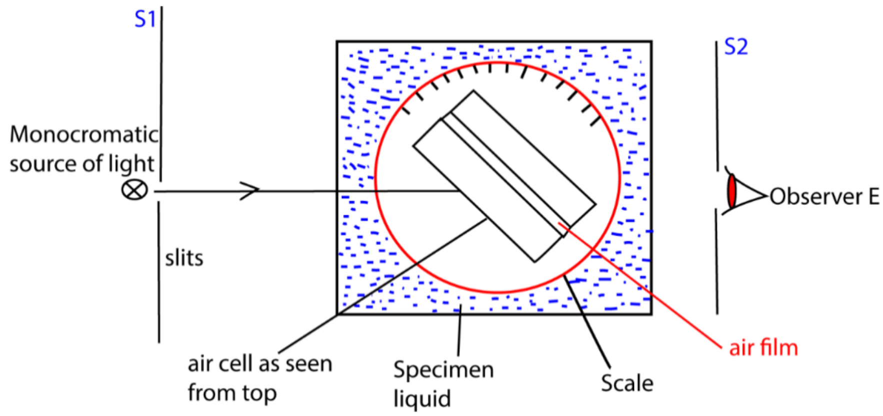
11. (a) (i) State the laws of refraction of light (02marks)

- The incident ray, the refracted ray and the normal at the point of incidence all lie in the same plane
- The ratio of the sine of angle incidence to the angle of refraction is constant for a given pair of the media.

(ii) State the conditions for total internal reflection to occur. (02marks)

- Angle of incidence must be greater than the critical angle.
- Light must be moving from a denser to less dense medium

(b) (i) Describe an experiment to determine refractive index of a liquid using air cell. (06marks)



- The air cell is immersed in a liquid under test.
- A beam of monochromatic light is directed onto the air cell and then observed through the cell from the opposite side at **E**.
- The cell is then rotated on one side until light is suddenly cut off and the angular position **θ1** is noted.
- The cell is again rotated in the opposite direction until light is suddenly cut off and the angular position **θ2** is noted.

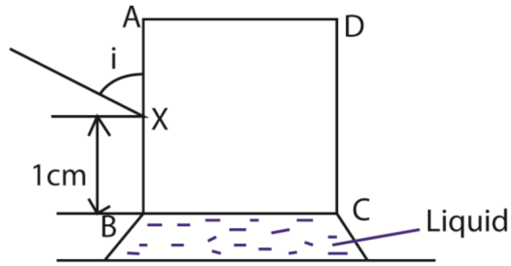
- The refractive index of the liquid can then be calculated from

$$\mathbf{n} = \frac{1}{\sin\theta} \quad \text{where } \boldsymbol{\theta} = \frac{\theta 1 + \theta 2}{2}$$

(ii) Explain the difficulty encountered in the experiment described in (b)(i) if white light is used (02marks)

White light does not give sharp extinction of light due to dispersion.

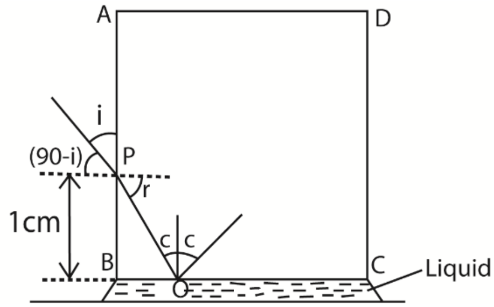
(c) A cube of glass of side 3cm and refractive index 1.5 is placed on a thin film of liquid as shown in the figure below



A ray of light in the vertical plane strikes AB of the glass cube at an angle i = 410. After refraction at X, the ray is reflected at the critical angle for glass-liquid interface.

(i) Calculate the critical angle for glass –liquid interface. (03marks)

Solution



From nsin i = constant

sin (90 – 41) = 1.5sin r

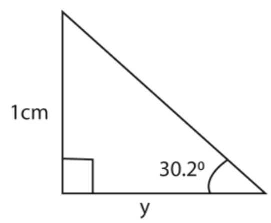
$r = 30.2^0$

At point Q

$r + c = 90^0$

$c = 90^0 - 30.2^0 = 59.8^0$

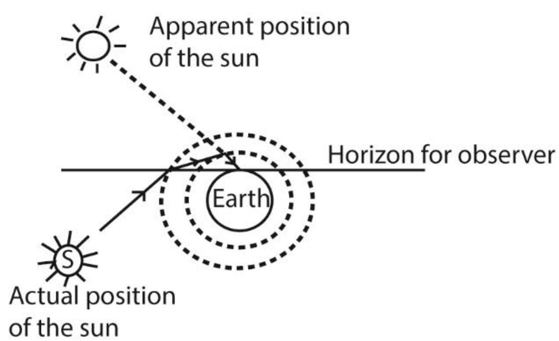
(ii) Find the position from B where the ray strikes the glass-liquid interface



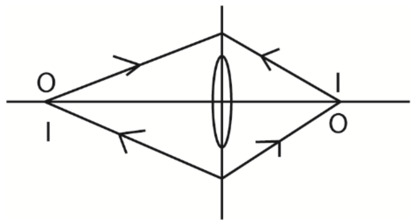
$y = \frac{1}{\tan 30.2} = 1.7cm$

(d) Explain why the rays from the sun can still be seen shortly after sunset (03marks)

As the sun sets, layers of air near the earth gets cooler and therefore optically denser than layers of the air above. This causes total internal refraction of light rays from the sun towards the earth.



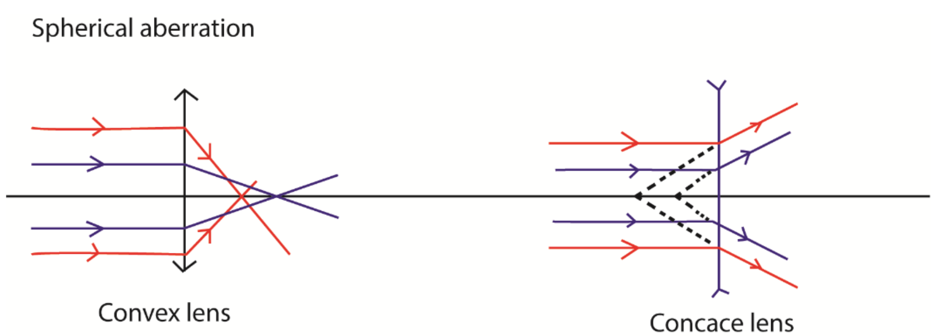
17. (a) with the aid of ray diagram, explain the following as applied to lenses
    (i) conjugate points. (02marks)



These are two points; O and I, on the opposite side of a convex lens such that an object and its image at these points are interchangeable.

(ii) spherical aberration (02marks)

Spherical aberration

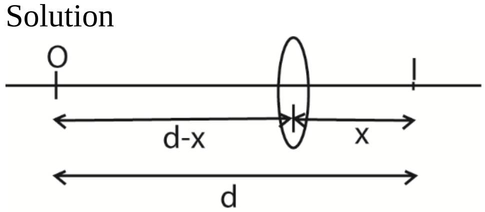


Spherical aberration occurs when the lens fails to focus all rays falling on it to the same point. Thus images formed by the lens at large apertures are therefore unsharp or blurred at the edges.

(b) An object, O, placed in front of a converging lens forms a real image, I, on the screen. The distance between the object and its real image is d. while that of the image from the lens is x.

Derive the expression for the least possible distance between the object and its real image (05marks)

Solution



u = d-x   v = x

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{f} = \frac{1}{d-x} + \frac{1}{x} = \frac{d}{dx - x^2}$

$x^2 - dx + fd = 0$

$x = \frac{d \pm \sqrt{d^2 - 4fd}}{2}$

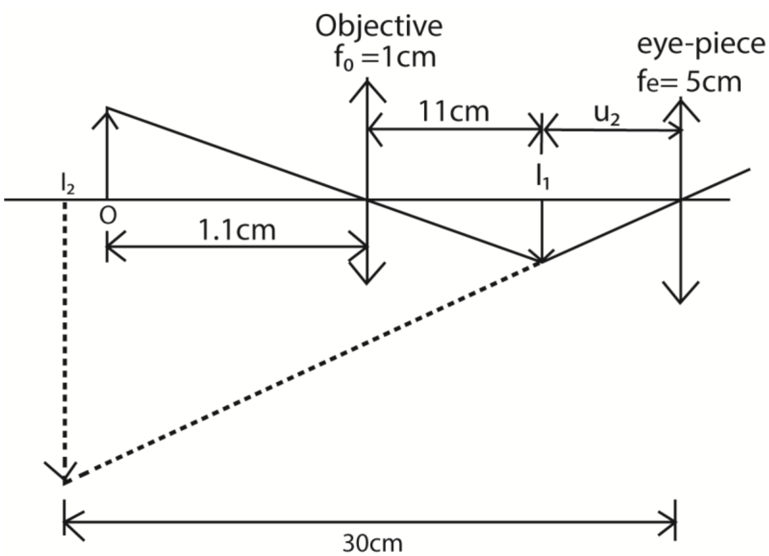
for real roots, $d^2 > 4fd$ or $d > 4f$

(c) Give the properties of lenses in achromatic combination. (03marks)-

- One lens should be concave and the other convex
- The lenses should be of different materials
- The dispersion caused by the concave lens should be completely cancelled by the convex lens. the dispersive power of the materials be $\frac{f_1}{f_2} = \frac{-w_1}{w_2}$
- The radii of curvature of concave and convex lenses should be numerically equal

(d) A compound microscope consists of two converging lenses of focal lengths 1.0cm and 5.0cm respectively. An object is placed 1.1cm from objective and the microscope is adjusted so that the final image formed 30cm from the eye- piece. Calculate

(i) the separation of the lenses (03marks)



Objective lens

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{1.0} = \frac{1}{1.1} + \frac{1}{v}$; v = 11cm

Eye piece

$\frac{1}{5.0} = \frac{1}{u_e} - \frac{1}{30}$; u_e = 4.3cm

$Separation = v + u_e$ = 11 + 4.3 =15.3cm

(ii) the magnifying power of the lenses. (03marks)

$$m = \left(\frac{v_e}{f_e} - 1\right)\left(\frac{v_0}{f_0} - 1\right)\frac{D}{v_e} = \left(\frac{-30}{5.0} - 1\right)\left(\frac{11}{1} - 1\right)\frac{25}{-30} = 58.3$$

(e) State two differences between a compound microscope and an astronomical telescope. (02marks)

Compound microscope	Astronomical telescope
- view near objects	- views distant objects
- objective lens has smaller focal length	- objective has longer focal length
- in normal adjustment, final image is at near point	- in normal adjustment final image is at infinity
- has greater resolving power	- has smaller resolving power

18. (a) Define the following terms as applied to a concave lens:

(i) principal focus' (01mark)

it is appoint on principal axis where rays of light originally parallel and close to principal axis appear to diverge from after reflection by the lens.

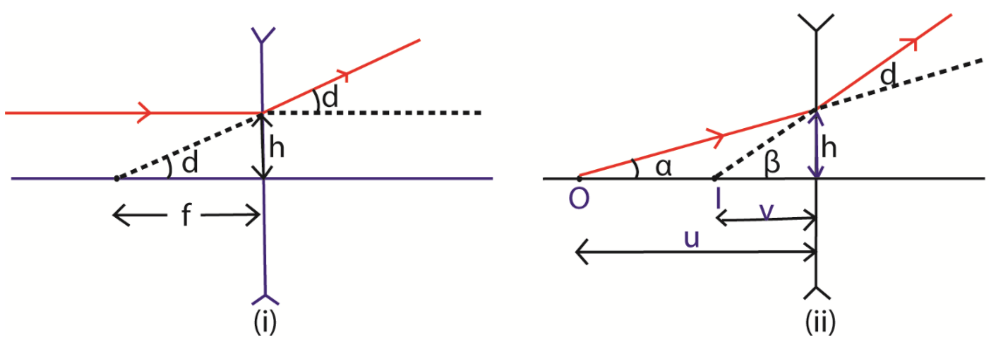
(ii) radii of curvature (01mark)

are radii of the sphere of which the lens surfaces form part

(b) A point object is placed at a distance u in front of a diverging lens of focal length, f, to form an image at a distance, v, from the lens.

Derive an expression that relates u. v. and f. (04marks)

Consider in each case a ray incident on the same lens at a small height **h** above the principal axis as shown:



From Fig (i), the close and parallel to principal axis ray appears to diverge from the focal point **F** and suffers a small deviation **d;** since h is very small

Thus $d \approx \tan d = -\frac{h}{f}$ = ---------------------------------- (i) (F is virtual)

From Fig (ii), the ray from a point object **O** suffers the same small deviation **D** to give rise to a point image **I**.

From geometry, β = α +d   or d = β - α

Since α and α are small; $\alpha \approx \tan\alpha = \frac{h}{u}$ and $\beta \approx \tan\beta = -\frac{h}{v}$ (image is virtual)

$$d = -\frac{h}{v} - \frac{h}{u} \quad \text{----------------------------- (ii)}$$

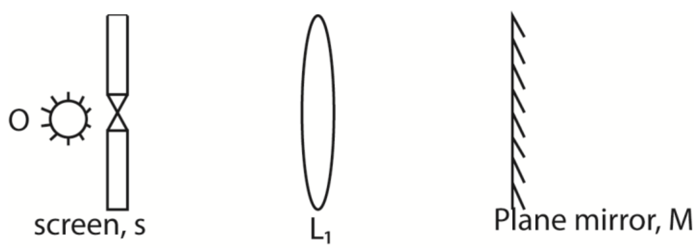
Equating equations (i) and (ii) gives

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

Thus $\frac{1}{f} = \frac{1}{u} + \frac{1}{u}$

(c) Describe an experiment to determine the focal length of a concave lens using a plane mirror, converging lens and illuminated object. (04marks

Setup



- The apparatus is shown above
- The wire gauze is illuminate with a bulb and the position of lens L_1 is adjusted until a sharp image of the wire gauze is formed on the object screen, S.
- The distance SL_1 is measured and recorded as f_1.
- The test lens L_2 is now cemented of L_1 and again placed between O and M.
- The position of the combined lens is adjusted until a sharp image of the wire gauze is formed on S.
- The distance SL_2 is measured as f_2.

  Focal length of the test lens, f, is then calculated from, $\frac{1}{f} = \frac{1}{f_2} - \frac{1}{f_1}$

(d) What is meant by a:

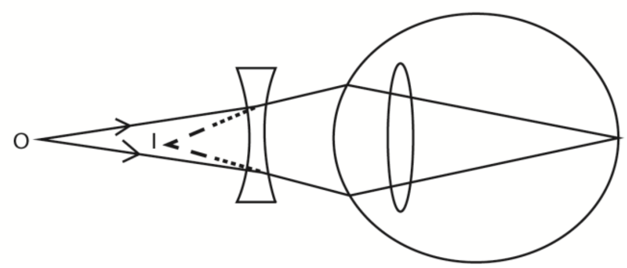
(i) visual angle (01mark)

Visual angle is the angle subtended by an object or image at the eye.

(ii) near point (01mark)

The near is the point at which the eye is able to view the object clearly with the greatest details.

(e) A person with a normal near point distance of 25cm wears spectacles with a diverging lens of focal length 200cm in order to correct the far point distance to infinity. Calculate the near point when viewing using the spectacles. (03marks)



The object at O appear to be at I, the near point for the eye.

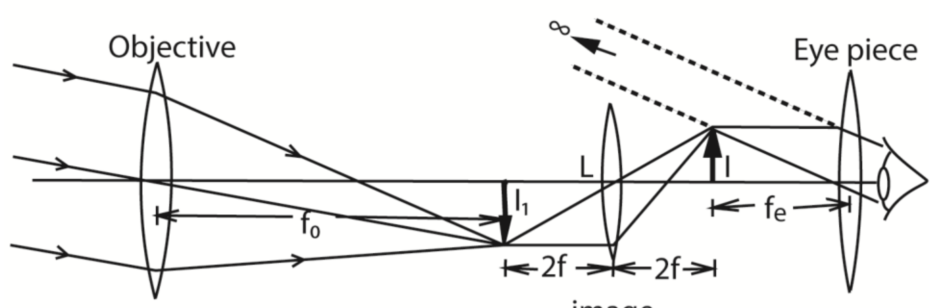
Now v= -25 cm and f = -200cm

Thus using $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$$\frac{1}{u} = \frac{1}{-200} + \frac{1}{25}$$

u = 28.6cm

(f) (i) Draw a ray diagram to show the formation of an image of a distant object in terrestrial telescope in normal adjustment. (03marks)



Terrestrial telescope

(iii) State two disadvantages of terrestrial telescope.(02marks)

- Long and bulky
- Extra diffraction occurs in erecting lens reducing the clarity of the final image
-

19. (a) What is meant by the term:

(i) refraction. (01mark)

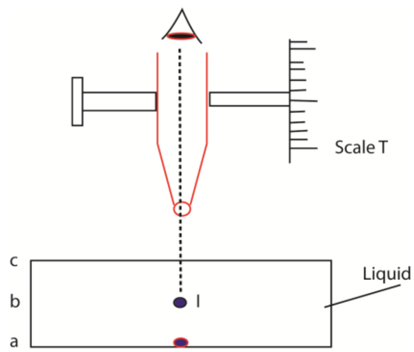
Refraction is the change in direction of propagation of light as it travels from one medium to another.

(ii) absolute refractive index? (01mark)

Absolute refractive index of a medium is the ratio of speed of light is vacuum to the speed of light in the medium.

(b) Describe an experiment to determine the refractive index of a liquid using a travelling microscope. (04marks)

Measurement of refractive index of a liquid using travelling microscope or by apparent depth method.



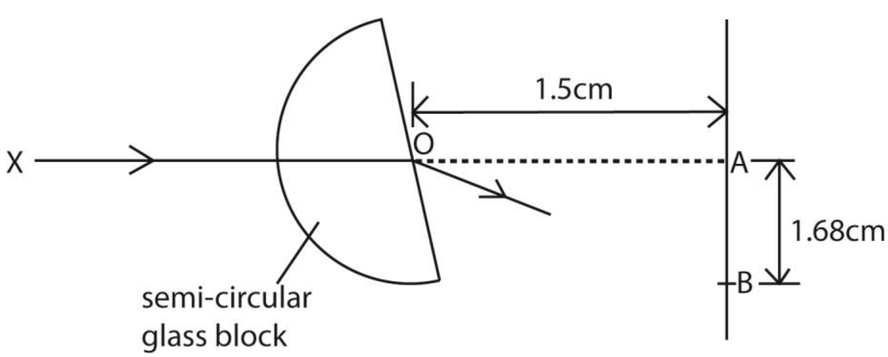
A vertically traveling microscope having a graduated scale **T** besides it is focused on sand particles placed at **O** on bottom of the container. The scale reading **a** on **T** is noted.

A liquid whose refractive index is required is filled in a container and the microscope is raised until the particles are refocused at **I**. The scale reading **b** is again noted.

Finally the traveling microscope is focused on the liquid surface giving a scale reading c.

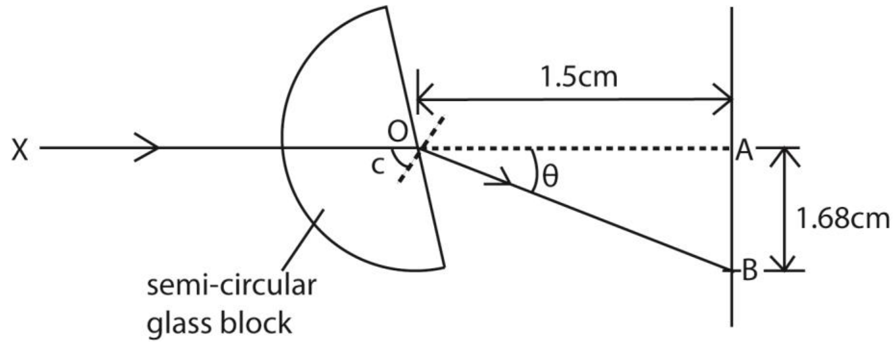
Thus $n_L = \left[\frac{c-a}{c-b}\right]$

(c) The figure below shows monochromatic light X incident towards A on vertical screen.



When the semicircular glass block is placed across the path of light with its flat face parallel to the screen, a bright spot is formed at A. When the glass block is rotated about a horizontal axis through O, the bright sport moves from A to B and then just disappears. At B, distance 1.68cm from A.

(i) Find the refractive index of the material of the glass block. (04marks)



When the spot just disappear at B, the total internal reflection just occurs

$n = \frac{1}{\sin c}$ where c = 90- θ

but $\tan\theta = \frac{1.68}{1.5} = 1.2$; θ = 48.2

c = 90- 48.2 = 41.8

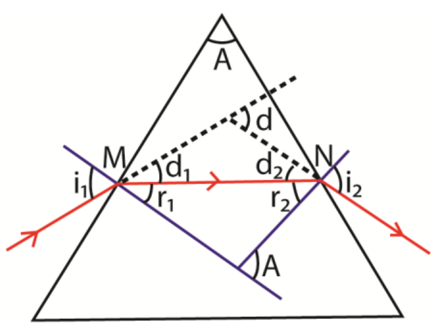
$n = \frac{1}{\sin 41.8} = 1.5$

(ii) Explain whether AB would be longer or shorter if the block of glass of higher refractive index was used.

When the refractive index is high the ray is refracted more, AB becomes longer.

(d) (i) A ray of monochromatic light is incident at a small angle of incidence on a small-angle prism in air. Obtain the expression, d= (n-1)A, for the deviation, d, of light by the prism, where A is the refracting angle of the prism and n, is the refractive index. (04marks)

Solution



The small refracting angle of this prism causes the angle i_1, r_1, r_2 and i_2 to be small such that $\sin i_1 \approx i_1$, $\sin r_1 \approx r_1$ $\sin r_2 \approx r_2$ and $\sin i_2 \approx i_2$

From the diagram, d = d1 + d_2

But $d_1 = i_1 - r_1$ and $d_2 = i_2 - r_2$

⇨ $d = (i_1 - r_1) + (i_2 - r_2)$

On simplifying $d = i_1 + i_2 - (r_1 + r_2)$

but $r1 + r_2 = A$

⇨ $d = i1 + i2 - A$ …………………………………………… ……(a)

At M Snell's law becomes.

$n_a \sin i_1 = n \sin r_1$

For small angles this gives $i_1 = nr_1$ …………………………………..(b)

Similarly at N Snell's law becomes $i_2 = nr_2$ ……………………….(c)

Substituting equation (b) and (c) in (a) gives

$d = nr_1 + nr_2 - A$

$d = n(r_1 + r_2) - A$

but $r_1 + r_2 = A$

⇨ $d = nA - A$

$\mathbf{d = (n - 1)A}$

(ii) Calculate the minimum deviation produced by a 60^0 prism if the refractive index of the glass is 1.50. (03marks)

$$\text{Using } n = \frac{\sin\left(\frac{D_{min}+A}{2}\right)}{\sin^{A}/_{2}}$$

$$1.5 = \frac{\sin\left(\frac{d_{min}+60}{2}\right)}{\sin\frac{60}{2}}$$

$$d_{min} = 37.18^0$$

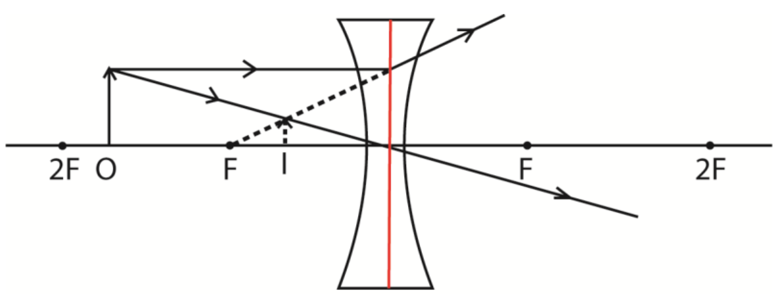
(iii) State any two applications of total internal reflection. (01marks)

- Transmission of light by optical fiber
- Reflecting prisms in binoculars, periscopes

20. (a) (i) Define principal focus of a concave lens. (01marks)

Principal focus of a concave lens is the point on the principal axis where rays of light parallel and close to principal axis appear to diverge from after refraction through the lens.

(ii) Draw a ray diagram to show formation of an image of finite object in a concave lens (02marks)



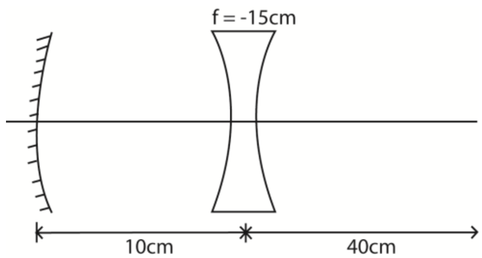
O = object I = image

(iii) Describe the image formed in (a)(ii) (01mark)

- it is virtual and diminished.

(b) A concave mirror of radius of curvature 20cm is arranged coaxially with a concave lens of focal length 15cm, placed 10cm from the mirror. An object, 3cm tall is placed in front the concave lens and its image is formed on a screen 40cm away from the lens.

(i) Find the position of the object. (07marks)



Action of the concave lens, f = -15, u = 40cm

$\frac{1}{v} = \frac{1}{f} - \frac{1}{u} = \frac{-1}{15} - \frac{1}{40} = \frac{-120}{11}$; v = -10.91cm

Action of concave mirror

u = 10 + 10.91 = 20.91cm, f = 10

$\frac{1}{10} = \frac{1}{20.91} + \frac{1}{v}$; v= 19.17

Action of the lens

u=9.17cm, f=-15cm

$\frac{1}{v} = \frac{1}{-15} + \frac{1}{9.17}$; v = 23.55cm in front of the lens

(ii) What is the height of the image formed? (03marks)

M =M_1 x M_2 x M_3= $\frac{v_1}{u_1} x \frac{v_2}{u_2} x \frac{v_3}{u_3} = \frac{10.91}{40} x \frac{19.17}{20.91} x \frac{23.55}{9.17}$ =0.64

Image height = 0.64 x 3 = 1.9

(iii) Explain what would happen if the lens was replaced with a similar one but of much smaller focal length. (03marks)

If the lens was replaced with one of a smaller focal length, the final image would have been smaller. This is because the power of a lens = $\frac{1}{f}$; therefore a lens of smaller focal length has a larger magnifying power.

(c) Explain how spherical aberration is minimized in a photographic camera.(03marks)

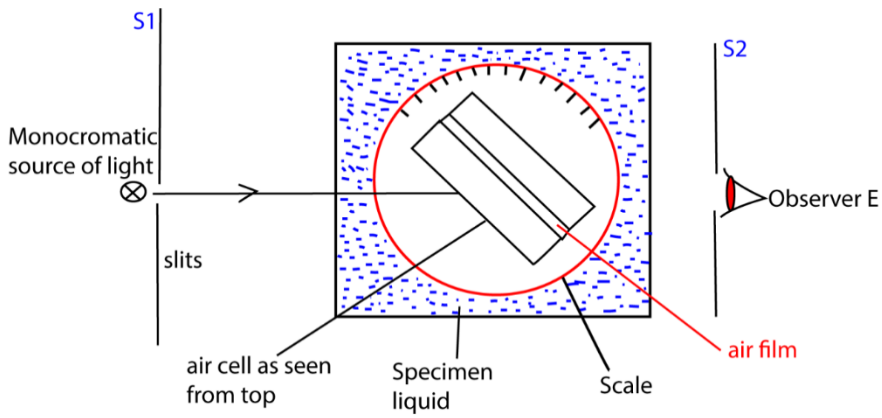
Spherical aberration in a photographic camera is minimized by the diaphragm. The diaphragm only allows central beam which forms a sharp image.

- using composite lens

21. (a) Define refractive index. (01mark)

Refractive index of a medium is the ratio of the speed of light in vacuum to the speed of lght in a medium.

(b) (i) Describe with the aid of a diagram, how the refractive index of a liquid can be determined using air cell. (05marks)



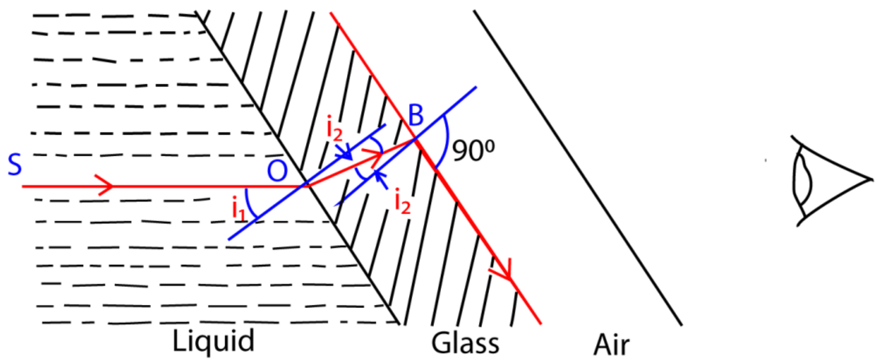
- The air cell is immersed in a liquid under test.
- A beam of monochromatic light is directed onto the air cell and then observed through the cell from the opposite side at **E**.
- The cell is then rotated on one side until light is suddenly cut off and the angular position **θ1** is noted.
- The cell is again rotated in the opposite direction until light is suddenly cut off and the angular position **θ2** is noted.

- The refractive index of the liquid can then be calculated from

$$\mathbf{n} = \frac{1}{\sin\theta} \quad \text{where } \boldsymbol{\theta} = \frac{\boldsymbol{\theta1 + \theta2}}{\mathbf{2}}$$

(ii) Derive the expression used to obtain the refractive index of the liquid in (b)(i) (03marks)

Setup



Ray **SO** is refracted along **OB** in glass. However, at **B** total internal just begins. Suppose $\mathbf{i_1}$ is the angle of incidence in the liquid, $\mathbf{i_2}$ is the angle of incidence in the glass while **n** and **ng** are the corresponding refractive indices, Then applying the relation **n sin i = a constant** gives

$n\sin i_l = n_g \sin i_2 = n_a \sin 90^0$

$\therefore\ n \sin i_l = n_a \sin 90^0$

but $n_a \sin 90 = 1$

Thus $n = \frac{1}{\sin i_1}$

Since, Angle i = $\frac{\theta_1 + \theta_2}{2}$

$n = \frac{1}{\sin\theta}$

(c) A prism of refractive angle 60^0 has refractive indices 1.515 and 1.529 for red and violet respectively. When white light is incident on one face of the prism, red light undergoes minimum deviation. Calculate the angle of

(i) incidence for white light (04marks)

At minimum deviation

$$n_r = \frac{\sin\left(\frac{D+A}{2}\right)}{\sin\frac{A}{2}} = \frac{\sin i}{\sin\frac{A}{2}}$$

$$\sin i = 1.51 sin\frac{60}{2}$$

i = 49.03

(ii) emergence for violet light(03marks)

At the first face, sini = nsinr

Sin r = $\frac{\sin 49.03}{1.529}$

r = 29.6^0

$r_1 + r_2 = 60$

$r_2 = 60 - 29.6 = 30.4$

At the second face

$1.529\sin30.4 = \sin i$

$i = 50.7^0$

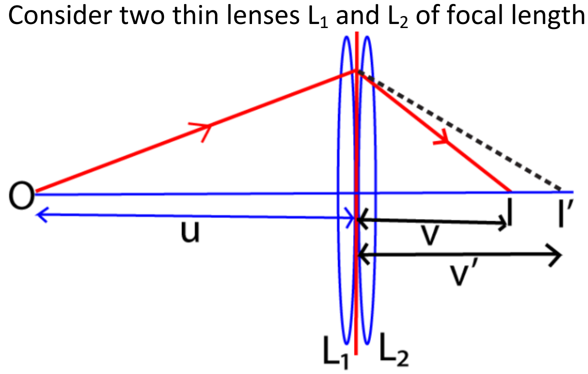
(d) Describe the adjustment that have to be made before a spectrometer can be used. (04 marks)

- The collimator is adjusted to produce parallel rays of light.
- The turn table is leveled.
- The telescope is adjusted to receive light from the collimator on its cross wire.

22. (a) (i) Show that the effective focal length, f, of two thin lenses in contact is given by

$\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$, where f_1 and f_2 are the foal lengths of the individual lenses. (04marks)

Consider two thin lenses L_1 and L_2 of focal length f_1 and f_2.



For lens L_1,

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

$\frac{1}{f_1} = \frac{1}{u} + \frac{1}{v'}$ ……………………….(i)

For L_2, I' acts as the object

$\frac{1}{f_2} = \frac{1}{-v'} + \frac{1}{v}$ …………………… (ii)

Eqn. (i) + Eqn. (ii)

$\frac{1}{f_2} + \frac{1}{f_2} = \frac{1}{u} + \frac{1}{v} = \frac{1}{F}$

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

Where F is the focal length of combined lens,

(ii) A compound lens consists of two lenses in contact having powers of +12.5D and -2.5D. Find the position and nature of the image of an object placed15.0cm from the compound lens. (03marks)

$f_1 = \frac{1}{12.5} = 0.08m = 8cm$

$f_2 = \frac{1}{-2.5} = 0.4m = -40cm$

From $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{8} - \frac{1}{40}$

Combined focal length f = 10cm

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

$\frac{1}{v} = \frac{1}{10} - \frac{1}{15}$; v = 30cm

The image is real (v is +ve) and magnified (v greater than u)

(b)(i) Define refractive index (01marks)

Refractive index is the ratio of the speed of light in vacuum to the speed of light in a medium

Or

The ration of sine of angle of incidence of a ray moving from vacuum to the sine of angle of refraction in a medium

(ii) An equi-convex lens is placed on a horizontal plane mirror and a pin held vertically above the lens is found to coincide with its image when positioned 20.0cm above the lens. When a few drops of liquid is placed between the lens and the mirror, the pin had to be raised 10.0cm to obtain coincidence with the image. If the refractive index of the lens is 1.5, find the refractive index of the liquid. (05marks)

Solution

f_g = 20cm, f_c = 30cm, f_L =?

From $\frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$

$\frac{1}{30} = \frac{1}{20} + \frac{1}{f_L}$

$\frac{1}{f_L} = \frac{-1}{60}$

$Also, \frac{1}{f_g} = (n_g - 1)\frac{2}{r}$

$\frac{1}{20} = (1.5 - 1)\frac{2}{r}$

$\frac{1}{r} = \frac{1}{20}$

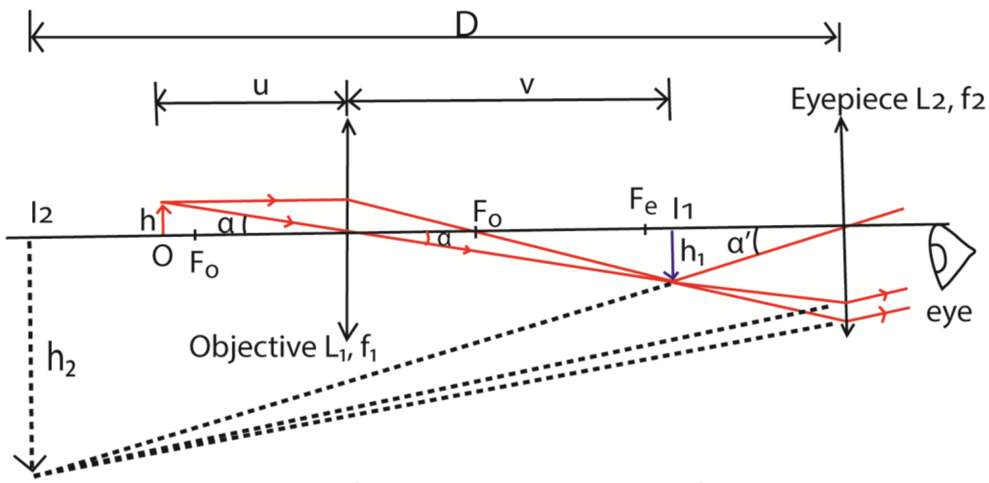
For the liquid lens, $\frac{1}{f_L} (n_L - 1)\frac{1}{r}$

$$\frac{-1}{60} = (n_L - 1)\frac{1}{20}$$
$$n_L = 1.33$$

(c) (i) What is meant by magnifying power of optical instrument? (01mark)

Magnifying power of optical instrument is the ratio of the angle subtended by the final image at the eye when using optical instrument to the angle subtended by the object at the naked eye.

(ii) Derive an expression for magnifying power of a compound microscope in normal adjustment. (05marks)



Compound microscope in normal use

For an aided eye (using the instrument)
For small angle, tanα' ≈ α' for small angle in radians
$\alpha' = \frac{h_2}{D}$ .... (i)
For unaided eye
$\alpha = \frac{h_1}{D}$ .... (ii)
Magnifying power, m = $\frac{\alpha'}{\alpha} = \frac{h_2}{D} \div \frac{h_1}{D} = \frac{\mathbf{h_2}}{\mathbf{h_1}}$

Or

Linear magnification can also be expressed as, m = $\frac{h_2}{h}\ x\ \frac{h}{h_1}$ = m_e x m_o.

Where, m_e and m_o are linear magnifications of the eye piece and objective lenses respectively.

$m_o = \frac{v}{f_0} - 1$ and me = $\frac{-D}{fe} - 1$

m = $(\frac{-D}{fe} - 1)(\frac{v}{f_0} - 1)$

(iii) Why should the objective and eye piece of a compound microscope have short focal length? (01 marks)

To achieve a big magnification

23. (a) What is meant by the following terms as applied to optics

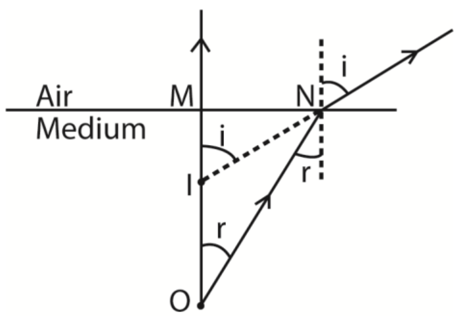
(i) refraction (01mark)

Refraction is the bending of light rays as they travel from one medium to another of different optical densities

(ii) critical angle (01mark)

Critical angle is the angle of incidence in an optically denser medium for which the angle of refraction in a less dense medium is 90^0.

(b) Show that the refractive index, n, of a medium is given by, n = $\frac{real\ depth}{apparent\ depth}$ (04marks)



A ray of light from object O, incident on the boundary at N is refracted and appears to come from I

From Snell's law, the refractive index of the medium, n = $\frac{\sin i}{\sin r}$

But sin i = $\frac{NM}{IN}$ and sin r= $\frac{MN}{ON}$

n = $\frac{NM}{IN} \div \frac{MN}{ON} = \frac{ON}{IN}$

when N is close to M; ON≈ OM and IN≈ IM

∴ n = $\frac{OM}{IM} = \frac{real\ depth}{apparent\ depth}$

(c) A scratch is made at the bottom of a thick glass container which is filled with water. The scratch appears displaced by 0.5cm when viewed from above the water. If the refractive indices of water and glass are 1.33 and 1.50 respectively, find the apparent displacement when water is removed and the scratch is again observed from above. (05marks)

Let t_1 and t_2 be the thickness of water and glass respectively d = $t_1\left(1-\frac{1}{n_w}\right)+\ t_2\left(1-\frac{1}{n_g}\right)$

= $t_1\left(1-\frac{1}{1.33}\right)+\ t_2\left(1-\frac{1}{1.5}\right)$

= $0.248t_1 + 0.333t_2 = 0.5$

When the water is removed, displacement = $0.5 - 0.333t_2$

(d) A ray of light incident at an angle, I, on a prism of an angle, A, passes through it symmetrically.

(i) Write the expression for deviation, d, of the ray in terms of i and A, (01mark)

d = 2i -A

(ii) Find the value of d if the angle of the prism is 60^0 and the refractive index of glass is 1.48. (03marks)

$$n=\frac{\sin\left(\frac{d+A}{2}\right)}{\sin\frac{A}{2}}$$

$$1.48=\frac{\sin\frac{d+60}{2}}{\sin\frac{60}{2}}$$

$$\frac{(d+60)}{2}=47.73$$

$$d=\ 35.5^0$$

(e) Describe how you would determine experimentally the angle of minimum deviation produced by a prism. (05marks)

Using a spectrometer

A. the spectrometer is adjusted as follows

- the telescope is adjusted to receive parallel rays.
- The collimator is adjusted to produce parallel rays
- The table is levelled

B. The angle is measured as follows

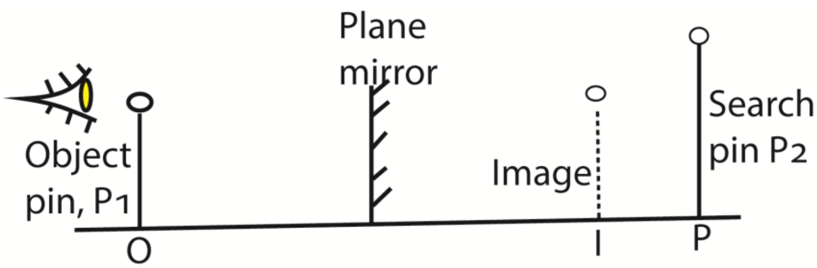
- The prism is placed on the table with its refracting edge facing away from collimator
- The telescope is turned to receive the refracted light from the opposite side of the prism.
- The table is turned while keeping the refracted light in view, until a point when the ray begins to move backwards. The position of the telescope on the scale is marked.
- The prism is now removed and the telescope turned to receive light directly from the collimator. The position of the telescope is again marked.
- The angle between the two positions is the angle of minimum deviation.

24. (a) (i) Distinguish between real and virtual images. (02marks)

A real image is one formed by actual intersession of rays and can be formed on the screen while a virtual image is formed by apparent intersession of rays and cannot be formed on a screen.

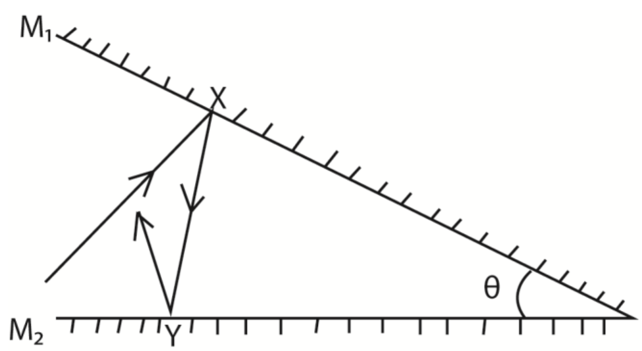
(ii) Describe how the position of an image in a plane mirror can be located (03marks)

Method 1: IMAGE LOCATION BY NO PARALLAX



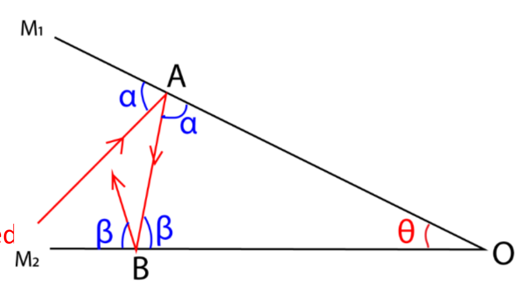
- An object pin **O** is placed in front of a plane mirror to form a virtual image **I**.
- A large search pin **P** is placed behind the mirror and moved to such a position that there is no parallax between pin **P2** and the image **I**.
- The image position has therefore been located.

(b) The diagram in the figure below shows a ray of light undergoing two successive reflections at points X and Y in two mirrors M_1 and M_2 inclined at an angle θ.



Show that the ray is deviated through an angle 2θ (03marks)

Consider an incident ray of light reflected successively from two mirrors M_1 and M_2 inclined at an angle θ to each other at O as shown



Let the glancing angles at A and B be α and β respectively.
Deviation by $M_1 = 2\alpha$ (clockwise direction)

Deviation by $M_2 = 2\beta$ (clockwise direction)

Total deviation $= 2\alpha + 2\beta$

$= 2(\alpha + \beta)$ ---------------------- (i)

But, $\alpha + \beta + \theta = 180^0$ (Angle sum of a triangle)

⇨ $\alpha + \beta = (1800 - \theta)$ ---------------------(ii)

Combining equation (i) and (ii) gives

Total deviation $= 2(180^0 - \theta)$ (clockwise direction)

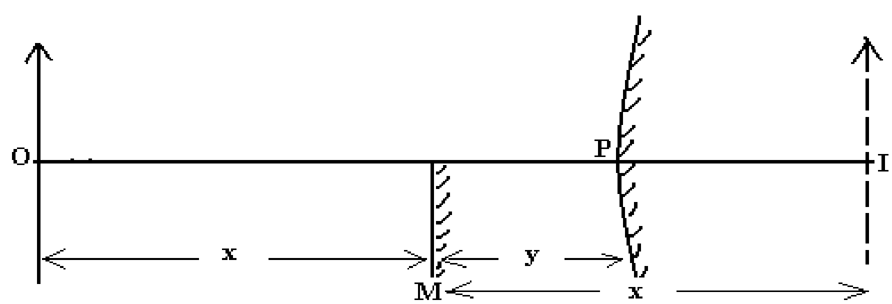
$= 360^0 - 2\theta$ (clockwise direction)

$= 2\theta$ (anti-clockwise direction)

(c) (i) What is a radius of curvature of a convex mirror? (01mark)

Radius of curvature of a convex mirror is the radius of a hollow sphere of which the mirror forms part

(ii) Describe the experiment to determine the focal length of a convex mirror using a plane mirror. (05marks)



(vii) An object pin **O** is placed in front of a convex mirror as shown in the diagram above

(viii) A virtual diminished image is formed at **I**.

(ix) A plane mirror **M** is placed between **O** and **P** so as to intercept half the field of view of the convex mirror.

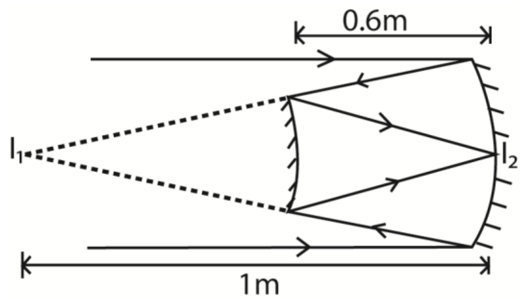
(x) Mirror **M** is adjusted until its own image of **O** coincides with **I** by no parallax method.

(xi) Measure the distances **x** and **y.**

(xii) The focal length of the mirror is calculated from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Where u = (x + y) and v = (v-x)(virtual)

(d) A small convex mirror is placed 0.60m from the pole and on the axis of a large concave mirror of radius of curvature 2.0m. The position of the convex mirror is such that a real image of a distant object is formed in the pane of a hole drilled through the concave mirror at its pole. Calculate the radius of curvature of the convex mirror. (04marks)



I1 is the virtual object of convex mirror that produces a real image, I2

Action of convex mirror;

u = -(1-0.6) = -0.4; v = 0.6

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v} = \frac{1}{-0.4} + \frac{1}{0.6}$

f = -1.2m

but radius of curvature = 2f = 2 x 1.2 = 2.4m

25. (a) (i) Define the terms linear magnification and angular magnification as applied to a lens. (02marks)

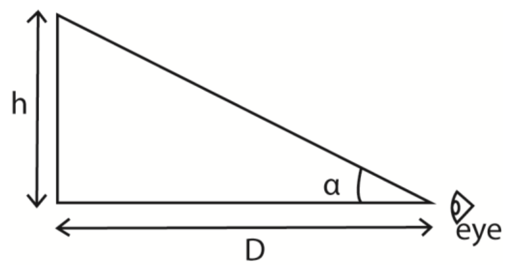
Linear magnification is the ratio of image height to the object height.

Angular magnification is the ration of the angle subtended by the final image at the eye using a lens to the angle subtended by the object to unaided eye

(ii) Derive the expression for magnifying power of a magnifying glass when the final image is formed at the near point. (04marks)

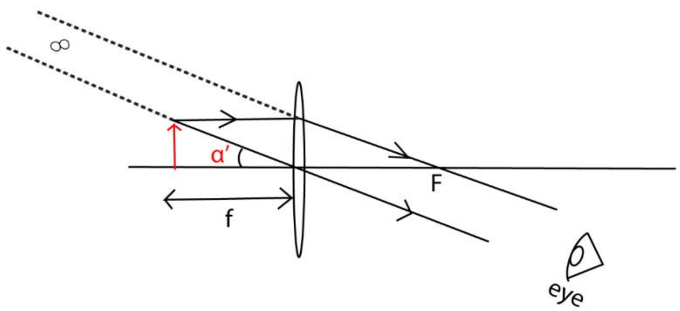
Solution

For the image to be formed at infinity, the object must be at, f.
Using unaided eye



The virtual angle, α, is given by tanα ≈ α =$\frac{h}{D}$ for small angle in radians …………….. (i)

If the final image at near point subtend an angle α' to the eye when a magnifying glass is used as given in the diagram below



For small angle tanα' ≈ α' =$\frac{h\prime}{f}$ for small angle in radians…………………….. (ii)

Linear magnification from (i) and (ii), m = $\frac{\alpha'}{\alpha}$ = $\frac{h\prime}{D}$ ÷ $\frac{h\prime}{f}$ = $\frac{h\prime}{f}$

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$ and multiplying through by v

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

Since, v = f

$\frac{D}{f} = m + 1$ or m = $\frac{D}{f}$-1 where f is the focal length

(b) An object is placed at a distance f + x from a converging lens of focal length, f. the lens produces an image at a distance, f + y from the lens. Show that f^2 =xy. (03marks)

u = f + x and v = f +y

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{f} = \frac{1}{f+x} + \frac{1}{f+y}$

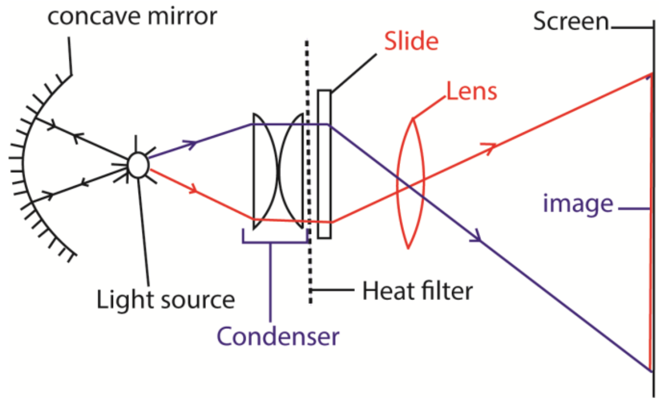
$f^2 = xy$

(c) (i) Describe with the aid of a labelled diagram the structure and operation of a simple projection lantern. (04marks)

Projection lantern

A **projector** is an instrument used to produce a large image of a small object.

- The slide, or film, is placed behind the **projector** lens outside its focal length and is illuminated buy a small but powerful source of light from concave reflector through condensing lenses.
- A magnified, real and inverted image on the screen



Area magnification = $\frac{Area\ of\ the\ image}{Area\ of\ the\ object}$

(ii) The slide of a projection lantern has dimension 36mm by 24mm. Find the focal length of the lens required to project an image 1.44m by 0.98m on a screen placed 4.0m from the lens. (04marks)

Area magnification = $\frac{1.44\ x\ 0.98}{36\ x\ 10^{-3}\ x\ 24\ x10^{-3}}$ = 1633.3

Linear magnification = $\sqrt{1633.3}$ = 40.4

From M = $\frac{v}{f} - 1$, v = 4.0m

40.4 =$\frac{4}{f} - 1$; f = 0.097m

(d) Distinguish between a chromatic and spherical aberration. (03marks)

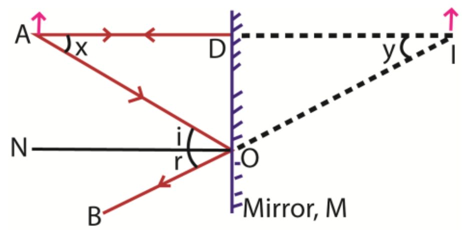
Chromatic aberration is the formation of blurred images with colored edges when white light is incident on a lens due to the fact that the lens has different focal lengths for the different colors.

Spherical aberration is the formation of blurred but non colored images when a wide beam of light is incident on a lens because the lens has different foci for marginal and paraxial rays.

26. (a) (i) State the laws of reflection (02marks)
    - Incident ray, refracted ray and the normal at the point of incidence all lie in the same plane
    - Angle of reflection is equal to the angle of incidence

(ii) Show that the image formed in a plane mirror is as far behind the mirror as the object is in front. (04marks)

Consider an object A placed in front of a mirror **M**.



A ray AD from A incident normally on the mirror at D is reflected back along DA. The Ray AO is reflected along OB and appears to come from point I behind the mirror. The intersection **I** of the rays AD and BO is the image position.

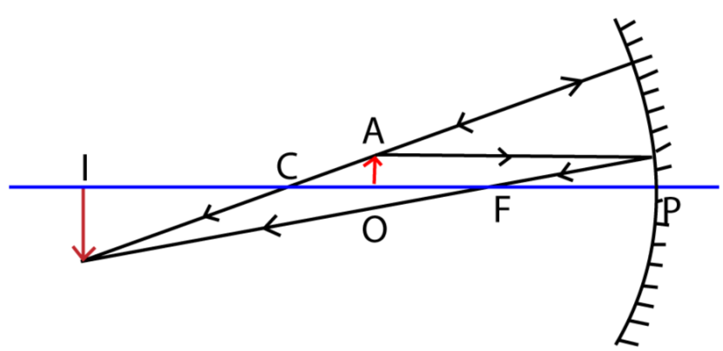
From above angles,
x = i (alternating angles)
i = r (2^{nd} law of reflection)
r = y (corresponding angles)
Combining all the equations gives
x = i = r = y

⇨ angle x = angle y
Tan x = t a n y

$$\therefore \quad \frac{DO}{AD} = \frac{DO}{DI}$$

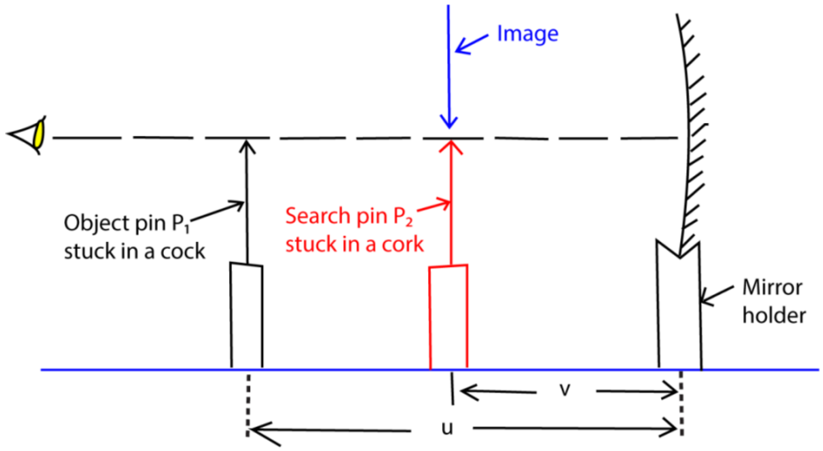
Thus AD = ID.
∴ The **image is as far behind the mirror as the object is in front**

(b) (i) Draw a ray diagram to show how a concave mirror forms a real image of a real object placed perpendicular to its principal axis. (01mark)



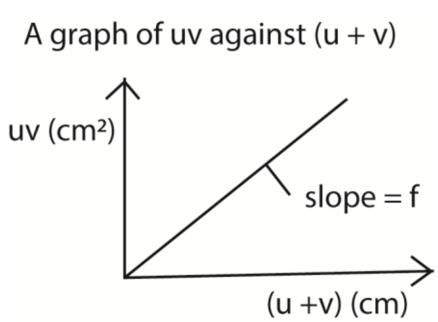
(ii) Describe an experiment, including a graphical analysis of the results to determine the focal length of a concave mirror using the No-parallax method. (06marks)

Experiment to determine focal length of concave mirror using no parallax method



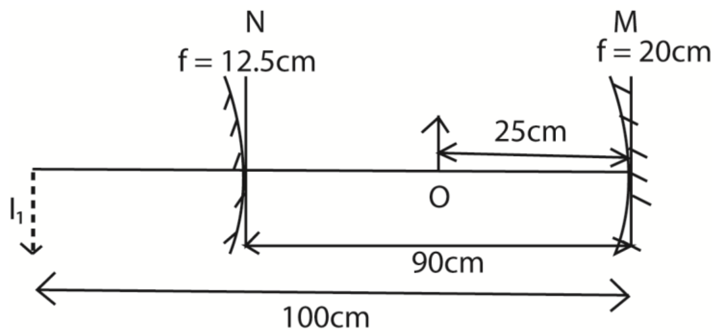
- An object pin $\mathbf{P_1}$ is placed at a distance **u** in front of a mounted concave mirror so that its tip lies along the axis of the mirror.
- A search pin $\mathbf{P_2}$ placed between the mirror and pin $\mathbf{P_1}$ is adjusted until it coincides with the image of pin $\mathbf{p_1}$ by no-parallax method.
- The distance **v** of pin $\mathbf{P_2}$ from the mirror is measured**.**
- The procedure is repeated for several values of **u** and the results are tabulated including values of **uv**, and **u+v.**

A graph of **uv** against **u+v** is plotted and the slope **s** of such a graph is equal to the focal length **f** of the mirror.



(c) A concave mirror M of focal length 20.0cmis placed 90cm in front of a convex mirror, N, of focal length 12.5cm. An object is placed on the common axis of M and N at a point 25.0 cm in front of M.

(i) Determine the distance from N of the image formed by reflection, first in M and then in N. (05marks)



For M

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{20} = \frac{1}{25} + \frac{1}{v}$; v = 100cm

For mirror N

u = -10cm, f = -12.5cm, v = ?

$\frac{-1}{12.5} = \frac{-1}{10} + \frac{1}{v}$; v = 50cm

So the distance of the final image from N is 50cm

(ii) find the magnification of the image formed in (c)(i) above (02marks)

Let the magnification due to M and N be M_1 and M_2 respectively

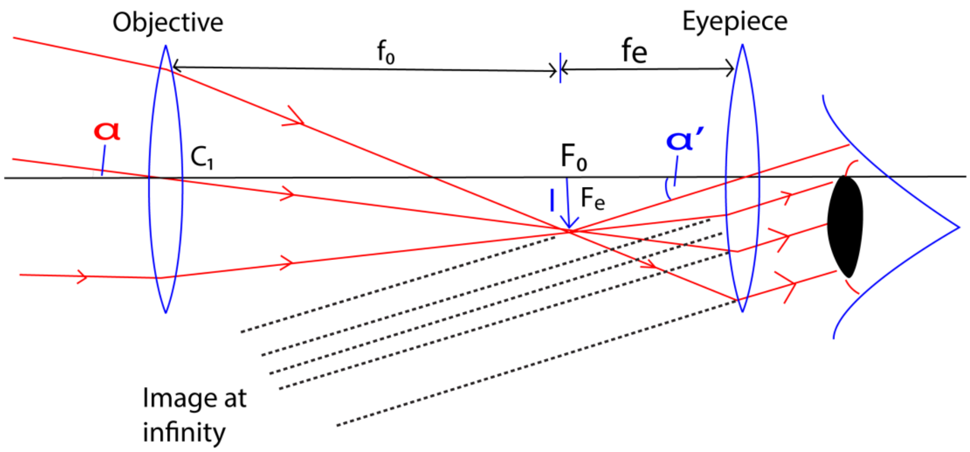
$M_1 = \frac{100}{25} = 4$ and $M_2 = \frac{50}{10} = 5$

Resultant magnification, M = M_1 x M_2 = 4 x 5 = 20

27. (a) What is meant by reversibility of light as applied to formation of a real image by a convex lens? (02marks)

Reversibility of light is the phenomenon of light travelling along its original path when its direction of travel is reversed.

(b) (i) Draw a ray diagram to show the action of an astronomical telescope in normal adjustment. (03marks)



Telescope in nornal use

(ii) Derive the expression for magnifying power of the telescope in (b)(i) above in terms of the focal length, f_0 and f_e of the objective and eyepiece respectively.

For an aided eye (using the instrument)
For small angle, tanα' ≈ α' for small angle in radians
$\alpha' = \frac{h}{f_e}$ ……………………………………………. (i)
Where, h, is the height of image I, f_e is the focal length of eye piece
For unaided eye
$\alpha = \frac{h}{f_0}$ ……………………………………………. (ii)
f_0 is the focal length of objective lens
Combining equations (i) and (ii)
Magnifying power, m = $\frac{\alpha'}{\alpha} = \frac{h}{f_e} \div \frac{h}{f_o} = \frac{f_o}{f_e}$

(iii) The objective and eyepiece of an astronomical telescope have focal length of 75.0cm and 2.5cm respectively. Find the separation of the two lenses if the final image is 25cm from eyepiece. (04marks)

Action of eyepiece
f = 2.5cm, v = -25cm (image is virtual)

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{u} = \frac{1}{2.5} + \frac{1}{25}$; u = 2.3cm

Separation of lenses = f_0 + u = 75 + 2.3 = 77.3cm

(c) (i) What is the significance of the eye-ring of an astronomical telescope? (02marks)

The eye ring is the best position where the eye is placed to view the image clearly

(ii) State two advantages of a reflecting telescope over refractive telescope. (02marks)

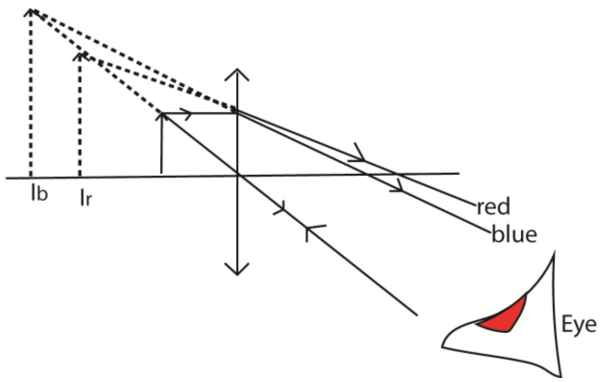
- has no spherical aberration

- has no chromatic aberration since there is no refraction

- high resolution since the objective lens can be made wider

- cheap since only one surface of objective requires grinding

(d) Explain why chromatic aberration is not observed in a simple microscope. (04marks)



In the lens the light rays from the object are dispersed to form colored images I_b and I_r due the different refractive indices; but when the eye is placed close to the lens, the mages subtend the same angle to the eye. The images overlap reducing chromatic aberration

28. (a) (i) What is meant by refraction of light? (01mark)

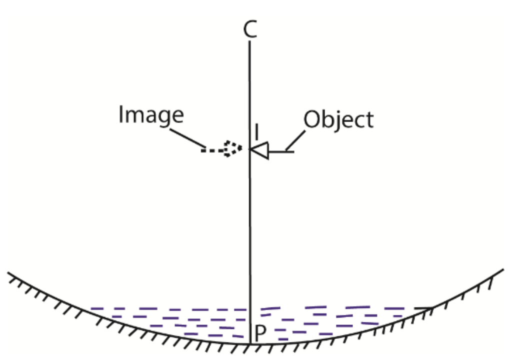
Refraction is the change in the direction of light from one medium to another due to different velocities of light.

(ii) State the laws of refraction. (02marks)

- incident ray, refracted ray and the normal at the point of incidence all lie in the same plane
- the ration of sini to sinr is constant for a given pair of media.

(b) Describe how the refractive index of a liquid can be determined using a concave mirror. (05marks)

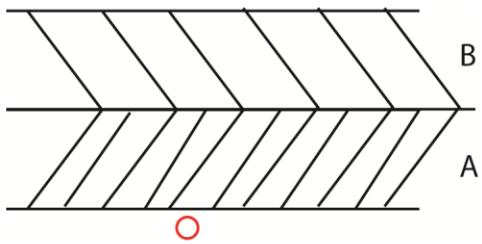
An experiment to determine refractive index of a liquid using a concave mirror



- A clamped pin with its tip along the principal axis above the concave mirror is coincided with its image at C and distance PC is measured

- A small quantity of the liquid under test is poured into a concave mirror and a new point I at which the object pin coincides with its image is obtained.
- Distance IP is measured.
- The required refractive index of a liquid, $\boldsymbol{n_l} = \frac{\boldsymbol{PC}}{\boldsymbol{IP}}$

(c)



Two parallel sided blocks A and B of thickness 4.0cm and 5.0cm respectively are arranged such that A lies on an object O as shown above.

Calculate the apparent displacement of O when observed from directly above, it the refractive indices of A and B are 1.52 and 1.66 respectively. (05marks)

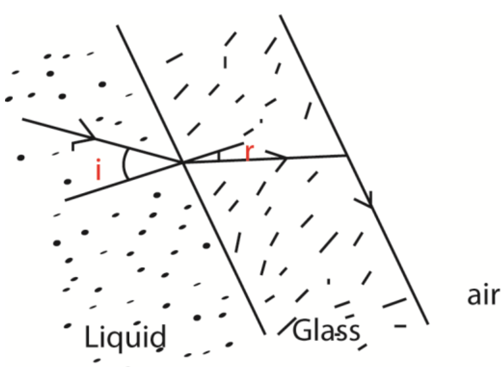
$$d = t_1\left(1 - \frac{1}{n_1}\right) + t_2\left(1 - \frac{1}{n_2}\right)$$

$$= 4\left(1 - \frac{1}{1.52}\right) + 5\left(1 - \frac{1}{1.66}\right) = 3.36\text{cm}$$

(d) (i) state two applications of total internal reflection. (02marks)

- Determination of refractive index of transparent medium
- Communication through optical fibers
- Radio broadcasting
- In binoculars

(ii)



In the figure above, a parallel sided glass slide is in contact with a liquid on one side and air on the other side. A ray of light incident on the glass slide from the liquid emerges in air along the glass air interface.

Derive an expression for the absolute refractive index, n_l, of the liquid in terms of absolute refractive index, n, of glass and the angle of incidence, i.

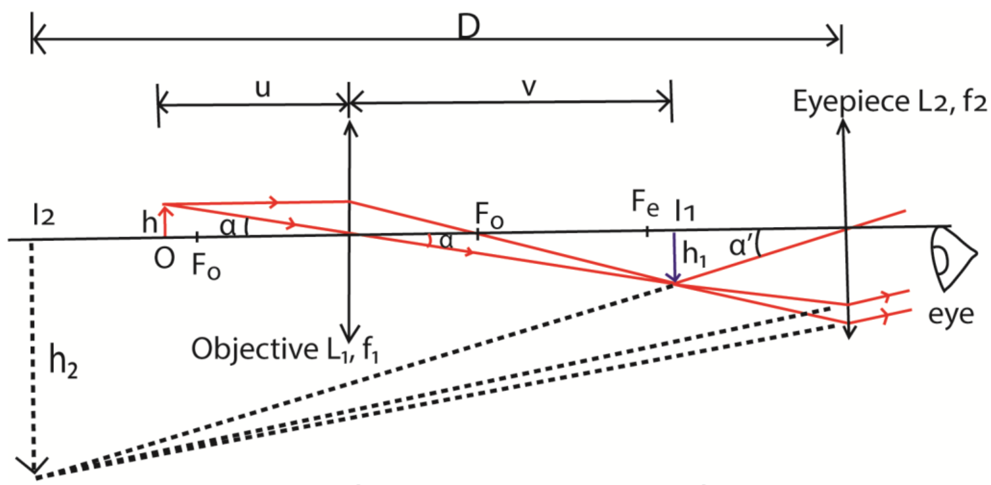
By Snell's law, nsini = constant

$n_L \sin i = n_g \sin r = n_a \sin 90^0$

$n_L = \frac{1}{\sin i}$

29. (a) (i) Define angular magnification of a compound microscope. (01mark)

(ii) Draw a labelled ray diagram to show how two converging lenses can be used to make a compound microscope in normal adjustment. (03marks)



Compound microscope in normal use

The objective forms a real magnified image of the object at a point between the principal focus of the eye piece and it optical center. The eye piece forms a virtual image at least distance of distinct vision (25cm)

(b) An object of size 2.0mm is placed 3.0cm in front of the objective of a compound microscope. The focal length of the objective is 2.5cm while that of the eye piece is 5.0cm. The microscope forms a virtual image of the object at the near point of the eye. Find the

(i) the size of the final image (05marks)

Action of objective lens

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{2.5} = \frac{1}{3} + \frac{1}{v}$; v = 15cm

Objective magnification = $\frac{v}{u} = \frac{15}{3} = 5$

Action of eye piece

f = 5.0cm, V = -25cm (image is virtual) u=?

$\frac{1}{5} = \frac{1}{u} - \frac{1}{25}$; u = 4.2cm

Eye piece magnification= $\frac{v}{u} = \frac{25}{4.2} = 6$

Effective magnification, M = M_1 x M_2 = 5 x 6 = 30

Height of the final image = M x h = 30 x 2 = 60mm

(ii) position of the eye ring

Eye ring is the image of objective in eye piece

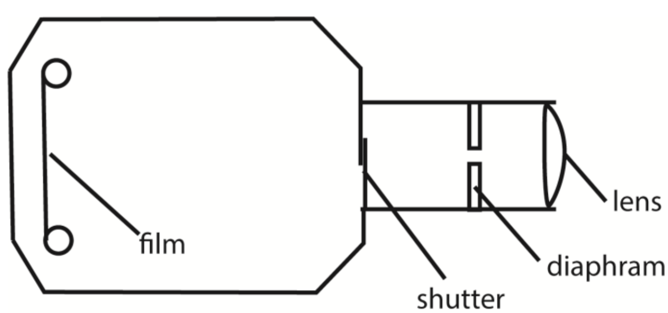
u = separation of lenses = $v_0 + u_e$ = 15 + 4.2 = 19.2cm

$\frac{1}{5} = \frac{1}{19.2} + \frac{1}{v}$; v = 6.76cm

Eye ring is 6.76cm from eye piece.

(c) (i) With the aid of labelled diagram, describe the essential parts of a photographic camera. (02marks)

Lens camera



- The lens focused light from the object on to film
- The diaphragm controls the amount of light reaching the film
- The shutter controls the exposure time of light reaching the film
- Film contain photosensitive chemicals and is where the image is stored.

(ii) Explain how chromatic and spherical aberration are minimized in a photographic camera. (02marks)

Correction of chromatic aberration

- Use **lenses** made of low-dispersion glasses, especially those containing fluorite

- By using combination of lenses of opposite nature (convex & concave) or chromatic doublet such that the dispersion produced by one lens is reversed by another.
- Placing the eye close to the lens such that images due to different colours subtend the same angle at the eye.

Means of reduction of spherical aberration

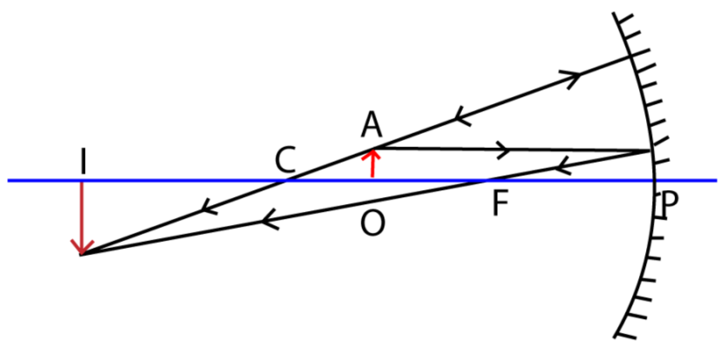
- Using lenses with an aspheric surface
- Using lens of small aperture.
- Using a stopper such that only light incident on the middle of the lens pass, but this method reduces the brightness of the image since it reduces the amount of light energy passing through the lens.

30. (a) Define the focal length of a concave mirror. (01mark)

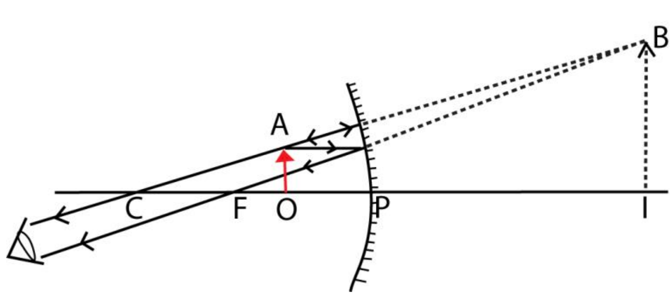
Focal length "f" of a concave mirror: it is the distance from the pole of the mirror to the point where paraxial rays incident and parallel to the principal axis converge after reflection by the mirror.

(b) An object is placed at a distance u from a concave mirror, the mirror forms an image of the object at a distance v. Draw diagrams to show the path of light rays when an image formed is

(i) real (02marks)

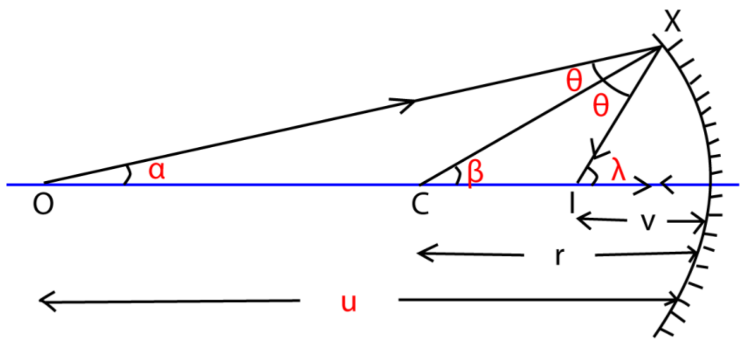


(ii) virtual (02marks)



(c) Use a geometrical diagram to derive the relation, $\frac{1}{v} + \frac{1}{u} = \frac{1}{f}$ (05marks)

Consider the incidence of ray **OX** on to a concave mirror from a point object **O** placed along the principal axis and then suddenly reflected in the direction XI making an angle ? with the normal CX.



Ray OP strikes the mirror incident normally at P and thus reflected back along its own path. The point of intersection I of the two reflected rays is the image position.

From Δ OXC; α + θ = β ………………………………… (i)

From Δ CXI; β + θ = λ ………………………………… (ii)

Eqn. (i) and (ii)

α + λ = 2β …………………………………………………… (a)

If X is close to P then.

$\alpha \approx \tan\alpha = \frac{XP}{u}$; $\beta \approx \tan\beta = \frac{XP}{r}$; $\lambda \approx \tan\lambda = \frac{XP}{v}$

Equation (a) becomes

$$\frac{XP}{u} + \frac{XP}{v} = \frac{2XP}{r}$$

$$\frac{1}{u} + \frac{1}{v} = \frac{2}{r}$$

But r = 2f

Thus, $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

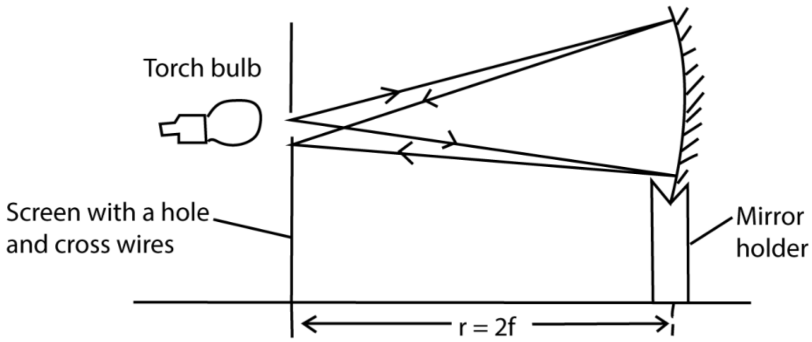
(d) A concave mirror of radius of curvature 40.0cm contains a liquid to a height 2.0cm. A pin clamped horizontally and viewed from above is observed to coincide with its image when it is 27.0 above the surface of the liquid. Calculate the refractive index of the liquid. (04marks)

R = 40.0cm, d = 2.0cm and h=27.0cm

$$n = \frac{R-d}{h} = \frac{40-2}{27} = 1.41$$

(e) You are provided with the following pieces of apparatus:

A screen with a cross wire, a lamp, a concave mirror, and a meter rule. Describe an experiment to determine the focal length of the concave mirror using the above apparatus.

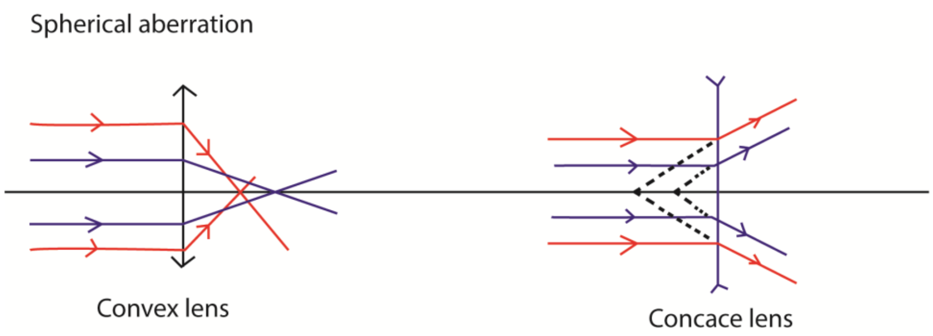


Align an illuminated bulb, a screen and a concave mirror mounted in a holder as shown above. The mirror position is adjusted to or from the screen until a sharp image of the cross-wire is formed on the screen besides the object. The distance **r** of the mirror from the screen is measured.

The required focal length $\mathbf{f} = \frac{r}{2}$

31. (a) (i) Explain the terms chromatic and spherical aberration in lenses. (04marks)

C***hromatic aberration*** (CA), also called chromatic distortion and spherochromatism, is a failure of a lens to focus all colors to the same point. It occurs due to dispersion since refractive index of the lens varies with the wave length of the color of light.



Spherical aberration occurs when the lens fails to focus all rays falling on it to the same point. Thus images formed by the lens at large apertures are therefore unsharp or blurred at the edges.

(ii) How are the aberrations in (a)(i) above minimized in reflecting telescope? (03marks)

Correction of chromatic aberration

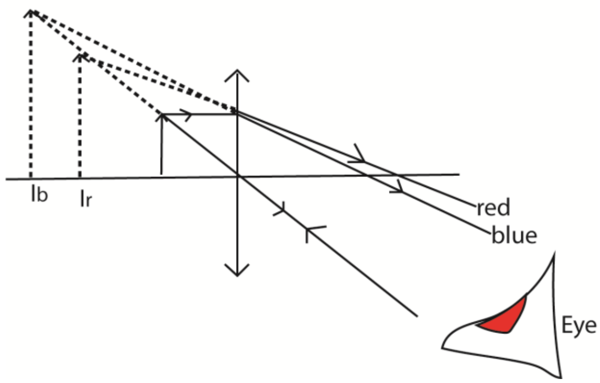
- Use **lenses** made of low-dispersion glasses, especially those containing fluorite
- By using combination of lenses of opposite nature (convex & concave) or chromatic doublet such that the dispersion produced by one lens is reversed by another.

- Placing the eye close to the lens such that images due to different colours subtend the same angle at the eye.

Means of reduction of spherical aberration

- Using lenses with an aspheric surface
- Using lens of small aperture.
- Using a stopper such that only light incident on the middle of the lens pass, but this method reduces the brightness of the image since it reduces the amount of light energy passing through the lens.

(b) With the aid of a diagram, explain why the image seen in the magnifying glass is almost free from chromatic aberration when the eye is close to the lens. (04marks)



In the lens the light rays from the object are dispersed to form colored images I_b and I_r due the different refractive indices; but when the eye is placed close to the lens, the mages subtend the same angle to the eye. The images overlap reducing chromatic aberration

(c) A converging lens is used to form an image of an object 1.2m away on the screen 0.05m from the lens.

(i) Find the focal length of the lens. (03marks)

Since the image is formed on a screen, then it is real, thus, v= 1.2m, u = 0.05m

From $\frac{1}{u} + \frac{1}{v} = \frac{1}{f}$

$\frac{1}{0.05} + \frac{1}{1.2} = \frac{1}{f}$; f = 0.048m

(ii) If the lens is now used to form an image of a distant object, how far from the screen would the clear image be formed? (02marks)

For the distant object, the image is formed at F = 0.048

The distance from the screen = 0.05- 0.048 = 0.002m

(iii) State the type of lens that should be placed close to the first lens in order to enable the image in (c)(ii) above be formed on the screen. (01mark)
Diverging lens

(iv) Calculate the focal length of the lens you have stated in (c)(iii) above. (03marks)
Let its focal length be f
Using $\frac{1}{F} = \frac{1}{f_1} + \frac{1}{f}$
$\frac{1}{0.05} = \frac{1}{0.048} + \frac{1}{f}$; f = -1.2m

32. (a) What is meant by the following terms as applied to a telescope?
(i) magnifying power (01mark)

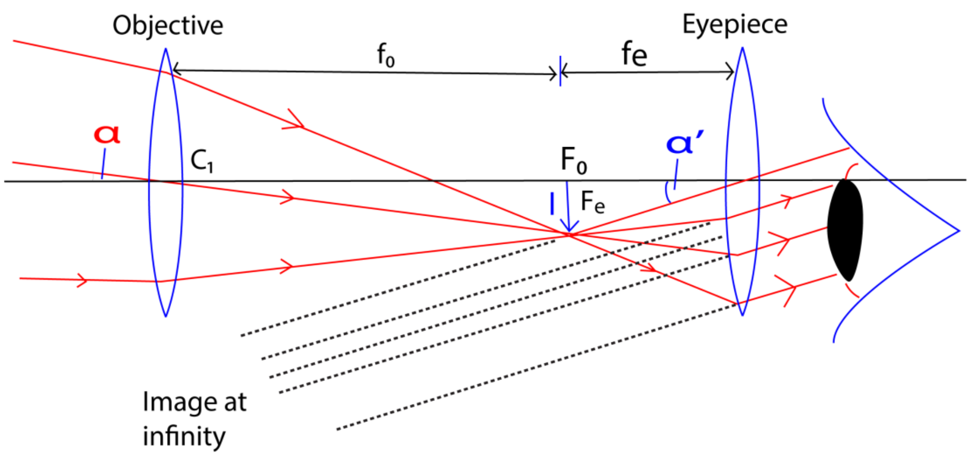
This is the ratio of the angle α' subtended at the eye by the image when using an a telescope to the angle, α, subtended at unaided eye by the object.

$M = \frac{\alpha'}{\alpha}$ where α' and α are in radians

(ii) eye-ring (01mark)

It is the image of objective in the eye piece. It is the best position for the eye to see the image clearly.

(b) (i) Draw a ray diagram to show the formation of the final image by an astronomical telescope in normal adjustment. (03marks)



Telescope in nornal use

(ii) With the aid of the diagram in (b) (i), derive an expression for the magnifying power of an astronomical telescope in normal adjustment. (04marks)

To obtain the magnification, m, we assume the eye is very close to the eye piece.

For an aided eye (using the instrument)
For small angle, tanα' ≈ α' for small angle in radians

$\alpha' = \frac{h}{f_e}$ ………………………………………… (i)

Where, h, is the height of image I, f_e is the focal length of eye piece

For unaided eye

$\alpha = \frac{h}{f_0}$ ………………………………………….. (ii)

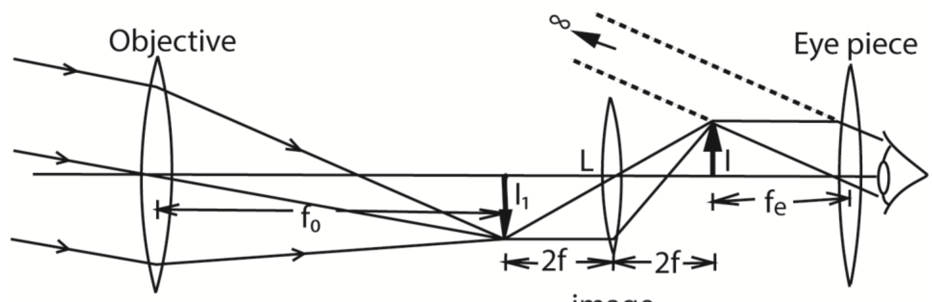
f_0 is the focal length of objective lens

Combining equations (i) and (ii)

Magnifying power, m = $\frac{\alpha'}{\alpha} = \frac{h}{f_e} \div \frac{h}{f_o} = \frac{\boldsymbol{f_o}}{\boldsymbol{f_e}}$

(iii) Give the disadvantage of the telescope in (b)(i) when used to view distant objects on earth. Describe how the telescope can be modified to overcome this disadvantage. (04marks)

- It forms inverted image. This can be overcome by using an erect lens or converting it into a terrestrial telescope as shown in the figure below.



(c) Find the separation of the eye-piece and objective of an astronomical telescope of magnifying power 20 and in normal adjustment, if its eyepiece has a focal length of 5cm. (04marks)

Focal length of objective,

M = $\frac{f_0}{f_e}$

⇨ f0= 20 x 5 = 100cm

Separation = $f_0 + f_e$ = 100 + 5 = 105cm

(d) State three advantages of a reflecting telescope over a refracting telescope. (03marks)

Advantages of reflecting telescopes

(i) There is no chromatic aberration since no refraction occurs at the objective

(ii) There is no spherical aberration since a paraboloidal mirror is used.

(iii) It is cheaper to construct since only one surface requires grinding.

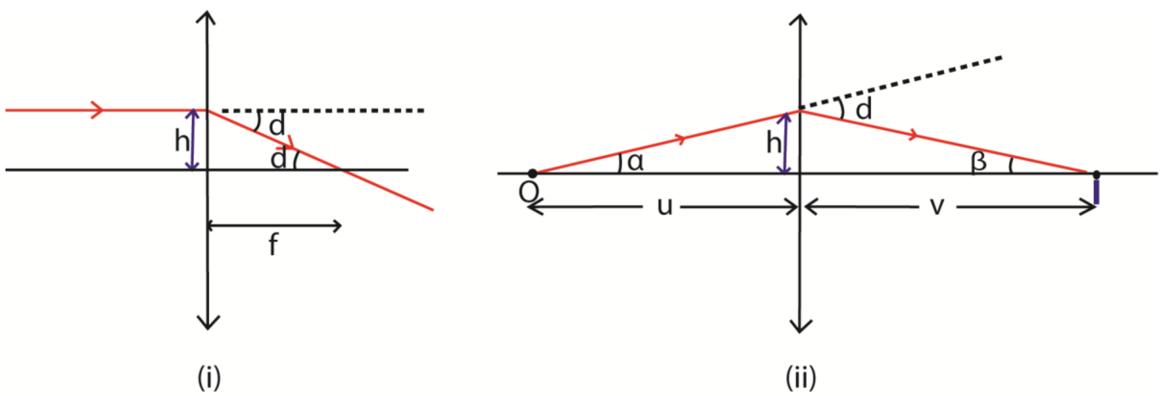
(iv) When curved mirrors of large diameter are used, a greater resolving power is obtained.

33. (a) Define the terms principal focus and power of a lens. (02marks)

Principal focus "F" of a lens is a point on the principal axis where paraxial rays incident on the lens and parallel to the principal axis converge or appear to diverge from after refraction by the lens.
Power lens is the reciprocal of the focal length in meters

(b) Derive the relation between the focal length, f, objective distance, u, and image distance, v, for a thin lens. (07marks)

Consider in each case a ray incident on the same lens at a small height **h** above the principal axis as shown:



From Fig (i), the ray parallel and close to principal axis is converged to the focal point **F** and suffer a **small** deviation **d**

where **d** $\approx$ tan d $= \frac{h}{f}$---------------------------------- (i)

From Fig (ii), the ray from a point object **O** suffers the same small deviation **D** to give rise to a point image **I**.

From geometry, d = α + β   where $\alpha \approx \tan\alpha = \frac{h}{u}$ and $\beta \approx \tan\beta = \frac{h}{v}$

$d = \frac{h}{u} + \frac{h}{v}$ ----------------------------- (ii)

Equating equations (i) and (ii) gives

$$\frac{h}{f} = \frac{h}{u} + \frac{h}{v}$$

Thus $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

(c) A thin converging lens, P, of focal length 10cm and a thin diverging lens, Q, of focal length 15cm are placed coaxially 50cm apart. If an object, O, is placed 12cm from P on the side remote from Q.

(i) find the position, nature and magnification of the final image. (07marks)

Action of P

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{u} = \frac{1}{10} - \frac{1}{12}$; u = 60cm

Action of Q

u = 50 -60 = -10cm

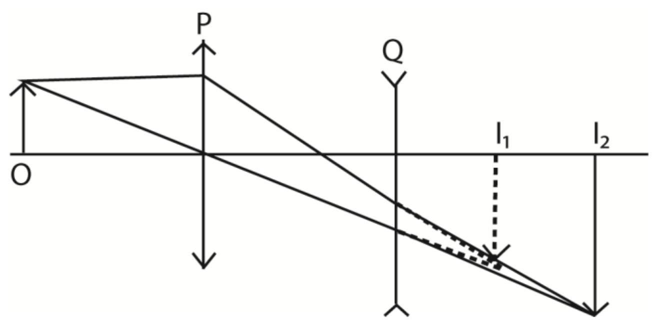
$\frac{1}{v} = -\frac{1}{15} - \left(-\frac{1}{10}\right)$, v = 30cm

The image is real 30cm from Q

Magnification, $M = M_1 \times M_2$

$$= \frac{v_1}{u_1} x \frac{v_2}{u_2} = \frac{60}{12} x \frac{30}{10} = 30$$

(ii) Sketch a ray diagram to show the formation of the final image. (02marks)



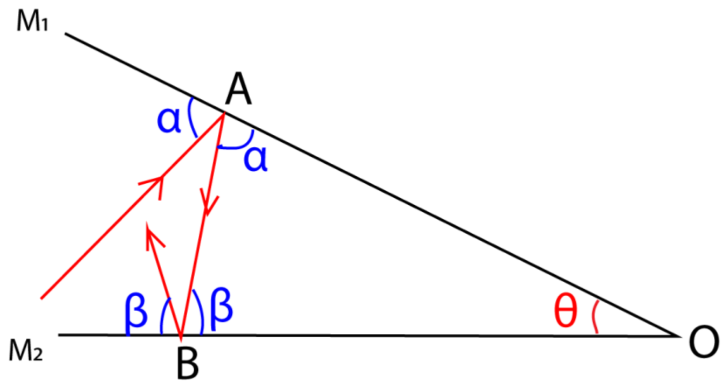
(d) Explain why lenses of narrow aperture are preferred to lenses of wide aperture in optical instruments (02marks)

Lenses with narrow aperture minimize spherical aberration because they only allow paraxial rays to be focus to one spot

34. (a) (i) State the laws of reflection of light. (02marks)
- The incident ray reflected ray and the normal at the point of incidence all lie in the same plane
- Angle of incidence is equal to the angle of reflaction.

(ii) Show that an incident ray of light reflected successively from two mirrors inclined at an angle θ to each other, is rotated through 2θ. (04marks)

Consider an incident ray of light reflected successively from two mirrors M_1 and M_2 inclined at an angle θ to each other at O as shown



Let the glancing angles at A and B be α and β respectively.

Deviation by M_1 = 2α (clockwise direction)

Deviation by M_2 = 2β (clockwise direction)

Total deviation = $2\alpha + 2\beta$

= $2(\alpha + \beta)$ ----------------------(i)

But, $\alpha + \beta + \theta = 180°$ (Angle sum of a triangle)

$\Rightarrow$ $\alpha + \beta = (180° - \theta)$ ---------------------(ii)

Combining equation (i) and (ii) gives

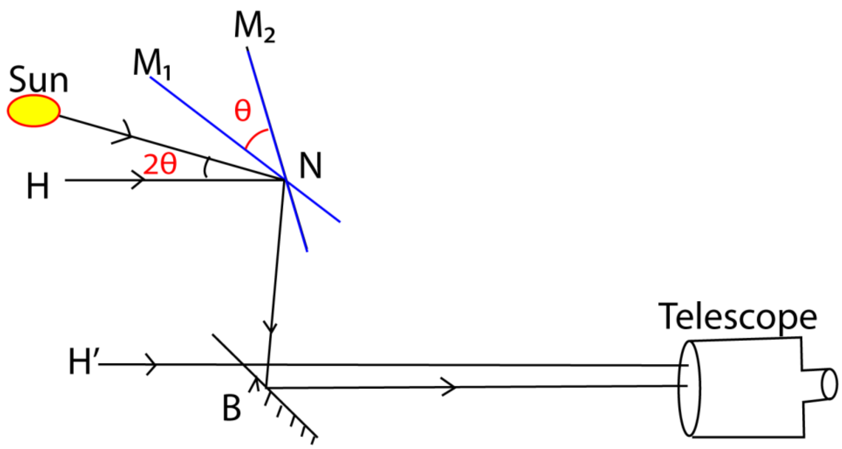
Total deviation = $2(180° - \theta)$ (clockwise direction)

= $360° - 2\theta$ (clockwise direction)

= 2θ (anti-clockwise direction)

(b) Describe how a sextant is used to measure the angle of elevation of a sun. (05marks)

The principle of a sextant is that, when the ray of light is reflected from two mirrors in succession in the same plane, then the angle between the incident and reflected ray is two times the angle between the mirrors.



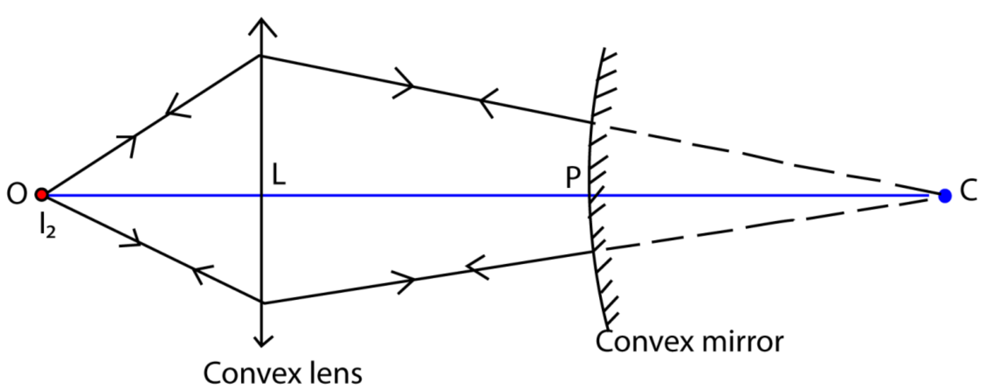
- A sextant consists of a fully silvered mirror M_1which can be rotated about a horizontal axis and a fixed half silvered mirror B.
- Mirror M_1 is adjusted to become parallel to B by rotating it until the image of the horizon (the line at which the earth's surface and the sky appear to meet), H' is seen directly through the unsilvered part of mirror B by successive reflection in mirror M_1 and B respectively

  Note that, if the two mirrors are parallel, the incident ray from any observed body must be parallel to the observer's line of sight through the horizon glass
- The mirror M_1 is rotated to position M_2 such that the image of the horizon H, and the sun coincides at H'
- The angle of rotation is measured from the scale on the instrument. The elevation of the sun is 2θ.

(c) (i) Describe an experiment to measure the focal length of a convex mirror. (05marks)

Determination of focal length of a convex mirror.

Method (1) Using a convex lens.



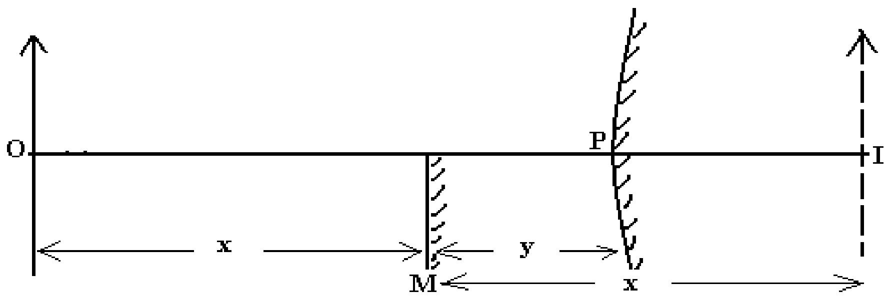
- The apparatus is arranged as shown above

- An object, O is placed in front of a convex lens L and its image formed at C
- The distance LC is measured and recorded.
- The convex mirror whose focal length, f, is required is placed is placed between L and C with its reflecting surface facing the lens.
- The lens is then moved along the axis, OC until a converging beam incident normally on the mirror forms its image at O
- Distance LP is measured

PC = LC – LP thus, f can be determined from f = $\frac{PC}{2}$

Or

Method (2) using No parallax.



(i) An object pin **O** is placed in front of a convex mirror as shown in the diagram above

(ii) A virtual diminished image is formed at **I**.

(iii) A plane mirror **M** is placed between **O** and **P** so as to intercept half the field of view of the convex mirror.

(iv) Mirror **M** is adjusted until its own image of **O** coincides with **I** by no parallax method.

(v) Measure the distances **x** and **y.**

(vi) The focal length of the mirror is calculated from $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Where u = (x + y) and v = (y-x)

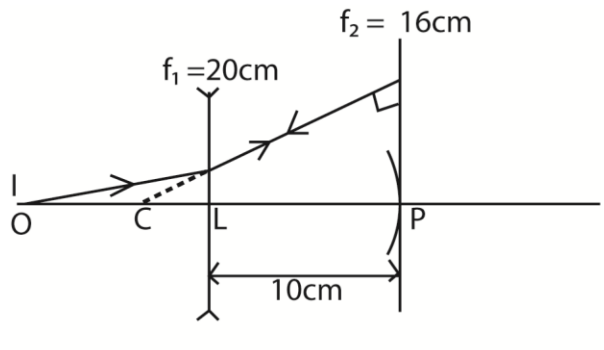
Note:

(i) The two images coincides when they are as far behind the plane mirror as the object is in front.

(ii) Substituting for u = x + y and v = y – x in the mirror formula gives $f = \frac{y^2 - x^2}{2y}$

(ii) A concave lens of focal length 20cm is placed 10cm in front of a concave mirror of focal length 16cm. Calculate the distance from the lens at which an object would coincide with its image. (04marks)

Ray diagram



The object to coincide with the image if the rays strike the concave mirror normally

i.e. CP = $2f_2$ = 16 x 2 = 32cm

but LP = 10cm

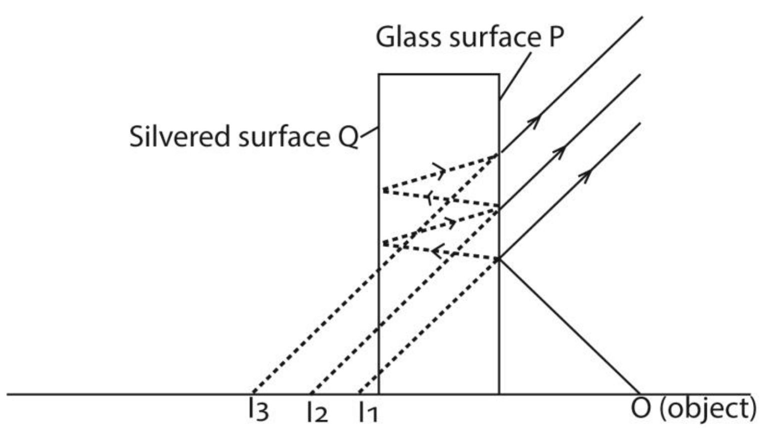
⇨ CL = 22cm
For concave mirror
Object distance be = u
Image distance = -22cm

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$-\frac{1}{22} = \frac{1}{u} - \left(\frac{-1}{22}\right); \text{ u = -220cm}$$

35. (a) Explain with aid of a diagram, why a thick plane mirror forms multiple images. (04marks)

Formation of multiple images in thick plane mirror

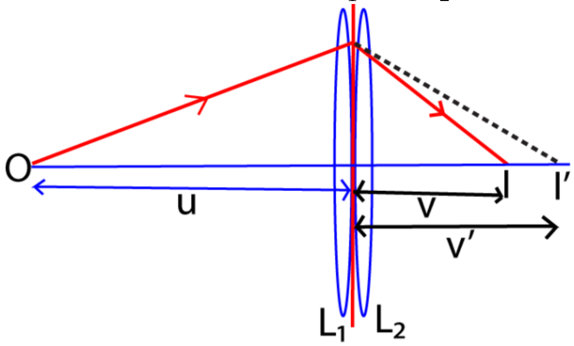


Multiple images are formed due to partial reflection and refraction at the non-silvered surface of the mirror.

- İmage I_1 is formed by reflection on the glass surface P
- The image I_2 (the brightest is formed by reflection of the most light on the silvered surface Q
- Others by partial refraction

(b) Derive an expression for the focal length of a combination of two thin converging lenses in contact, in terms of their focal lengths. (05marks)

Consider two thin lenses L_1 and L_2 of focal length f_1 and f_2.



For lens L_1,

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

$$\frac{1}{f_1} = \frac{1}{u} + \frac{1}{v'} \quad \text{..........................(i)}$$

For L_2, I' acts as the object

$$\frac{1}{f_2} = \frac{1}{-v'} + \frac{1}{v} \quad \text{........................(ii)}$$

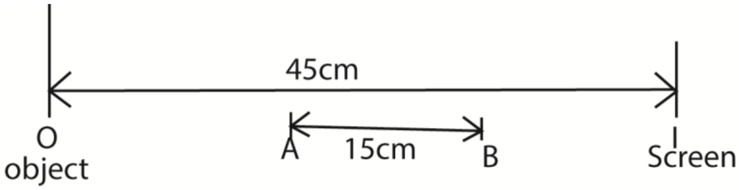
Eqn. (i) + Eqn. (ii)

$$\frac{1}{f_2} + \frac{1}{f_2} = \frac{1}{u} + \frac{1}{v} = \frac{1}{F}$$

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

Where F is the focal length of combined lens,

(c)



In the diagram above, the image of the object is formed on the screen when a convex lens is placed at A or B. if A and B are 15cm apart, find the

(i) Focal length of the lens. (03marks)

Since O and I are conjugate points, then for position A

u = OA = $\frac{1}{2}(45 - 15)$ = 15cm

v = 45- 15 = 30 cm

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{f} = \frac{1}{15} + \frac{1}{30}$

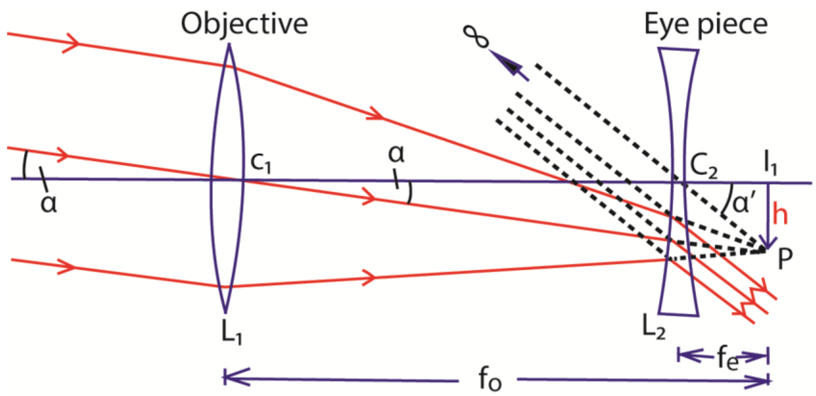
f = 10cm

(ii) Magnification of the image formed when the lens is at B. (03 marks)

u = 30.0cm, v = 15cm

M = $\frac{v}{u} = \frac{15}{30} = 0.5$

(d) Draw a ray diagram of a Galilean telescope and derive the expression for magnifying power when in normal adjustment. (05marks)



Galilean telescope in normal adjustment

Magnifying power, m = $\frac{\alpha'}{\alpha}$

For small angles, α and α' are measured in radians

$\alpha \approx \tan \alpha = \frac{h}{fe}$ and $\alpha' \approx \tan \alpha = \frac{h}{fo}$

Substituting for α and α'

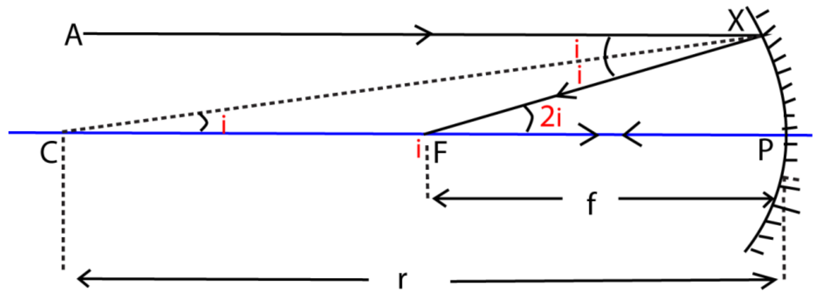
Magnifying power, m = $\frac{\alpha'}{\alpha} = \frac{h}{f_e} \div \frac{h}{f_o} = \frac{\boldsymbol{f_0}}{\boldsymbol{f_e}}$

36. (a) (i) State the laws of reflection of light. (02marks)

- Incident ray reflected ray and the normal at the point of incidence all lie in the same plane
- The angle incidence is equal to the angle of reflection.

(ii) Show, with the aid of a ray diagram, that the radius of curvature of a concave mirror is twice the focal length of the mirror. (05marks)

Consider the reflection of a paraxial ray, AX, parallel to the principal axis of a concave mirror as shown.



Taking FP = focal length and C = centre of curvature, then, CX, is the normal to the mirror surface and, CP, is the radius of curvature.
tan 2i ≈ 2i

If, X, is close to P, then tan 2i ≈ 2 i $= \frac{XP}{FP}$--------------- (for small angles)

$$\Rightarrow \quad 2i = \frac{XP}{FP} \quad \text{---(i)}$$

Similarly tan i ≈ i = $\frac{XP}{CP}$

$$i = \frac{XP}{CP} \quad \text{--- (ii)}$$

Combining equations (i) and (ii) gives,

$$2\frac{XP}{CP} = \frac{XP}{FP}$$

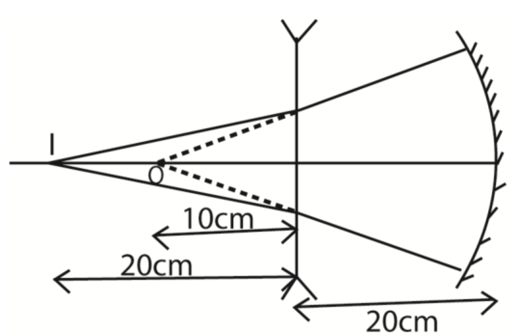
Canceling XP throughout and simplifying for CP gives

CP = 2FP where CP = r, FP = f

∴**r = 2f**.

(b) An object is placed 20cm in from of a diverging lens place coaxially with a concave mirror of focal length 15cm. When the concave mirror is 20cm from the lens, the final image coincides with the object.

(i) Draw a ray diagram to show how the final image is formed. (02marks)



(ii) Determine the focal length of the diverging lens. (04marks)

Action of the diverging lens, u = -10cm

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{f} = \frac{1}{-10} + \frac{1}{20}$$

f = -20cm

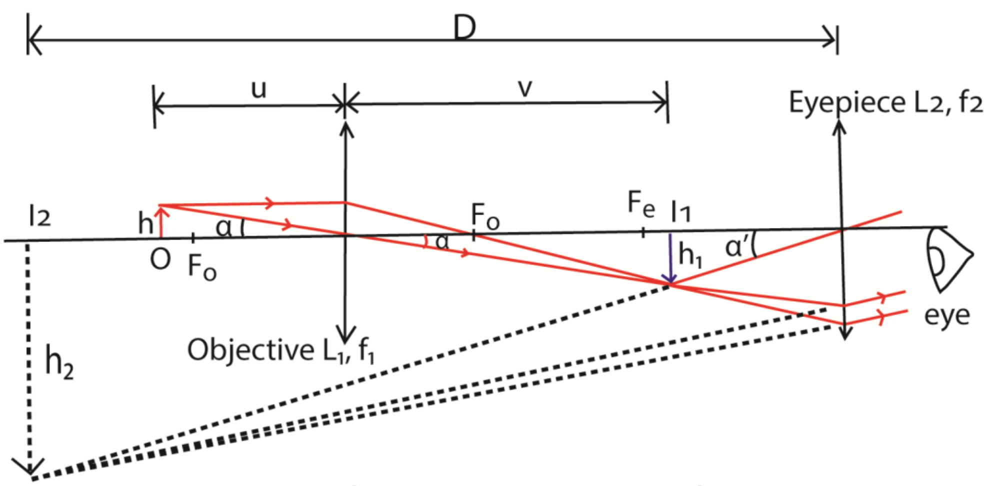
(c) (i) Define angular magnification of an optical instrument. (01mark)

Angular magnification is the ration of the angle subtended by the final image when using an instrument to the angle subtended by the object at the unaided eye

(ii) What is meant by exit pupil of a compound microscope? (02marks)

The exit pupil is the image of objective passes through the exit pupil (assuming no loss at the lens surfaces)

(iii) Describe with the aid of a diagram, the structure and action of a compound microscope in normal adjustment. (04marks)



Compound microscope in normal use

The objective forms a real magnified image of the object at a distance less than f_e from the eye piece.

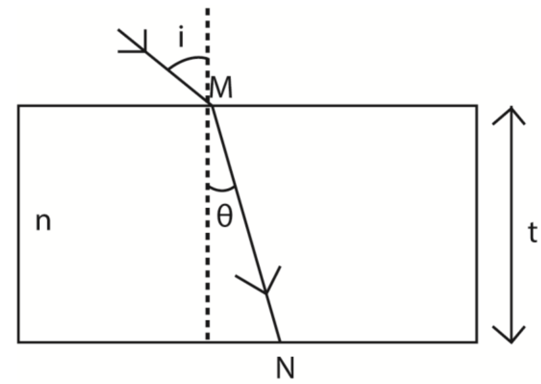
The eye piece form a virtual magnified image of the intermediate image at nearest distance of distinct vision (D=25 cm)

37. (a) (i) What is meant by a refractive index of a material? (01marks)
Refractive index of a material is the ratio of the speed of light in the vacuum to the speed of light in the medium

Or

It is the ratio of sine of an angle of incidence in the vacuum to sine of angle of refraction in the medium for light entering the medium from the vacuum

(ii) Mono chromatic light incident on a block of material placed in a vacuum is refracted through an angle θ. If the block has a refractive index, n and is of thickness, t, show that light takes a time $\frac{ntsec\,\theta}{c}$ to emerge from the block where c is the speed of light in the vacuum. (03marks)



Let T be the time spent in the medium

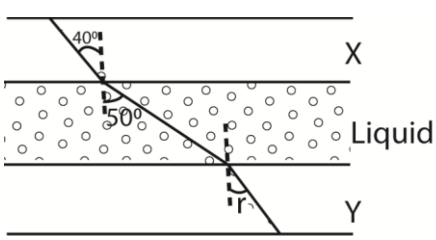
V = $\frac{MN}{T}$

But $\frac{t}{MN} = cos\theta$ => MN = tsecθ

V = $\frac{tsec\theta}{T} = \frac{c}{n}$

T = $\frac{ntsec\theta}{c}$

(b)



In the figure above, a layer of liquid is confined between two transparent plates X and Y of refractive indices1.54 and 1.44 respectively. A ray of monochromatic light making an angle of 40^0 with the normal to the interface between X and the liquid is refracted through an angle of 500 by the liquid. Find the

(i) Refractive index of the liquid (03marks)
nsini = constant
1.54sin 40^0 =nsin50^0
n = 1.29

(ii) Angle of refraction, r, in the medium, Y. (02marks)
1.44sin r = 1.54sin40^0
r = 43.4^0

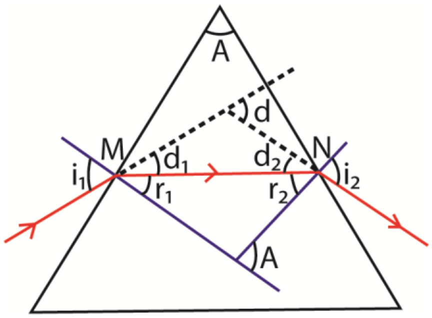
(iii) Minimum angle of incidence in medium X for which the light will not emerge in Y (04marks)

$1.54\sin i = 1.44\sin 90^0$

$i = 40.5^0$

(c) (i) A ray of monochromatic light is incident at a small angle of incidence on a small angle prism in air. Obtain the expression, d = (n-1)A for deviation of light by the prism (05marks)

The small refracting angle of this prism causes the angle $\mathbf{i_1, r_1, r_2}$ and $\mathbf{i_2}$ to be small such that $\mathbf{\sin i_1 \approx i_1, \sin r_1 \approx r_1 \sin r_2 \approx r_2}$ and $\mathbf{\sin i_2 \approx i_2}$.



From the diagram, $d = d_1 + d_2$

but $d_1 = i_1 - r_1$ and $d_2 = i_2 - r_2$

⇨ $d = (i_1 - r_1) + (i_2 - r_2)$

On simplifying $d = i_1 + i_2 - (r_1 + r_2)$

but $r_1 + r_2 = A$

$d = i_1 + i_2 - A$ ----------------------(a)

At M Snell's law becomes.

$n_a \sin i_1 = n \sin r_1$

For small angles this gives $i_1 = nr_1$ --------------------------------(b)

Similarly at N Snell's law becomes $i_2 = nr_2$ --------------------------------(c)

Substituting equation (b) and (c) in (a) gives

$d = nr_1 + nr_2 - A$

$d = n(r_1 + r_2) - A$

but $r_1 + r_2 = A$

⇨ $d = nA - A$

∴ $\mathbf{d = (n - 1)A}$

(ii) Light of two wavelengths is incident at a small angle on a thin prism of refractive angle 50 and refractive indices 1.52 and 1.50 for the two wavelength. Find the angular separation of the two wavelengths after refraction by the prism. (03marks)

$d_1 = (n_1-1)A = (1.52 - 1)5^0 = 2.60^0$

$d_2 = (n_2 - 1)A = (1.50 – 1)5^0 = 2.50^0$

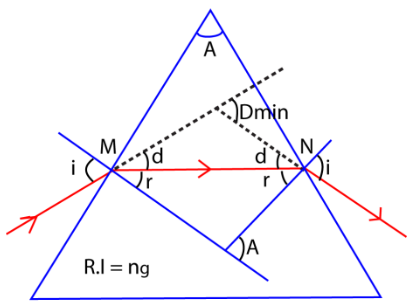
Angular dispersion = $d_1 – d_2 = 2.60 – 2.50 = 0.10^0$

38. (a) State the laws of refraction of light (02marks)

- the incident ray, refracted ray and the normal at the point of incidence all lie in the same plane
- for given frequency of light, the ratio of the angle of incidence to sine of angle of refraction is constant for a given pair of media.

(b) (i) Derive an expression for the refractive index of a prism in terms of refracting angle A and the angle of minimum deviation, D. (05marks)

At minimum deviation, light passes **symmetrically** through the prism. That is to say, the angle of incidence is equal to the angle of emergence.



Consider a ray on one face of the prism at an angle **i1**and leaves it at an angle **i2** to the normal as shown

For minimum deviation, $i_1 = i_2 =$ **i** and $r_1 = r_2 =$ **r**. From the diagram, Dmin = d + d

Dmin = 2d where d = i - r

Dmin = 2i – 2r---------------------------- (a)

But r + r = A

⇨ 2r = A **OR** $r = \frac{A}{2}$ -------------------------------------- (b)

Combining equation (a) and (b) gives

Dmin = 2i – A

$i = \frac{D_{mim}+A}{2}$ ---------------------------------(c)

At M Snell's law becomes

$n_a \sin i = n_g \sin r$

$n_g = \frac{n_a \sin i}{\sin r}$--------------------------------(d)

Substituting equation (b) and (c) in (d) gives

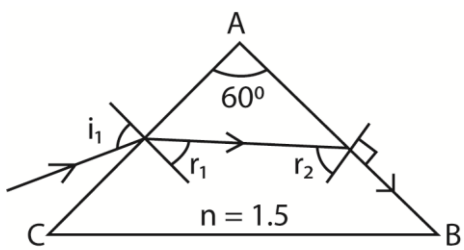
$$n_g = n_a \frac{\sin\left(\frac{D_{min}+A}{2}\right)}{\sin A/_2}$$

Since $n_a = 1$,

$$n_g = \frac{\sin\left(\frac{D_{min}+A}{2}\right)}{\sin A/_2}$$

(ii) Monochromatic light is incident on one refracting face of a prism of refracting angle 60^0, made of glass of refractive index 1.50.

Calculate the least angle of incidence for the ray to emerge through the second refracting face. (05marks)



Using Snell's law on face AB

$1.5\sin r_2 = \sin 90^0$

$r_2 = 41.8$

Also applying Snell's law on face AC

$r_1 = 60 - 41.8 = 18.2^0$

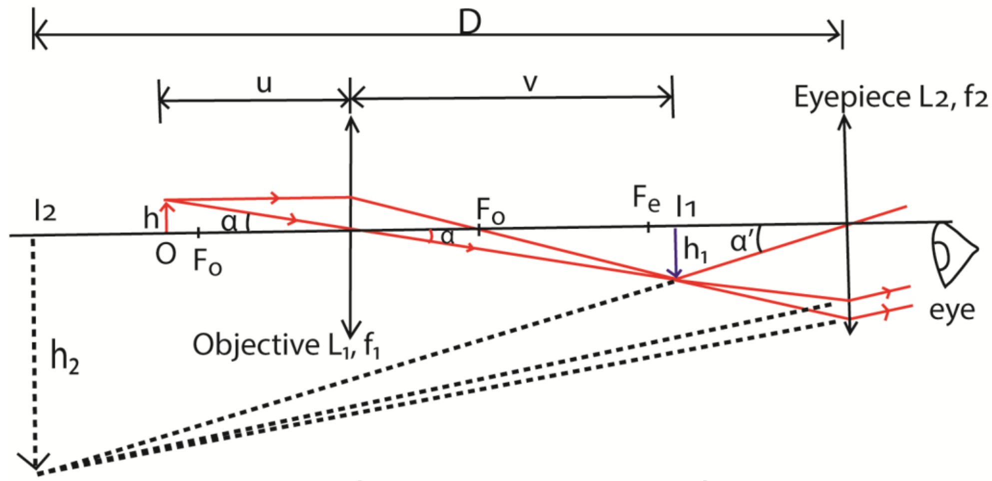
$\sin i = 1.5\sin 18.2$

$i = 27.9^0$

(c) (i) State three differences between compound microscopes and telescopes. (03marks)

Compound microscope	Astronomical telescope
- View near objects - Objective lens has smaller focal length - In normal adjustment the final image is at near point - Has greater resolving power	- View distant object - Objective lens has longer focal length - In normal adjustment, final image at infinity - Has lower resolving power

(ii) Describe, with the aid of a ray diagram, how a compound microscope forms a final image at near point.(05marks)



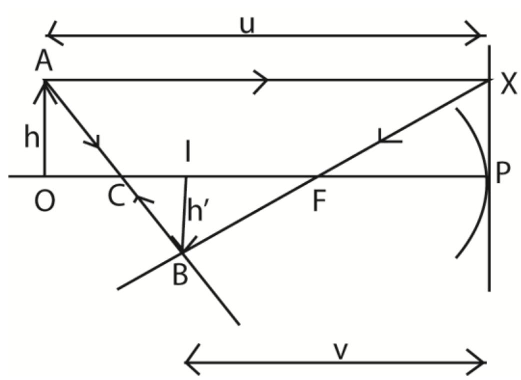
Compound microscope in normal use

The objective forms a real magnified image of the object at a distance less than f_e from the eye piece.

The eye piece form a virtual magnified image of the intermediate image at nearest distance of distinct vision (D=25 cm)

39. (a) Define the terms radius of curvature and focal length of a converging mirror. (02marks)
Radius of curvature of a converging mirror is the distance from the pole of the converging mirror to the center of curvature.
Focal length of converging mirror is the distance from the pole of the mirror to the principal focus.

(b) (i) Draw a ray diagram to show the formation of a real image of a real object in a converging mirror (02marks)



(ii) Use the ray diagram in (b)(i) to derive the expression, $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$; where u. v and f are the object distance, image distance and focal length respectively. (05marks)
PC = r and PF = f

Triangle OAC and triangle ICB are similar

$\frac{OA}{IB} = \frac{u-2f}{2f-v}$

Also triangle

Triangle

XRF and PQF are similar

$\frac{XP}{IB} = \frac{PF}{IF} = \frac{PF}{IP-PF}$

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

But XP = OA

$\therefore \frac{u-2f}{2f-v} = \frac{f}{v-f}$

$uv - uf - 2vf + 2f^2 = 2f^2 - vf$

$uv - uf - vf = 0$

after dividing by uvf

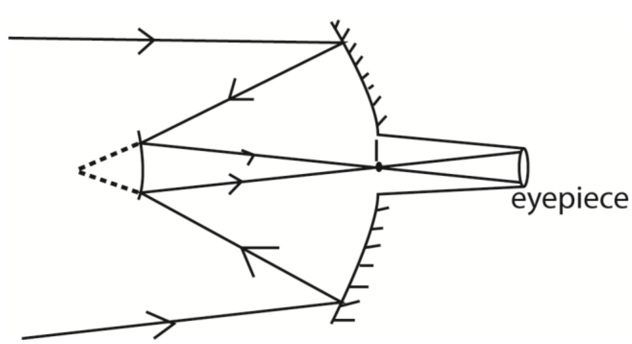
$\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

(c) (i) With the aid of ray diagram, describe the structure and action of a reflecting telescope in normal adjustment. (05marks)

The objective is a large parabolic mirror with a circular aperture of long focal length. A beam of from a distant object is reflected and intercepted by a convex mirror.

The convex mirror forms a real and inverted image at I, the pole of the objective mirror and principal focus of the eyepiece

The eyepiece forms a virtual, magnified image at infinity.



(ii) State two advantages of reflecting telescope over an astronomical telescope. (02marks)

- has high resolving power
- has no chromatic aberration
- produce brighter images
- cheap
- spherical aberration is minimized
-

(d) An astronomical telescope has objective of focal length 100cm and eyepiece of focal length 10cm. Calculate the separation of the objective if the lenses are arranged in such a way that the final image is formed at 25cm from the eye. (04marks)

Action of the eyepiece

f = 10cm, v = -25cm, u= ?

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$\frac{1}{10} = \frac{1}{u} - \frac{1}{25}$, u = 7.1cm

Separation of lenses = f_0 + u

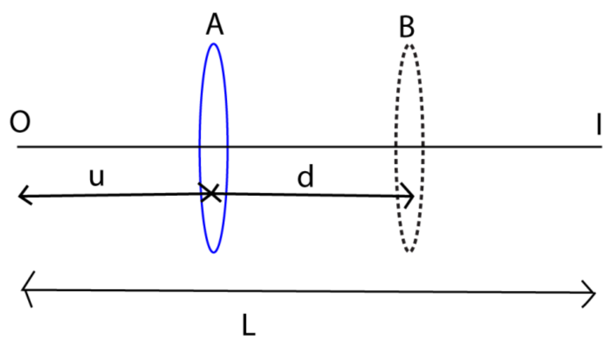
=100 + 7.1 = 107.1cm

40. (a) Define the principal focus of a converging lens. (1mark)

The principal focus of a converging lens is the point on the principal axis at which paraxial rays converge after refraction by the lens.

(b) A converging lens of focal length, f, is placed between a finite object and a screen. The position of the screen is adjusted until a clear magnified image is obtained on the screen. Keeping the screen fixed in this position, a distance L from the object, the lens is displaced through a distance, d, to obtain a clear diminished image on the screen.

(i) Draw a ray diagram to show the formation of the image in the two cases. (02marks)



(ii)Show that $L^2 - d^2 = 4df$ (05marks)

Lens A forms an image of O at I

By the principle of reversibility of light, an object at I forms an image at O. When the object and the screen are fixed, another clear image can be formed by the lens when moved from A to B.

From the diagram

OB = IA and OA =IB

OA + BI = L-d

OA + OA + L-d (since OA + IB)

2OA = L-d

AO = $\frac{L-d}{2}$ = u ……………………(i)

Also, AI = AB + BI

AI = AB + OA (since OA = BI

AI = d +$\frac{L-d}{2} = \frac{L+d}{2}$ = v

Using the formula $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

$$\frac{1}{f} = \frac{1}{\frac{L-d}{2}} + \frac{1}{\frac{L+d}{2}}$$

$$\frac{1}{f} = \frac{4L}{L^2-d^2}$$

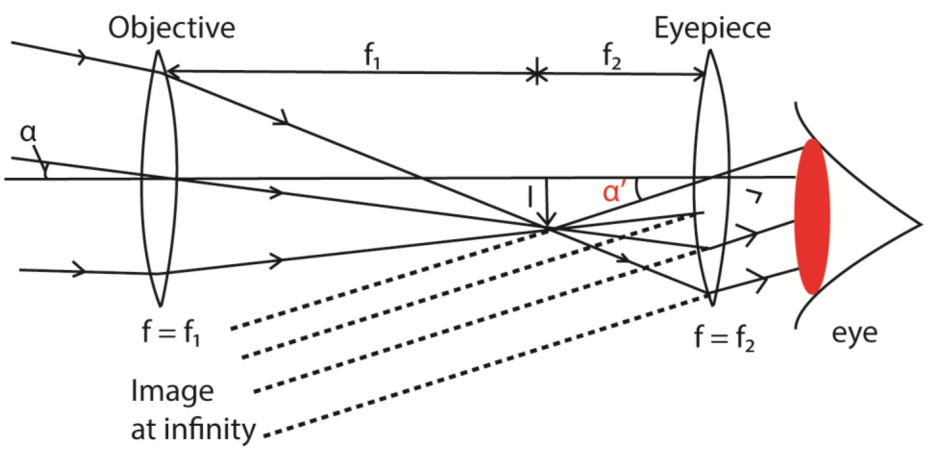
(iii) Find the product of the magnifications produced in the two cases. (02marks)

$$M_1 = \frac{(L+d)/_2}{(L-d)/_2} = \frac{L+d}{L-d}$$

$$M_2 = \frac{(L-d)/_2}{(L+d)/_2} = \frac{L-d}{L+d}$$

$$M_1M_2 = \frac{L+d}{L-d}\ x\ \frac{L-d}{L+d} = 1$$

(c) (i) Draw a ray diagram to show how two converging lenses, one of long focal length, f_1, and the other of shorter focal length, f_2, can be arranged to make an astronomical telescope in normal adjustment. (02marks)



(ii) Derive the expression for the magnifying power of the telescope in this setting. (03marks)

For an aided eye (using the instrument)

For small angle, tanα' ≈ α' for small angle in radians

$\alpha' = \frac{h}{f_e}$ .... (i)

Where, h, is the height of image I, f_e is the focal length of eye piece

For unaided eye

$\alpha = \frac{h}{f_0}$ .... (ii)

f_0 is the focal length of objective lens

Combining equations (i) and (ii)

Magnifying power, $m = \frac{\alpha'}{\alpha} = \frac{h}{f_e} \div \frac{h}{f_o} = \frac{\boldsymbol{f_o}}{\boldsymbol{f_e}}$

(d) The objective of a compound microscope has focal length of 2.0cm while the eyepiece has a focal length of 5.0cm. An object is placed at a distance of 2.5cm in front of the objective. The distance of the eyepiece from the objective is adjusted so that the final image is 25cm in front of the eyepiece. Find the distance between the objective and the eyepiece. (05marks)

From $\frac{1}{f} = \frac{1}{u} + \frac{1}{v}$

Action of eyepiece

$\frac{1}{5} = \frac{1}{u} - \frac{1}{25}$, u = 4.2cm

Action of objective

$\frac{1}{2} = \frac{1}{2.5} + \frac{1}{v}$, v = 10.0cm

Separation = u + v= 10.0 + 4.2 = 14.2cm

41. (a) (i) What is meant by refraction of light? (01mark)

Refraction is the bending of light rays at the interface between two media of different optical densities.

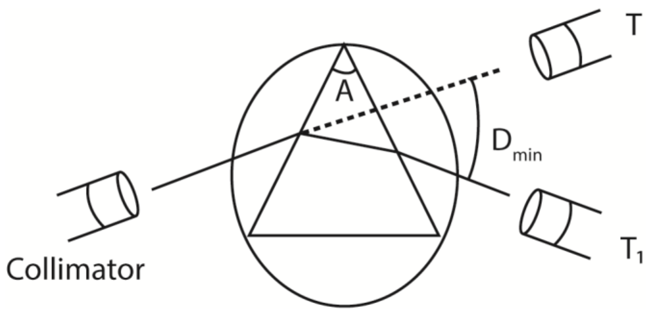
Or

It is the change n velocity of light at the interface between two media of different optical densities

(ii) State laws of refraction (02marks)

- Incident ray, refracted ray at the point of incidence all lie in the same plane
- the ration of the sine of incident angle to the sine of angle of refraction is constant for a given pair of the medium
-

(b) Describe how the refractive index of a material of a glass prism of known refractive angle can be determined using a spectrometer (06marks)



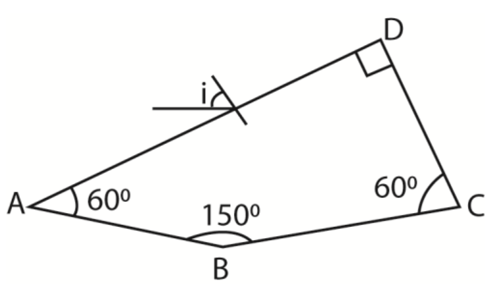
Before the spectrometer is put in to use, 3 adjustments must be made onto it and these include,

(i) The collimator is adjusted to produce parallel rays of light.
(ii) The turntable is leveled.
(iii) The telescope is adjusted to receive light from the collimator on its cross wire

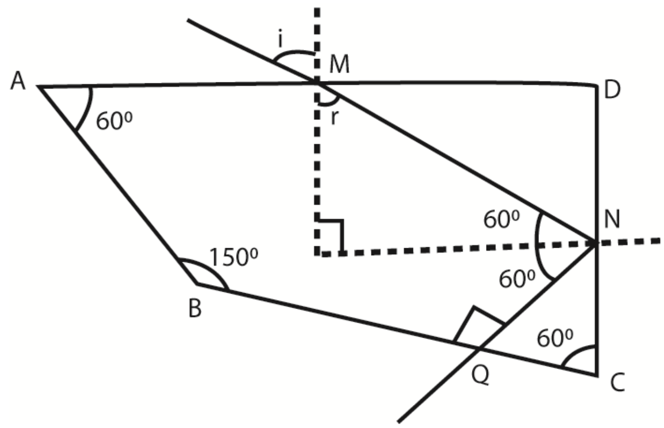
- A prism of know refractive angle A is placed on the table with refractive angle facing away from the collimator
- The table is turned in the direction of the base of the prism until light is seen.
- Keeping the light in view. The prism, table and telescope are turned until light moves in opposite direction. Position T_1 is noted.
- The table is fixed and prism is removed,
- The telescope is turned in opposite direction until the parallel light is incident at the cross wire. Position T and angle of minimum deviation D_{min} are noted.
- The refractive index of glass is obtained from

$$n = \frac{sin\frac{(A+D_{min})}{2}}{\sin\frac{A}{2}}$$

(c)



A ray of light is incident on face Ad of a glass bloc as shown in the figure above. The refractive index of the material of the glass block is 1.52. If the ray emerges normally through face BC after total internal reflection, calculate the angle, i. (05marks)



From the diagram r = 30^0

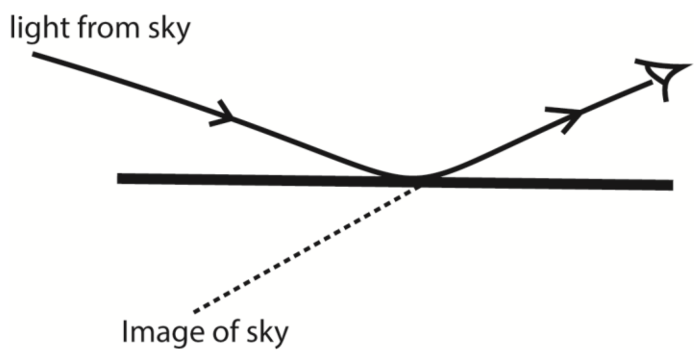
From Snell's law, nsini = constant

1sini = 1.52sin 30

i = 49.5^0

(d) Explain how a mirage is formed. (03marks)

Mirage is what is observed as a pool of water on a tarmac road at some distance a head on a hot day. It is formed by total internal reflection because on hot day, the hot air near the earth surface has lower refractive index than cool air above it.



(e) An object at a depth of 3.0m below the surface of water is observed directly from above the surface. Calculate the apparent displacement of the object if the refractive index is 1.33. (03marks)

Refractive index = $\frac{Real\ depth}{Apparent\ depth}$

$1.33 = \frac{3.0}{Apparent\ depth}$

Apparent depth = 2.25

Displacement = 3 – 2.25 = 0.75cm

Thank you so much

Compiled by Dr. Bbosa Science