UNIT – VI

OPTICS

CHAPTER 9

RAY OPTICS AND OPTICAL INSTRUMENTS

Syllabus

- *Reflection of light, spherical mirrors, mirror formula. Refraction of light, total internal reflection and its applications, optical fibres, refraction at spherical surfaces, lenses, thin lens formula, lens-maker's formula. Magnification, power of a lens, combination of thin lenses in contact.*
- *Refraction and dispersion of light through a prism. Scattering of light—blue colour of the sky and reddish appearance of the sun at sunrise and sunset.*
- *Optical instruments : Microscopes and astronomical telescopes (reflecting and refracting) and their magnifying powers.*

Chapter Analysis

List of Topics	2016		2017		2018
	D	OD	D	OD	D/OD
Reflection by spherical Mirrors	–	–	1 Q (3 marks)	–	–
Reflection through Glass Slab, Prism and Lenses and Total Internal Reflection	1 Q (5 marks)	1 Q (1 mark) 1 Q (2 marks) 1 Q (3 marks)	–	1 Q (1 mark) 1 Q (3 marks) 1 Q (5 marks)	–
Optical Instruments	1 Q (3 marks)	1 Q (5 marks)	2 Q (2 marks)	1 Q (3 marks)	–

TOPIC-1
Reflection by Spherical Mirrors

Revision Notes

- Light is a form of energy. Ray of light represents direction of propagation of light energy.
- The speed of light in vacuum is the highest speed attainable in nature. Its approx. value is 3.0×10^8 m/s.
- When light falls on any object/surface, there are three optical phenomenon which occur *i.e.*, reflection, refraction and absorption of light by the object/surface.

  By law of conservation of energy, sum of reflected, absorbed and transmitted light is always equal to the incident light.
- Depending upon the amount of light it reflects, transmits or absorbs objects are classified into good reflector, transmitter or absorber of light.

Spherical Mirror

➢ Curved shaped mirrors are known as spherical mirrors. Depending upon the type of curve of reflecting surface, spherical mirrors are categorized as :
  - **Concave Mirror :** A spherical mirror, whose reflecting surface is curved inwards is called a concave mirror. It means reflecting (polished) surface faces the center of the sphere from which it is made.
  - **Convex Mirror :** A spherical mirror whose reflecting surface is curved outwards is called a convex mirror.

Important Terms related to spherical mirrors

➢ The mid point or the centre of the reflecting surface of the mirror is known as **pole** of the mirror. It is represented by P.

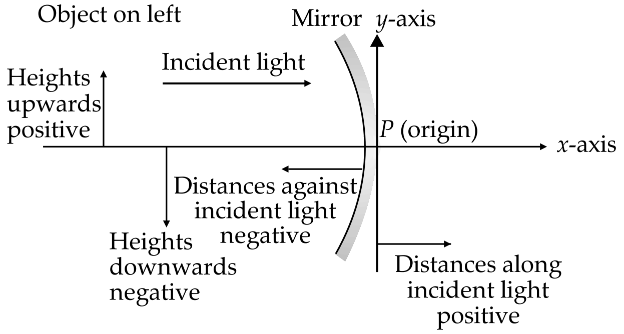
➢ The centre of the hollow sphere from which the mirror is made, is known as **centre of curvature**. It is represented by C. Centre of curvature in concave mirror is in front of the mirror and in convex mirror, it is behind the mirror.

➢ An imaginary straight line which joins Pole and Centre of curvature of the mirror is known as **principal axis** and the distance between the Centre of curvature and Pole of the mirror is called the **radius of curvature**. It is represented by R.

➢ For mirrors whose radius of curvature is much larger than aperture, there will be relation between R and f such that
$$f = \frac{R}{2}$$

➢ Image is perception of object. If rays emanating from a point actually meet at another point then that point is real image of the object; The image will be virtual if the rays do not actually meet but appear to meet from the point when produced backward.

The Cartesian Sign Convention



➢ **Image formation in concave mirror for different positions of object**

Position of the object	Position of the image	Size of the image	Nature of the image
At infinity	At the focus F	Highly diminished, point sized	Real and inverted
Beyond C	Between F and C	Diminished	Real and inverted
At C	At C	Same size	Real and inverted
Between C and F	Beyond C	Enlarged	Real and inverted
At F	At infinity	Highly Enlarged	Real and inverted
Between P and F	Behind the mirror	Enlarged	Virtual and erect

➢ **Image formation in convex mirror for different positions of object**

Position of the object	Position of the image	Size of the image	Nature of the image
At infinity	At the focus F, behind the mirror	Highly diminished point sized	Virtual and Erect
Between infinity and the pole P of the mirror	Between P and F, behind the mirror	Diminished	Virtual and Erect

Reflection of Light by Spherical Mirror

➢ When light falls on an object, it bounces the light in the same medium from where the light comes. This is called the reflection of light.

- Mirrors are good reflectors. A mirror can be made by silvering a metal surface with glass in front and paint at its back.

  Laws of Reflection : It is observed that light follows the following laws while reflecting from any type of surface.

  (i) The angle of incidence is equal to the angle of reflection, and

  (ii) The incident ray, the normal to the surface at the point of incidence and the reflected ray, all lie in the same plane.

- **Mirror Formula :** In a spherical mirror, there is a relation between object's distance u, image distance v and principal focus of the mirror f.

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

- **Magnification by Mirror :** The extent by which mirror extends or reduces the size of image with respect to object is called the magnification factor of mirror. It is represented by m. If size of an object is h and its image by spherical mirror is h'. Then magnification factor of mirror is

$$m=-\frac{v}{u}=\frac{h_i}{h_o}$$

Know the Formulae

- Mirror focal length $\frac{1}{f}=\frac{1}{u}+\frac{1}{v}$
- Mirror magnification $m=-\frac{v}{u}=\frac{h_i}{h_o}$

Objective Type Questions

(1 mark each)

Q. 1. The phenomena involved in the reflection of radio waves by ionosphere are similar to

(a) reflection of light by a plane mirror.

(b) total internal reflection of light in air during a mirage.

(c) dispersion of light by water molecules during the formation of a rainbow.

(d) scattering of light by the particles of air.

[NCERT Exemplar]

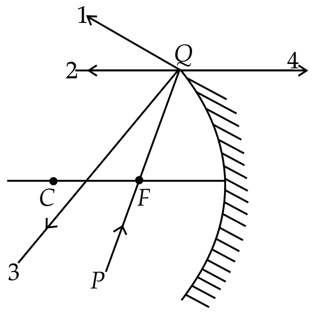
Ans. Correct option : (b)

Explanation : Radiowaves are reflected by a layer of atmosphere called the Ionosphere, so they can reach distant parts of the Earth. The reflection of radiowaves by ionosphere is due to total internal reflection. It is the same as total internal reflection of light in air during a mirage, that is, angle of incidence is greater than critical angle.

Ionosphere is transparent optical medium and radiowave is reflected back.

Reflection through transparent surface is total internal reflection so that internal reflection of radiowave takes place.

Q. 2. The direction of ray of light incident on a concave mirror is shown by *PQ* while directions in which the ray would travel after reflection is shown by four rays marked 1, 2, 3 and 4 (Figure). Which of the four rays correctly shows the direction of reflected ray?



(a) 1. **(b) 2.**

(c) 3. **(d) 4. [NCERT Exemplar]**

Ans. Correct option : (b)

Explanation : Incidence ray *PQ* is coming through principal focus *F* so it must be parallel to principal axis, that is, either 2 or 4.

As it is a concave mirror so, ray cannot go behind the mirror so ray (4) is discarded.

So, ray 2 is the reflected ray.

Q. 3. A car is moving with at a constant speed of 60 km h^{-1} on a straight road. Looking at the rear-view mirror, the driver finds that the car following him is at a distance of 100 m and is approaching with a speed of 5 kmh^{-1}. In order to keep track of the car in the rear, the driver begins to glance alternatively at the rear and side mirror of his car after every 2 s till the other car overtakes. If the two cars were maintaining their speeds, which of the following statement(s) is/are correct?

(a) The speed of the car in the rear is 65 km/h.

(b) In the side mirror the car in the rear would appear to approach with a speed of 5 kmh^{-1} to the driver of the leading car.

(c) **In the rear view mirror the speed of the approaching car would appear to decrease as the distance between the cars decreases.**

(d) **In the side mirror, the speed of the approaching car would appear to increase as the distance between the cars decreases.**

[NCERT Exemplar]

Ans. Correct option : (d)

Explanation : When rear car approaches, initially it appears at rest as image is formed at focus. When car approaches nearer this speed will appear to increase.

Q . 4. An object approaches a convergent lens from the left of the lens with a uniform speed 5 m/s and stops at the focus. The image

(a) **moves away from the lens with an uniform speed 5 m/s.**

(b) **moves away from the lens with an uniform acceleration.**

(c) **moves away from the lens with a non-uniform acceleration.**

(d) **moves towards the lens with a non-uniform acceleration.** **[NCERT Exemplar]**

Ans. Correct option : (c)

Explanation : As the object approaches a convergent lens from the left of the lens with a uniform speed of 5 m/s, so the image will move away from the lens with a non-uniform acceleration, and the image moves slower in the beginning and faster later on from F to $2F$ and when the object moves from $2F$ to F, the image will move from $2F$ to infinity. At $2F$, the speed of the object and image will be equal.

Q. 5. The radius of curvature of the curved surface of a planoconvex lens is 20 cm. If the refractive index of the material of the lens be 1.5, it will

(a) **act as a convex lens only for the objects that lie on its curved side.**

(b) **act as a concave lens for the objects that lie on its curved side.**

(c) **act as a convex lens irrespective of the side on which the object lies.**

(d) **act as a concave lens irrespective of side on which the object lies.** **[NCERT Exemplar]**

Ans. Correct option : (c)

Explanation : As we know the relations between f, μ, R_1 and R_2 is known as lens maker's formula :

$$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

$$R_1 = \infty,\ R_2 = -R$$

$$f = \frac{R}{(\mu - 1)}$$

Given that,

$$R = 20 \text{ cm},$$

$$\mu = 1.5$$

Put the values;

$$f = \frac{R}{\mu - 1} = \frac{20}{15 - 1} = 40 \text{ cm}$$

As $f > 0$, it means converging nature of the lens.

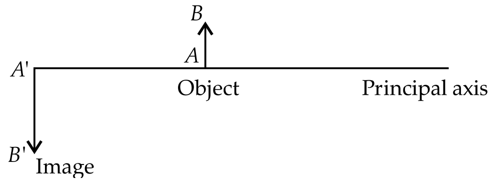
So, lens act as a convex lens irrespective of the side on which the object lies.

Very Short Answer Type Questions **(1 mark each)**

Q. 1. When an object is placed between f and $2f$ of a concave mirror, would the image formed be (i) real or virtual and (ii) diminished or magnified ? U **[Delhi I, II, III 2015]**

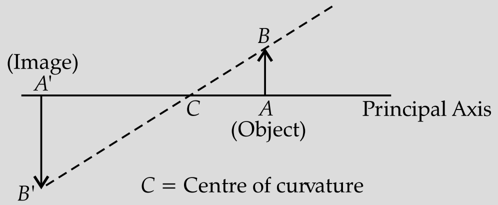
Ans. (i) Real, **(ii)** magnified. ½+½

AI **Q. 2. Redraw the diagram given below and mark the position of the centre of curvature of the spherical mirror used in the given set up.**



A **[CBSE SQP 2014]**

Ans.



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[CBSE Marking Scheme 2014]

Detailed Answer :

Line joining the object and image same point (B & B') should be passes through C as it is undeviated.

As the image is enlarged and real from the mirror. It is concave mirror and object is placed between C and F and image is formed beyond C. Hence C is in between object and the image. **1**

Commonly Made Error

- Many candidates could not understand that BB' cut the principal axis at C. They arbitrarily choose C.

Q. 3. Which mirror does have a real focus? R

Ans. Concave mirror. In concave mirror, parallel rays after reflecting from mirror actually meet at focus. **1**

Q. 4. Why are convex mirror preferred over plane mirrors as rear view mirrors? U

Ans. Convex mirror is preferred over plane mirrors as rear view mirrors because as it gives diminished image of object and hence can cover larger field of view. **1**

Q. 5. Name the mirror which are used in R

(i) Security mirror

(ii) Solar furnace

Ans. (i) Convex mirror

(ii) Concave mirror ½+½ = 1

Short Answer Type Questions-I (2 marks each)

Q. 1. Use the mirror equation to show that an object placed between f and $2f$ of a concave mirror forms an image beyond $2f$. R **[Foreign 2017; Delhi 2015]**

Ans. $\frac{1}{v}+\frac{1}{u} = \frac{1}{f}$ (f is $-ve$) ½

If, $u = -f$

$\Rightarrow \frac{1}{v} = 0$

$\Rightarrow v = \infty$ ½

If, $u = -2f$ ½

$\Rightarrow \frac{1}{v} = \frac{-1}{2f}$

$\Rightarrow v = -2f$ ½

Hence, if $-2f < u < -f$

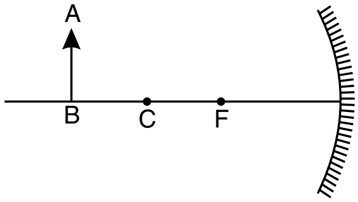
then, $-2f < v < \infty$

[CBSE Marking Scheme 2017]

Commonly Made Error

- Many candidates got confused in understanding the question. Some candidates wrote wrong range when they converted $\frac{1}{u}, \frac{1}{v}$ & $\frac{1}{f}$ into u, v & f respectively.

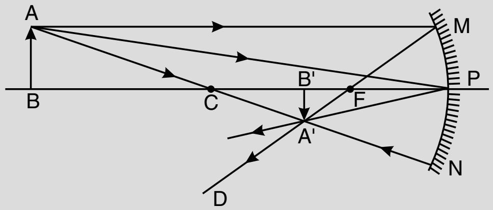
AI **Q. 2. An object AB is kept in front of a concave mirror as shown in the figure.**



(i) Complete the ray diagram showing the image formation of the object.

(ii) How will the position and intensity of the image be affected if the lower half of the mirror's reflecting surface is painted black ? A **[O.D. 2012]**

Ans. (i)



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(ii) The position of image will remain same/ unchanged, but the intensity of the image will decrease. **1**

[CBSE Marking Scheme 2012]

Q. 3. A concave (or convex mirror) is held under water. Will its focal length change? U

Ans. No, The focal length of small aperture mirror is half of its radius. It does not depend upon the refractive index of the surrounding medium. **1+ 1**

Commonly Made Error

- Many candidates got confused mirror with lens and wrote the answer 'yes'.

Q. 4. State two positions in which a concave mirror produces a magnified image of a given object. List two differences between the two images. R

Ans. A concave mirror forms a magnified image of an object when

Case-1 : Object is between center of curvature (C) and principal focus (F) of the mirror

Case-2 : Object is between principal focus (F) and pole (P) of the mirror.

Difference :

In first case the image is real and inverted while in case-2, the image would be virtual and erect. **1+ 1**

Q. 5. You are given a concave mirror, plane mirror and a convex mirror. How can you distinguish between them by just looking at your face in them. State the common nature of the image that you see in all of them. U

Ans. Plane mirror forms same size of image. Concave mirror forms enlarged image whereas convex mirror forms diminished image.

All images are virtual and erect. **1+ 1**

Answering Tips

- Try to visualize the image formation in all the mirrors.

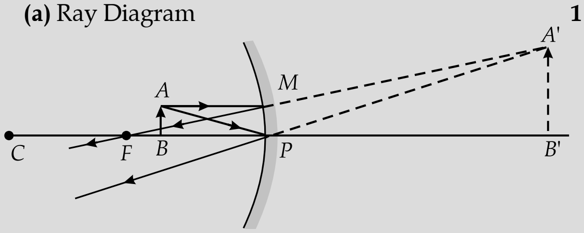
Short Answer Type Questions-II (3 marks each)

Q. 1. (a) With the help of a ray diagram, show how a concave mirror is used to obtain an erect and magnified image of an object.

(b) Using the above ray diagram, obtain the mirror formula and the expression for linear magnification. **[CBSE Comptt. 2018]**

Ans. (a) Ray diagram **1**
(b) Obtaining
(i) mirror formula **1½**
(ii) expression for liner magnification **½**

(a) Ray Diagram **1**



From similar triangles $A'B'F$ and MPF, we have

$$\frac{B'A'}{PM} = \frac{B'F}{FP}$$

or $$\frac{B'A'}{BA} = \frac{B'F}{FP} \quad \text{(Since PM = BA)}$$

From similar triangles $A'B'P$ and ABP, we have

$$\frac{B'A'}{BA} = \frac{B'P}{BP} \qquad ½$$

Hence, $$\frac{B'F}{FP} = \frac{B'P}{BP}$$

Now, $$B'F = B'P + PF$$
$$= (+v) + (-f)$$
$$= v - f$$
$$BP = -u \qquad ½$$

$\therefore$ $$\frac{v-f}{-f} = \frac{+v}{-u}$$

or $$\frac{-v}{f}+1 = \frac{-v}{u} \qquad ½$$

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

This is the mirror formula.

Linear magnification $= \dfrac{B'A'}{BA}$

From similar triangle $A'B'P'$ and ABP, we get

$$\frac{B'A'}{BA} = \frac{B'P}{BP}$$

$\therefore$ Linear magnification

$$m = \frac{B'P}{BP} = \frac{+v}{-u} = -\frac{v}{u} \qquad ½$$

[CBSE Marking Scheme 2018]

Q. 2. (i) Calculate the distance of an object of height *h* from a concave mirror of radius of curvature 20 cm, so as to obtain a real image of magnification 2. Find the location of image also.
(ii) Using mirror formula, explain why does a convex mirror always produce a virtual image.

R **[CBSE Delhi 2017]**

Ans. (i) Given, $R = -20$ cm and magnification $m = -2$

Focal length of the mirror

$$f = \frac{R}{2} = -10 \text{ cm} \qquad ½$$

Magnification, $$m = -\frac{v}{u}$$

$$-2 = -\frac{v}{u} \qquad ½$$

$\Rightarrow$ $$v = 2u$$

Using mirror formula,

$\Rightarrow$ $$\frac{1}{f} = \frac{1}{v}+\frac{1}{u} \qquad ½$$

$\Rightarrow$ $$-\frac{1}{10} = \frac{1}{2u}+\frac{1}{u}$$

$\Rightarrow$ $$u = -15 \text{ cm}$$

$\therefore$ $$v = 2 \times -15 \text{ cm}$$
$$= -30 \text{ cm} \qquad ½$$

(ii) $$\frac{1}{f} = \frac{1}{v}+\frac{1}{u} \qquad ½$$

Using sign convention, for convex mirror, we have

$$f > 0, u < 0$$

From the formula

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

$\because$ f is positive and u is negative,

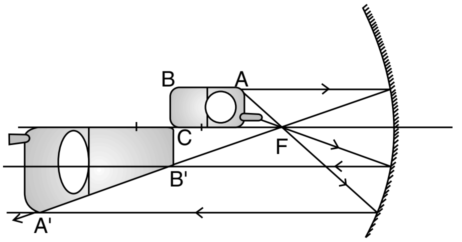
$\Rightarrow$ v is always positive, hence image is always virtual. ½

[CBSE Marking Scheme 2017]

Q. 3. (i) A mobile phone lies along the principal axis of a concave mirror. Show, with the help of a suitable diagram, the formation of its image.
(ii) Explain why magnification is not uniform.
(iii) Suppose the lower half of the concave mirror's reflecting surface is covered with an opaque material. What effect this will have on the image of the object ? Explain.

A **[Delhi I, II, III 2014]**

Ans. (i)



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(ii) As mobile lies in the horizontal direction so different parts of the mobile has different distance from the mirror. According to their horizontal distance from the mirror linear magnification is not uniform in vertical plane. **1**

(iii) The image would be sharp but intensity gets reduced due to blocking of lower half rays. In this situation, rays of light coming from the object will be reflected by the upper half of the mirror. These rays meet at the other side of the mirror to form the image of the given object. **1**

AI **Q. 4. Use the mirror equation to show that :**
(i) An object placed between *f* and 2*f* of a concave mirror produces a real image beyond 2*f*.
(ii) a convex mirror always produces a virtual image independent of the location of the object.
(iii) an object placed between the pole and the focus of a concave mirror produces a virtual and enlarged image.

A**[OD 2011]**

Ans. (i) Try yourself Similar Q. 1 Short Answer Type Questions-I

(ii) Try yourself Similar Q. 2 (ii) Short Answer Type Questions-II

(iii) Using mirror formula

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

For concave mirror,

$$f < 0$$

$$\Rightarrow \quad \frac{1}{v}+\frac{1}{u} < 0$$

$$\frac{1}{v}-\frac{1}{u} < 0 \quad \text{(putting the sign of } u\text{)}$$

$$\therefore \quad \frac{1}{v} < \frac{1}{u}$$

$v > u$ as v is always positive so image is virtual.

Now, $m = \left|\frac{v}{u}\right| > 1$, Hence image is always enlarged. **1**

Commonly Made Error

- Many candidates made lengthy calculations, which were not required. In some cases they started with correct formula, but did wrongly sign conversions in between.

Q. 5. Show that the spherical mirror formula holds equally to a plane mirror. A

Ans. Using mirror formula

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

For plane mirror $f = \infty$ **1**

Hence

$$\frac{1}{v}+\frac{1}{u} = 0$$

So, $\quad v = -u$ **1**

It means the image is at equal distance and in opposite side of object. This is the true condition in image formation through plane mirror. Hence spherical mirror formula holds equally to a plane mirror. **1**

Long Answer Type Questions

(4 marks each)

AI **Q. 1.(i) Draw a ray diagram to show image formation when the concave mirror produces a real, inverted and magnified image of the object.**

(ii) Obtain the mirror formula and write the expression for the linear magnification.

(iii) Explain two advantages of a reflecting telescope over a refracting telescope.

A **[Delhi & O.D. 2018]**

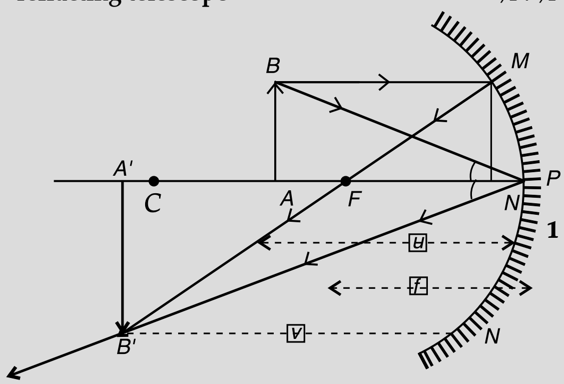
Ans. (i) Ray diagram to show the required image formation **1**

(ii) Derivation of mirror formula **2½**

Expression for linear magnification **½**

(iii) Two advantages of a reflecting telescope over a refracting telescope **½+½**

(i)



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(ii) In the above figure ΔBAP and $\Delta B'A'P$ are similar

$$\Rightarrow \quad \frac{BA}{B'A'} = \frac{PA}{PA'} \quad \text{...(i) ½}$$

Similarly, ΔMNF and $\Delta B'A'F$ are similar

$$\Rightarrow \quad \frac{MN}{B'A'} = \frac{NF}{FA'} \quad \text{...(ii)}$$

As $\quad MN = BA$

$NF \approx PF$

$FA' = PA' - PF$ ½

$\therefore$ Equation (ii) takes the following form

$$\frac{BA}{B'A'} = \frac{PF}{PA'-PF} \quad \text{...(iii) ½}$$

Using equation (i) and (iii)

$$\frac{PA}{PA'} = \frac{PF}{PA'-PF} \quad ½$$

For the given figure, as per the sign convention,

$PA = -u$

$PA' = -v$

$PF = -f$

$$\Rightarrow \quad \frac{-u}{-v} = \frac{-f}{-v-(-f)} \quad ½$$

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

$$uv - uf = vf$$

Dividing each term by uvf, we get

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

$$\Rightarrow \quad \frac{1}{f} = \frac{1}{v} + \frac{1}{u} \quad ½$$

Linear magnification $= -\frac{-v}{u}$,

(alternatively, $m = \frac{h_i}{h_o}$) ½

(iii) Advantages of reflecting telescope over refracting telescope

(i) Mechanical support is easier ½+½

(ii) Magnifying power is large

(iii) Resolving power is large

(iv) Spherical aberration is reduced

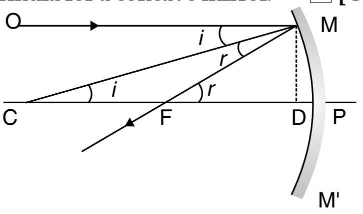
(v) Free from chromatic aberration **(any two)**

[CBSE Marking Scheme 2018]

Q. 2. (i) Prove that for a concave mirror, the radius of curvature is twice the focal length for small aperture as compare to its radius of curvature.

(ii) With the help of a suitable diagram, derive the mirror formula for a concave mirror. A **[CBSE 2011, 2009]**

Ans. (i)



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Let us consider MM' as small aperture concave mirror. The line through centre of curvature MC is perpendicular to the mirror. Applying law of reflection,

$$\angle OMC = \angle CMF$$

($\because$ angle of incidence = angle of reflection)

$$\angle MCF = \angle OMC \text{ (alternate angles)}$$

Hence $\angle MCF = \angle CMF$

So, $CF = MF$

Since aperture of mirror is very small, D is very near to P and we can put

$$CF = FP$$

$$PC = 2PF$$

$$R = 2f \quad \textbf{2}$$

Or $f = \dfrac{R}{2}$ **Hence proved.**

(ii) Try yourself Similar Q. 1 (ii) Long Answer Type Question. **2**

TOPIC-2
Refraction through Glass Slab, Prism and Lenses and Total Internal Reflection

Revision Notes

- **Refraction of light :** Refraction is deviation of light when it obliquely travels from one medium to another medium. Snell experimentally found the following laws of refractions.

Laws of Refraction of Light

- The incident ray, the refracted ray and the normal to the interface of two transparent media at the point of incidence, all lie in the same plane.
- The ratio of sine of angle of incidence to the sine of angle of refraction is a constant, for the light of a given colour and for the given pair of media. This constant value is called the refractive index of the second medium with respect to the first medium.

$$\frac{\sin i}{\sin r} = \text{constant } (n_{21})$$

This is known as Snell's law.

- From Snell's law

$$\sin i = \sin r \times n_{21}.$$

It shows that if $\angle i = 0$ then $\angle r$ is also zero. This proves that why light rays do not deviate when they travel normally from one medium to another.

- If the first medium is air, then this refractive index is known as the absolute refractive index of the second medium. The absolute refractive index of a medium is expressed by

$$n_2 = \frac{\text{velocity of light in free space}}{\text{velocity of light in mediun}} = \frac{c}{v} \text{ since, } c > v \Rightarrow n_2 > 1$$

- If light ray enters from one medium to another medium in such a way that bending of light is away from normal then second medium is optically rarer than the first medium. If bending of light is towards normal then second medium is optically denser than the first medium.

Principle of Reversibility

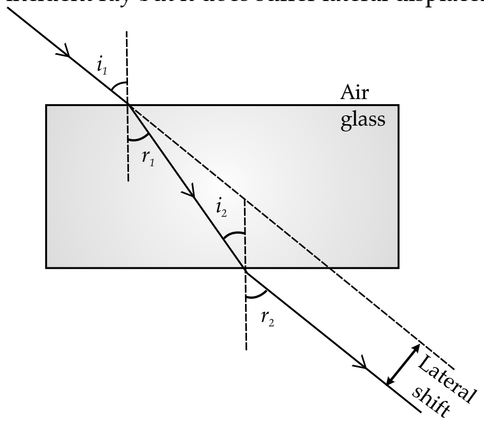
- According to the principle of reversibility, the path of light is reversible even if it is going through several media. It means light follows exactly the same path when its direction is reversed.
- Applying this rule we may find that if light travels through several media say medium 1 to medium 2 and then to medium 3 then to medium 1.

$$n_{21} \times n_{32} \times n_{13} = 1$$

- Though refraction rules are universal but direction of emergent ray depends upon the shape of the medium or in other words shape and angle between incident and emergent interfaces (refracting surfaces).

Refraction through glass slab

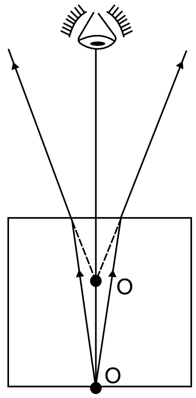
- In a glass slab refracting surfaces are plane and parallel to each other.
- Emergent ray is parallel to the incident ray but it does suffer lateral displacement.



- The apparent depth of the object is always less than actual depth when looking through glass or water .

$$\text{Rise of image} = \text{Real depth}\left(1 - \frac{1}{n_{21}}\right)$$

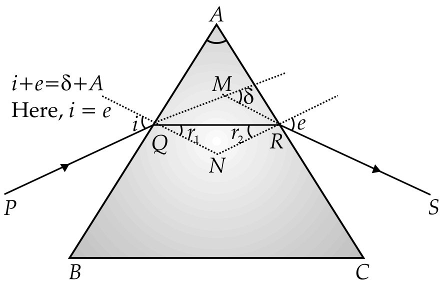
Here, $$n_{21} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

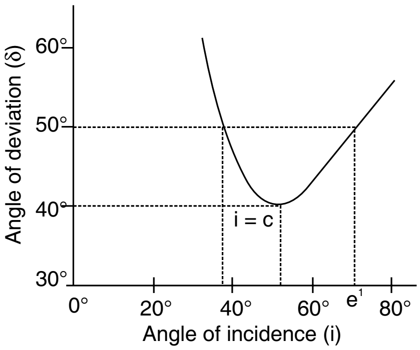


- Following phenomena occur due to the refraction of light.
  - Bottom of surface of water pool seems to be raised.
  - The letter appears to be raised when we seeing it through a glass slab
  - Object looks bigger than its actual size and raised when we dip it into liquid.
  - Twinkling of stars
  - Delayed sunset and early sunrise

Refraction through Prism

- In prism, refracting surfaces are planes but inclined to each other.
- Refracting ray always bends towards the base.
- Angle of deviation , $\delta = ((i - r_1) + (e - r_2)$
- **Angle of minimum deviation :** When incident angle is increased gradually the angle of deviation initially decreases, and after obtaining a minimum value, it starts increasing again. This minimum deviation is called angle of minimum deviation δ_m.





(i) $i + e = \delta + A$ Here, $i = e$ ...(i)

(ii) $r_1 + r_2 = A$ ...(ii)

- At minimum deviation stage it is observed that angle of $i_1 = i_2 (= i)$ and $r_1 = r_2 (= r)$, then

$$r = \frac{A}{2} \quad \text{... using (ii)}$$

$$i = \frac{\delta_m + A}{2} \quad \text{.... using (i)}$$

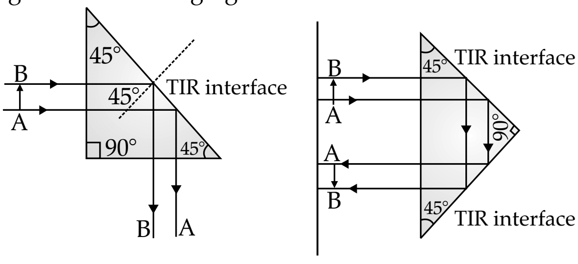
$$n_{21} = \frac{n_2}{n_1} = \frac{\sin[(A+\delta_m)/2]}{\sin[A/2]}$$

As angle of prism and deviation can be found experimentally, this equation is used to determine the refractive index of the material of prism.

- For thin prism, $\delta_m = (n_{21} - 1)A$. This equation implies that thin prisms do not deviate light much.
- When light travels from an optically denser medium to a rarer medium at the interface, sometime it is reflected into the same medium. This reflection is called the internal reflection.
  - Critical angle is that value of incident angle for which angle of refraction is 90°. The refracted ray just brushes the surface. The critical angle for water-air, glass-air and diamond-air are 45°, 42° and 24° respectively.

$$n_{12} = \frac{1}{\sin C} \quad \text{(where, } C \text{ is critical angle.)}$$

  - If the incidence angle is more than the critical angle, refraction is not possible and incident ray reflects in denser medium. This is known as total internal reflection.
- Hence, conditions for total internal reflection are :
  - Incident ray is in denser medium.
  - Angle of incidence should be larger than critical angle.
- Natural phenomenon based upon total internal reflection
  - **Mirage :** On hot summer days, light from tall objects successively bends away from the normal due to gradual air density decrease towards the earth. This results total internal reflection and formation of inverted images of distant tall objects. It causes an optical illusion to the observer. This phenomenon is called mirage.
  - **Brilliance of diamond :** Refractive index of diamond is very high ($n \approx 2.42$). Their brilliance is mainly due to the total internal reflection of light inside it.
- **Applications of total internal reflection :**
  - In optical fibers for optical communication.
  - **Prism :** Prisms designed to bend light by 90° or by 180º make use of total internal reflection. Such a prism is also used to invert images without changing their size.



TIR → total internal reflection

➢ **Refraction at spherical surface :** If the rays are incident from a medium of refractive index n_1, to another medium of refractive index n_2, the formula comes out to be

$$\frac{n_2}{v}-\frac{n_1}{u}=\frac{n_2-n_1}{R}$$

Where, R = radius of curvature of spherical surface and object is placed at rarer medium.
u = object distance from spherical surface
v = image distance from spherical surface

➢ **Lens :** A lens is a piece of transparent glass which is bounded by two surfaces out of which at least one surface is spherical .
There are two types of lenses
- **Convex lens :** A convex lens is one which is thinner at sides and thick at centre.
- **Concave lens :** A concave lens is one which is thicker at sides and thin at centre.

➢ **Relation between object distance, image distance with focal length of lens :**
The relation can be expressed as

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

➢ **Magnification by lens :**

$$m=\frac{\text{height of the image } (h')}{\text{height of the object } (h)}=\frac{v}{u}$$

➢ **Power of a lens :**
The power of a lens is defined as the reciprocal of its focal length. It is represented by the letter P. The power P of a lens of focal length f is given by

$$P=\frac{1}{f}$$

The SI unit of power is diopter when focal length is in metre. It is denoted by D. Hence one diopter is a power of lens whose focal length is 1 metre.
- When two or more lenses are combined then the power of combined lens is sum of individual power of lenses.

$$P = P_1 + P_2 + ...$$

➢ **Lens maker's Formula :**

$$\frac{1}{f}=(n_{21}-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right) \qquad \left(n_{21}=\frac{n_2}{n_1}\right)$$

Power of a lens, $$P=\frac{1}{f(m)}.$$

So, the above formula is used to make lenses of required power. Hence this formula is known as lens maker's formula.

- **Image formation in convex lens for different positions of object**

	Position of the image	**Relative size of the image**	**Nature of the image**
At infinity	at focus F_2	Highly diminished point sized	Real and inverted
Beyond $2F_1$	Between F_2 and $2F_2$	Diminished	Real and inverted
At $2F_1$	at $2F_2$	Same sized	Real and inverted
Between $2F_1$ and $2F_2$	Beyond $2F_2$	Enlarged	Real and inverted
At Focus F_1	At infinity	Infinitely enlarged	Real and inverted
Between focus F_1 and optical centre	On the same side of the lens as object	Enlarged	Virtual and Erect

- **Image formation in concave lens for different positions of object**

Position of the object	**Position of the image**	**Relative size of the image**	**Nature of the image**
At infinity	At focus F_1	Highly diminished point sized	Virtual and Erect
Between infinity and the optical center O of the lens	Between focus F_1 and optical center O	Diminished	Virtual and Erect

- **Dispersion of white light through Prism :** Splitting of white colour into its constituent colours is known as dispersion of light. This is due to different colours having different deviations.
  - The seven colours are violet, indigo, blue, green, yellow, orange and red. The acronym of this colour band is **VIBGYOR**.
  - Different colours of light have different wavelengths and different frequency in medium. This is the cause of dispersion.
  - In vacuum, the speed of light is independent of wavelength. Thus, vacuum (or air approximately) is a non-dispersive medium in which all colours travel with the same speed. This also follows from the fact that sunlight reaches us in the form of white light (combination of all colours) and not as its components in day (noon) time. On the other hand, glass is a dispersive medium.
  - **Angular dispersion through thin prism** = $\delta_V - \delta_R = (n_V - n_R)A$. The relation shows that it depends upon the angle of prism A.
  - **Power of dispersion,** $\omega = \dfrac{\delta_V - \delta_R}{\delta_Y} = \dfrac{n_V - n_R}{n_Y}$ is independent of A. It is property of dispersive material.
  - **Recombination of white light :** If we place an inverted identical prism after the first prism, all components colours of light recombine and again became a beam of white light.
- **Phenomenon related to dispersion of light :**
  - **Formation of Rainbow :** Rainbow is the natural phenomenon of dispersion of light. After a rain shower when sky becomes clear and sunny, we may observe a rainbow in a direction opposite to the direction of sun when sun is at our backside. It is caused due to the combined effect of refraction, total internal reflection and dispersion of sunlight by the raindrops suspended in the air.
  - In **primary rainbow**, there is only single total internal reflection before different colours reach observer's eye. In this rainbow, observer see red colour at top and violet at bottom.
  - In **secondary rainbow**, there are two total internal reflections before different colours reach observer's eye. In this rainbow, observer see violet colour at top and red at bottom.
  - Secondary rainbow is higher (50° – 53°) on sky than the primary rainbow (40° – 42°).
  - Intensity of secondary rainbow is lower than the primary rainbow.
- **Scattering of light :** When light deviates randomly from its path due to its interaction with small particles, it is known as scattering of light.
- **Tyndall Effect :** The Tyndall effect is the scattering of light as a beam of light passes through a colloid. The individual suspension particles scatter and reflect light, making the beam visible.
- The colour of the scattered light depends on the size of the scattering particles.
- For $a << \lambda$, where, a is the size of scattering particle, one has Rayleigh scattering which is proportional to $\dfrac{1}{\lambda^4}$. For $a >> \lambda$, *i.e.*, large scattering objects (for example, raindrops, large dust particles) ; all wavelengths are scattered nearly equally.
- **Phenomenon related to scattering of light :**
  - Colour of the clear sky is blue.
  - Reddening of the Sun at sunrise and sunset.
  - White appearance of Clouds.
- **Principal focus :** Incident ray parallel to the principal axis, after refraction from lens either converge to a point (in case of convex lens) after the lens or appear to diverge from a point (in case of concave lens) before the lens. This point is called the principal focus of the lens.

Know the Formulae

- **Snell's law of refraction** $\dfrac{\sin i}{\sin r}$ = constant (n_{21})
- $n_{21} = \dfrac{c}{v}$
- $n_{21} \times n_{32} \times n_{13} = 1$
- Rise of image = Real depth $\left(1 - \dfrac{1}{n_{21}}\right)$

- Deviation through prism $\delta = (i - r_1) + (e - r_2)$
- For thin prism, $\delta_m = (n_{21} - 1)A$
- Relation between refractive index, angle of prism and minimum deviation

$$n_{21} = \frac{\sin\frac{(\delta_m + A)}{2}}{\sin\left(\frac{A}{2}\right)}$$

- Condition for Total internal reflection are
  - Incident ray is in denser medium.
  - Angle of incident should be larger than critical angle.
- $n_{21} = \frac{1}{\sin C}$
- For lens $\frac{1}{f} = \frac{1}{v} - \frac{1}{u}$ & $m = \frac{h'}{h} = \frac{v}{u}$
- Power of lens P = $\frac{1}{f}$
- When two or more lenses are combined then the power of combined lens is sum of individual power of lenses.
  - $P = P_1 + P_2 + \ldots$
- Lens maker's Formula

$$\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad \left(n_{21} = \frac{n_2}{n_1}\right)$$

- Angular dispersion through thin prism = $\delta_v - \delta_r = (n_v - n_r)A$.
- Power of dispersion $\omega = \frac{\delta_v - \delta_r}{\delta_y} = \frac{n_v - n_r}{n_y}$

Objective Type Questions

(1 mark each)

Q. 1. You are given four sources of light each one providing a light of a single colour red, blue, green and yellow. Suppose the angle of refraction for a beam of yellow light corresponding to a particular angle of incidence at the interface of two media is 90°. Which of the following statements is correct if the source of yellow light is replaced with that of other lights without changing the angle of incidence?

(a) The beam of red light would undergo total internal reflection.

(b) The beam of red light would bend towards normal while it gets refracted through the second medium.

(c) The beam of blue light would undergo total internal reflection.

(d) The beam of green light would bend away from the normal as it gets refracted through the second medium.

[NCERT Exemp. Q. 9.5, Page 55]

Ans. Correct option : (c)

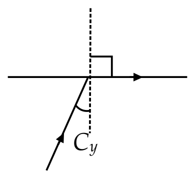
Explanation : According to the Cauchy relationship,

$$\lambda \propto \frac{1}{\mu}$$

Smaller the wavelength higher the refractive index and so that smaller the critical angle

So, light rays are passing from denser to rarer medium.

As $\sin C = \frac{1}{\mu}$ so, $C \propto \frac{1}{\mu} > \mu_v > \mu_g > \mu_y > \mu_R$



So, critical angle for $C_v < C_g < C_Y < C_R$, that is, critical angle of blue and green light is smaller than that of yellow and it is greater for red colour light. As the angle of refraction for yellow light is for a particular incident angle, this incidence angle is critical angle for yellow. Let it be C_Y.

As we know that, $C_R > C_v$.

So, it will not get total internal reflection and $C_V < C_Y$, $C_G < C_Y$.

So, light of blue and green colour get total internal reflection.

Q. 2. A ray of light incident at an angle θ on a refracting face of a prism emerges from the other face normally. If the angle of the prism is 5° and the prism is made of a material of refractive index 1.5, the angle of incidence is :

(a) 7.5°. **(b) 5°.**
(c) 15°. **(d) 2.5°.**

[NCERT Exemplar]

Ans. Correct option : (a)

Explanation : Given that,

$$A = 5^\circ$$
$$\mu = 1.5$$
$$i_2 = 0^\circ$$
$$r_2 = 0^\circ$$

As we know that,

$$r_1 + r_2 = A$$
$$r_1 = A - r_2$$
$$= 5 - 0 = 5^\circ$$

From Snell's law :

$$\mu = \frac{\sin i_1}{\sin r_1}$$

$$\sin i_1 = \mu \sin r_1$$
$$= 1.5 \times \sin 5^\circ$$
$$= 1.5 \times 0.087$$
$$= 0.1305$$
$$= 7.5^\circ$$

Q. 3. A passenger in an aeroplane shall

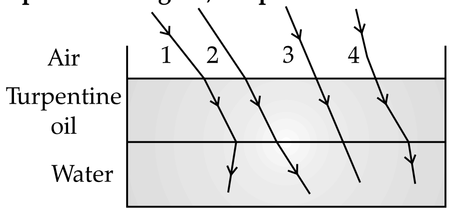
(a) never see a rainbow.
(b) may see a primary and a secondary rainbow as concentric circles.
(c) may see a primary and a secondary rainbow as concentric arcs.
(d) shall never see a secondary rainbow.

[NCERT Exemplar]

Ans. Correct option : (b)

Explanation : A passenger in an aeroplane may see primary and secondary rainbow as concentric circles due to the dispersion of sunlight.

Q. 4. The optical density of turpentine oil is higher than that of water while its mass density is lower. Figure shows a layer of turpentine floating over water in a container. For which one of the four rays incident on turpentine in Figure, the path shown is correct?



(a) 1. **(b) 2.**
(c) 3. **(d) 4.**

[NCERT Exemplar]

Ans. Correct option : (b)

Explanation : $\mu_A < \mu_T > \mu_W$

As incident ray passes from air to turpentine oil to water it means, from rare to denser then denser to rarer so first it bends towards normal then away from normal so the path shown is correct for ray (2).

Q. 5. A short pulse of white light is incident from air to a glass slab at normal incidence.

After travelling through the slab, the first colour to emerge is

(a) blue. **(b) green.**
(c) violet. **(d) red.**

[NCERT Exemplar]

Ans. Correct option : (d)

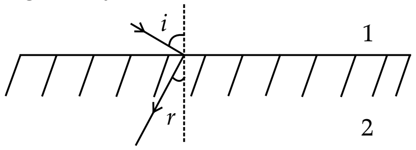
Explanation : As we know that the velocity of wave is :

$$v = \nu\lambda$$

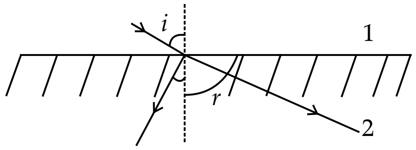
When light ray goes from one medium to other medium, the frequency of light remains unchanged. So, $v \propto \lambda$ or greater the wavelength, greater the speed. And, the light of red colour is of highest wavelength and therefore of highest speed. So, after travelling through the slab, the red colour emerges first.

Q. 6. There are certain materials developed in laboratories which have a negative refractive index (Figure). A ray incident from air (medium 1) into such a medium (medium 2) shall follow a path given by :

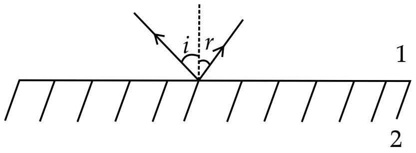
(a)



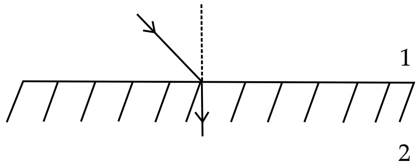
(b)



(c)



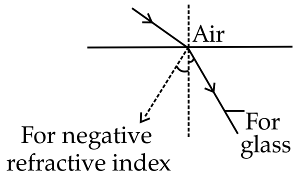
(d)



[NCERT Exemplar]

Ans. Correct option : (a)

Explanation : The negative refractive index materials are those in which incident ray from air (medium 1) to (medium 2) then it refracts or bends differently or opposite and symmetric to normal to that of positive refractive index medium.



Very Short Answer Type Questions (1 mark each)

Q. 1. How does the angle of minimum deviation of a glass prism vary, if the incident violet light is replaced by red light ? Give reason. R **[OD 2017]**

Ans. (i) Decreases ½

(ii) $n_{Violet} > n_{Red}$ ½

[CBSE Marking Scheme 2017]

Detailed Answer :

We know , $\delta_m = (n_{21} - 1)A$. Hence larger the refractive index, larger the deviation. As refractive index of glass for violet is more than the refractive index of glass for red, hence deviation will decrease if the incident violet light is replaced by red light. **1**

AI **Q. 2. Why does sun appear red at sunrise and sunset ?** R **[O.D., 2016]**

Ans. At the time of sunrise or sunset, sun is at horizon. Hence sunrays have to travel longer distance before reaching to our eye. During this travel shorter wavelength get scattered as we receive only longer wavelengths *i.e.,* red, orange. This is the reason sun appear red at sunrise and sunset. **1**

[CBSE Marking Scheme 2016]

Q. 3. An object is placed in front of convex lens made of glass. How does the image distance vary if the refractive index of the medium is increased in such a way that still it remains less than the glass? R **[CBSE SQP 2016]**

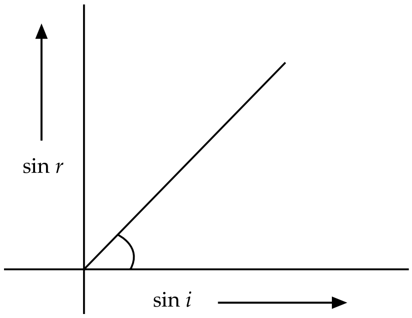
Ans. From the lens maker's formula, it is clear that n_{21} decreases then focal length increase. ½

$$\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \qquad \left(\because n_{21} = \frac{n_2}{n_1}\right)$$

Here refractive index of the glass with respect to surrounding material decreases. Hence, focal length increases which will also increase the image distance. ½

[CBSE Marking Scheme 2016]

Q. 4. A ray of light is incident on a medium with angle of incidence '*i*' and is refracted into a second medium with angle of refraction '*r*'. The graph of sin i versus sin *r* is as shown. Find the ratio of the velocity of light in the first medium to the velocity of light in the second medium.



R **[CBSE SQP 2018-19]**

Ans. From the graph, $\tan\theta = \dfrac{\sin r}{\sin i}$ ½

$$\frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

$$\frac{v_1}{v_2} = \cot\theta \quad ½$$

[CBSE Marking Scheme 2018]

Q. 5. Define the power of a lens. Write its S.I. unit. R **[CBSE Comptt. 2018]**

Ans. The power of a lens equals to the reciprocal of its focal length (in metre). ½

Also accept

$$P = \frac{1}{f(\text{metre})} \quad ½$$

Do not deduct mark if student does not write the word metre.

(Alternatively,

Power of a lens is the ability of conversion/ diversion of the rays incident on the lens.)

SI Unit : Diopter (D) **1**

[CBSE Marking Scheme 2018]

AI **Q. 6. (i) What is the relation between critical angle and refractive index of a material ?**

(ii) Does critical angle depend on the colour of light ? Explain. R **[O.D. 2013, 2009]**

Ans. (i) Refractive index $(n) = \dfrac{1}{\sin C}$ ½

where, C is the critical angle.

(ii) Yes, Since, refractive index depends upon the wavelength of light, the critical angle for a given pair of media is different for different wavelengths (colours) of light. ½

Q. 7. For the same value of angle of incidence, the angles of refraction in three media *A*, *B* and *C* are 15°, 25° and 35° respectively. In which medium would the velocity of light be minimum ? U **[OD 2012]**

Ans. Velocity of light would be minimum in medium '*A*'. **[CBSE Marking Scheme 2012] 1**

Detailed Answer :

Since the refractive index of the material

$$n = \frac{c}{v} = \frac{\sin i}{\sin r}$$

where, c is the velocity of light in vacuum and v is velocity of light in that medium.

Refractive index shows the material's bending power of light. Hence for same value of angle of incidence, the material in which angle of refraction is minimum that would have greatest refractive index. So, A has maximum refractive index and hence velocity of light is minimum in it.

Q. 8. A concave lens of refractive index 1.5 is immersed in a medium of refractive index 1.65. What is the nature of the lens ? A **[Delhi 2015]**

Ans. The lens behaves as a convex lense.

When the refractive index of a surrounding medium is more than refractive index of material of concave lens than the nature of the lens changes. **1**

Commonly Made Error

- Many candidates wrote the correct lens makers formula but could not relate that (n_{21} – 1) is still positive, so nature of lens will not change.

Answering Tips

- Solve a few problems based on lens maker's formula and learn what happens when the lens is immersed in (a) rarer medium (b) a denser medium.

Q. 9. Write the relationship between angle of incidence '*i*', angle of prism '*A*' and angle of minimum deviation for triangular prism. R **[Delhi 2013]**

Ans. $A + \delta_m = 2i$ **1**

[CBSE Marking Scheme 2013]

AI **Q. 10. If the wavelength of light incident on a convex lens is increased, how will its focal length change ? [O.D. Comptt. I, II, III 2013]**

Ans. If the wavelength of light incident on a convex lens is increased, its focal length will also increase. **1**

[CBSE Marking Scheme 2013]

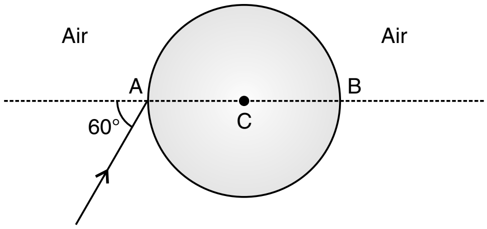
Q. 11. Under what condition does a biconvex lens of glass having a certain refractive index act as a plane glass sheet when immersed in a liquid ?

[Delhi I, II, III 2012]

Ans. When the refractive index of glass is equal to the refractive index of the liquid.
(**Alternatively,** when $\mu_L = \mu_g$) **1**

[CBSE Marking Scheme 2012]

Q. 12. A ray of light falls on a transparent sphere with centre *C* as shown in the figure. The ray emerges from the sphere parallel to the line *AB*. Find the angle of refraction at *A*, if refractive index of the material of the sphere is $\sqrt{3}$. [Foreign 2014]



Ans. $\because \quad \dfrac{\sin i}{\sin r} = \mu$

$\therefore \quad \dfrac{\sin 60°}{\sin r} = \sqrt{3}$

$\therefore \quad \sin r = \dfrac{1}{2}$ **1**

$r = 30°$

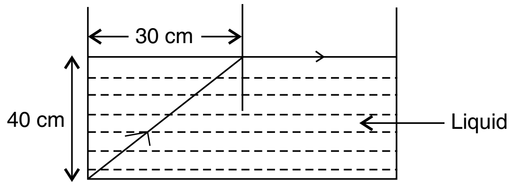
[CBSE Marking Scheme 2014]

Short Answer Type Questions-I

(2 marks each)

Q. 1. (i) Define refractive index of a medium.

(ii) In the following ray diagram, calculate the speed of light in the liquid of unknown refractive index.



U **[CBSE Comptt. 2017]**

Ans. (i) Refractive index of a medium is the ratio of speed of light (c) in free space to the speed of light (v) in that medium. **1**

$$\mu = \frac{c}{v}$$

(ii) $$\mu = \frac{c}{v} = \frac{1}{\sin i_c}$$ **½**

$$= \frac{3\times10^8}{v} = \frac{1}{\frac{30}{50}}$$

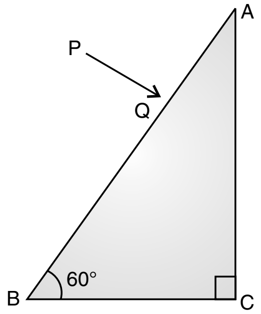
$$v = \frac{30}{50}\times3\times10^8$$

$= 1{\cdot}8 \times 10^8$ m/s **½**

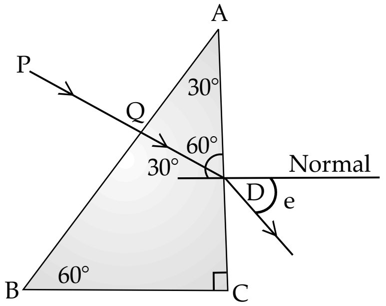
[CBSE Marking Scheme, 2016]

AI **Q. 2. A ray *PQ* incident normally on the refracting face *BA* is refracted in the prism *BAC* made of material of refractive index 1.5. Complete the path of ray through the prism. From which face will the ray emerge ? Justify your answer.**

A **[O. D. I, II, III 2016]**



Ans.



1

At plane AC, the incident angle = 30°

If critical angle for total internal reflection= S_C

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

$$\Rightarrow \quad \sin C = \frac{1}{1.5}$$

$$= 0.67 \text{ hence, } C > 30°$$

(sin 30° = 0.5)

As incident angle is less than critical angle, it would emerge out from AC. In the figure path of the ray is shown. 1

$$\frac{\sin 30°}{\sin e} = \frac{1}{1.5}$$

$$\therefore \quad \sin e = 1.5 \times \sin 30°$$

$$= 1.5 \times 0.5 = 0.75$$

$$\therefore \quad e = 48°$$

Commonly Made Error

- Several students could not get angle C correctly from $\frac{1}{\sin C} = n$ well understood.

AI **Q. 3. A convex lens is placed in contact with a plane mirror. A point object at a distance of 20 cm on the axis of this combination has its image coinciding with itself. What is the focal length of the lens ?**

R **[CBSE OD 2014]**

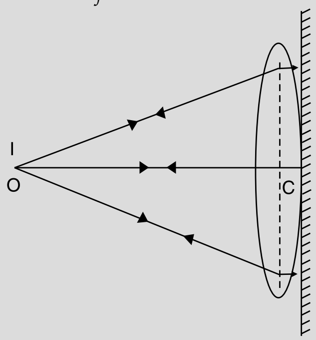
Ans. According to the question

Object distance, = 20 cm.

Image distance = 20 cm

As the image I of the object coincides with O, the rays refracted first from the lens and then reflected by the plane mirror must be retracing their path. It is the condition only when rays refracted by the convex lens fall normally on the mirror *i.e*, the refracted rays form a beam parallel to principal axis of the lens. Hence the object O must be at the focus of the convex lens.

$$f = CO = 20 \text{ cm}$$ 1



1

[CBSE Marking Scheme 2014]

Q. 4. (i) Why does white light disperse when passed through a glass prism ?

(ii) Using lens maker's formula, show how the focal length of a given lens depends upon the colour of light incident on it. U **[Delhi 2015]**

Ans. (i) Refractive index of glass for different wavelengths (colours) of light ray is different. Hence different colours bend with different angles. This give dispersion of white light when it passes through a glass prism. 1

(ii) As the refractive index of the medium with respect to air (medium 1) depends on the wavelength or colour of light, focal length of the lens would change with colour. 1

$$\frac{1}{f} = (n_{21} - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$

Q. 5. Write the conditions for observing a rainbow. Show, by drawing suitable diagrams, how one understands the formation of a rainbow.

R **[O.D. Comptt. I, II, III 2014]**

Ans. The conditions for observing a rainbow are :

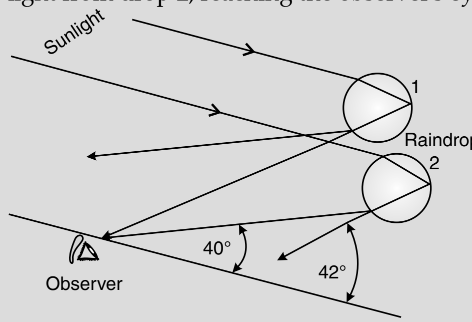
(i) The sun comes out after a rainfall. ½

(ii) The observer stands with the sun towards his/her back. **(Any one)** ½

Formation of a rainbow :

(a) The rays of light reach the observer through a refraction, followed by a reflection and a refraction.

(b) Figure shows red light, from drop 1 and violet light from drop 2, reaching the observer's eye.



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[CBSE Marking Scheme 2014]

Q. 6. (i) Write the necessary conditions for the phenomenon of total internal reflection to occur.

(ii) Write the relation between the refractive index and critical angle for a given pair of optical media.

R **[Delhi I, II, III 2013]**

Ans. Conditions for Total internal reflection are

(i) Incident ray is in denser medium.

(ii) Angle of incidence should be larger than critical angle. 1

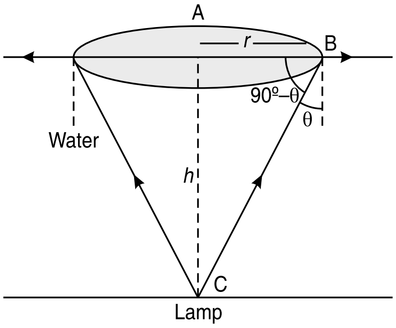
$$n_{12} = \frac{1}{\sin C}$$

Where C is the critical angle. 1

Q. 7. A small bulb (assumed to be a point source) is placed at the bottom of a tank containing water to a depth of 80 cm. Find out the area of the surface of water through which light from the bulb can emerge. Take the value of the refractive index of water to be $\frac{4}{3}$. A **[Delhi Comptt. I, II, III 2013]**

Ans. Actual depth of the bulb in water, $(d_1) = 0.8$ m

Refractive index of water, $\mu = \frac{4}{3}$



Where, Angle of incidence = θ

Angle of refraction = 90°

Since the bulb is a point source, the emergent light can be considered as a circle of radius r

$$\mu = \frac{\sin 90°}{\sin i}$$

$$\frac{4}{3} = \frac{\sin 90°}{\sin\theta}$$

or, $$\sin\theta = \frac{3}{4}$$

$$\cos\theta = \sqrt{1-\sin^2\theta} = \frac{\sqrt{7}}{4}$$

$$\tan\theta = \frac{3}{\sqrt{7}}$$ **1**

From the figure $$\tan\theta = \frac{r}{h}$$

$$\frac{3}{\sqrt{7}} = \frac{r}{0.8}$$

$\therefore$ $$r = 0.8\times\frac{3}{\sqrt{7}}$$

$$= 0.91 \text{ m}$$

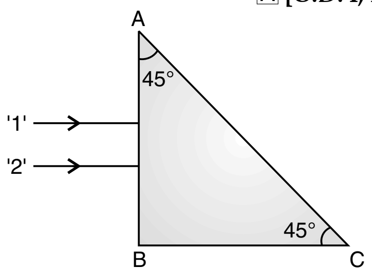
Area of the surface of water through light emerge

$$= \pi r^2 = \pi\,(0.91)^2 = 2.6 \text{ m}^2$$

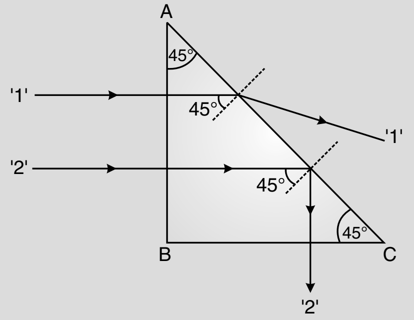
Hence, the area of the surface of water through which the light from the bulb can emerge is approximately 2.6 m^2. **1**

AI Q. 8. Two monochromatic rays of light are incident normally on the face *AB* of an isosceles right-angled prism *ABC*. The refractive indices of the glass prism for the two rays '1' and '2' are respectively 1.35 and 1.45. Trace the path of these rays after entering through the prism.

A **[O.D. I, II, III 2014]**



Ans.



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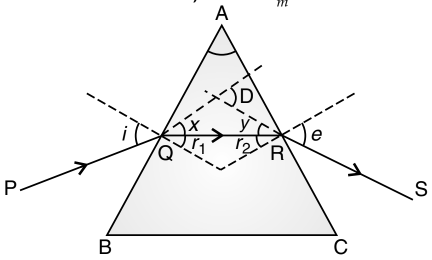
[CBSE Marking Scheme 2014]

Q. 9. Figure shows a ray of light passing through a prism. If the refracted ray *QR* is parallel to the base *BC*, show that (i) $r_1 = r_2 = A/2$, (ii) angle of minimum deviation, *D* or $D_m = 2i - A$.



R **[Foreign 2014, CBSE SQP, 2013, O.D. Comptt. I, II, III 2012]**

Ans. (i) From given figure, $A = r_1 + r_2$ ½

As the ray QR is parallel to the base BC,

then $r_1 = r_2$, and $i = e$

Therefore, $2r_1$ (or $2r_2$) $= A$ ½

$\Rightarrow$ $r_1 = r_2 = A/2$

(ii) $D = x + y$ $D = (i - r_1) + (e - r_2)$ ½

$D = (i + e) - (r_1 + r_2)$

or $D = 2i - A$ ½

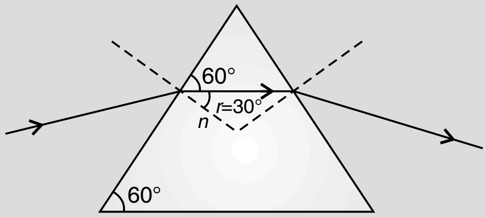
[CBSE Marking Scheme 2014]

Answering Tips

- Solve few numericals, including not only minimum deviation case but other cases as well. Students should draw diagrams while solving numericals.

Q. 10. A ray of light, incident on an equilateral glass prism ($\mu_g = \sqrt{3}$) moves parallel to the base line of the prism inside it. Find the angle of incidence for this ray. A **[Delhi I, II, III 2012]**

Ans.



From the diagram, $r = 30°$ ½

Also $\quad n_{21} = \dfrac{\sin i}{\sin r}$ ½

or, $\quad \sqrt{3} = \dfrac{\sin i}{\sin 30°}$

or, $\quad \sin i = \sqrt{3} \times \dfrac{1}{2}$ ½

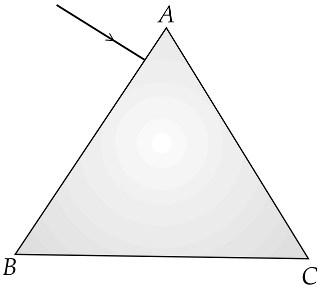
or, $\quad i = 60°$ ½

[CBSE Marking Scheme 2012]

Short Answer Type Questions-II (3 marks each)

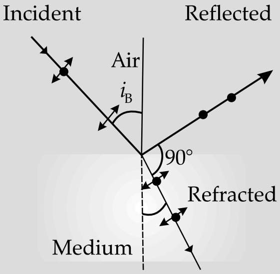
Q. 1. (i) Show using a proper diagram how unpolarized light can be linearly polarised by reflection from a transparent glass surface.

(ii) The figure shows a ray of light falling normally on on the face *AB* of an equilateral glass prism having refractive index $\frac{3}{2}$, placed in water of refractive index $\frac{4}{3}$. Will this ray suffer total internal reflection on striking the face *AC* ? Justify your answer.



A **[CBSE 2018, 2012]**

Ans. (i) The diagram, showing polarisation by reflection is as shown. [Here the reflected and refracted rays are at right angle to each other.]



½

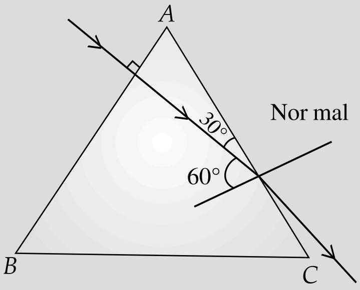
$\therefore \quad r = \left(\dfrac{\pi}{2} - i_B\right)$

$\therefore \quad \mu = \left(\dfrac{\sin i_B}{\sin r} = \tan i_B\right)$ ½

Thus light gets totally polarised by reflection when it is incident at an angle i_B (Brewster's angle), where $i_B = \tan^{-1}\mu$ ½

(ii) The angle of incidence, of the ray, on striking the face AC is $i = 60°$ (as from figure)

Also, relative refractive index of glass, with respect to the surrounding water, is



$$\mu_r = \frac{\frac{3}{2}}{\frac{4}{3}} = \frac{9}{8}$$

Also $\quad \sin i = \sin 60° = \dfrac{\sqrt{3}}{2} = \dfrac{1.732}{2}$

$= 0.866$

For total internal reflection, the required critical angle, in this case, is given by ½

$$\sin i_C = \frac{1}{\mu} = \frac{8}{9} \simeq 0.89$$

$\therefore \quad i < i_C$

Hence the ray would not suffer total internal reflection on striking the face *AC*. ½

[The student may just write the two conditions needed for total internal reflection without analysis of the given case.

The student may be awarded (½+½) mark in such a case.

[CBSE Marking Scheme 2018]

AI **Q. 2. (i) Monochromatic light of wavelength 589 nm is incident from air on a water surface. If μ for water is 1·33, find the wavelength, frequency and speed of the refracted light.**

(ii) A double convex lens is made of a glass of refractive index 1·55, with both faces of the same radius of curvature. Find the radius of curvature required, if the focal length is 20 cm.

U **[OD I, II, III, 2016]**

Ans. (i) $\quad \lambda = \dfrac{589 \text{ nm}}{1{\cdot}33} = 442{\cdot}8 \text{ nm}$ ½

Frequency, $\quad \nu = \dfrac{3 \times 10^8 \text{ ms}^{-1}}{589 \text{ nm}}$

$= 5{\cdot}09 \times 10^{14}$ Hz ½

Speed $\quad v = \dfrac{3 \times 10^8}{1{\cdot}33}$ m/s

$= 2{\cdot}25 \times 10^8$ m/s ½

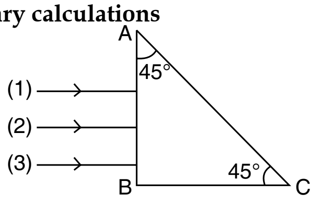
(ii) $$\frac{1}{f} = \left[\frac{\mu_2}{\mu_1} - 1\right]\left[\frac{1}{R_1} - \frac{1}{R_2}\right]$$ ½

$$\therefore \quad \frac{1}{20} = \left[\frac{1{\cdot}55}{1} - 1\right]\frac{2}{R}$$ ½

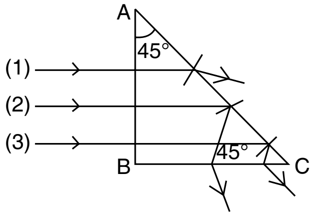
$$\therefore \quad R = (20 \times 1{\cdot}10) \text{ cm} = -22 \text{ cm}$$ ½

[CBSE Marking Scheme 2016]

Q. 3. Three rays (1, 2, 3) of different colours fall normally on one of the sides of an isosceles right angled prism as shown. The refractive index of prism for these rays is 1.39, 1.47 and 1.52 respectively. Find which of these rays get internally reflected and which get only refracted from AC. Trace the paths of rays. Justify your answer with the help of necessary calculations U **[OD 2017]**



Ans. At plane AC, the incident angle for ray 1, ray 2 and ray 3 = 45°



1

Let critical angle for total internal reflection for ray 1 = C_1

$$1.39 = \frac{1}{\sin C_1}$$

$$\Rightarrow \quad \sin C_1 = \frac{1}{1.39} = 0.719$$

Hence $C_1 > 45°$ (sin 45 = 0.707) ½

Let critical angle for total internal reflection for ray 2 = C_2

$$1.47 = \frac{1}{\sin C_2}$$

$$\Rightarrow \quad \sin C_2 = \frac{1}{1.47} = 0.68$$

Hence $C_2 < 45°$ ...½

Let critical angle for total internal reflection for ray 3 = C_3

$$1.52 = \frac{1}{\sin C_3}$$

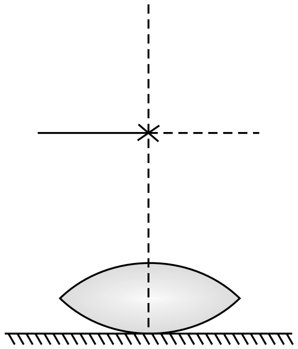
$$\Rightarrow \quad \sin C_3 = \frac{1}{1{\cdot}52} = 0.657$$

Hence $C_3 < 45°$ ½

As in case of ray 1, incident angle is less than critical angle, it would emerge out from AC. In the figure path of the ray 1 is shown.

In case of ray 2, ray 3, incident angle is greater than critical angle, they would get total internal reflection at AC and emerge from BC. In the figure path of the ray 2 and 3 are shown. ½

Q. 4. A symmetric biconvex lens of radius of curvature R and made of glass of refractive index 1·5, is placed on a layer of liquid placed on top of a plane mirror as shown in the figure. An optical needle with its tip on the principal axis of the lens is moved along the axis until its real, inverted image coincides with the needle itself. The distance of the needle from the lens is measured to be *x*. On removing the liquid layer and repeating the experiment, the distance is found to be *y*. Obtain the expression for the refractive index of the liquid in terms of *x* and *y*. U



[Delhi & OD 2018; Delhi Comptt. 2014]

Ans. Lens maker's formula ½

Formula for 'combination of lenses' ½

Obtaining the expression for μ 2

(a) Let μ_1 denote the refractive index of the liquid. When the image of the needle coincides with the lens itself; its distance from the lens, equals the relevant focal length. ½

With liquid layer present, the given set up, is equivalent to a combination of the given (convex) lens and a concavo plane/plano concave 'liquid lens'.

We have $$\frac{1}{f} = (\mu - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right)$$ ½

and $$\frac{1}{f} = \left(\frac{1}{f_1} + \frac{1}{f_2}\right)$$ ½

as per the given data,

$$\frac{1}{f_2} = \frac{1}{y} = (1{\cdot}5 - 1)\left(\frac{1}{R} - \frac{1}{(-R)}\right)$$ ½

$$= \frac{1}{R}$$

$$\therefore \quad \frac{1}{x} = (\mu_l - 1)\left(-\frac{1}{R}\right) + \frac{1}{y} = \frac{-\mu_l}{y} + \frac{2}{y}$$ ½

$$\therefore \quad \frac{\mu_1}{y} = \frac{2}{y} - \frac{1}{x} = \left(\frac{2x-y}{xy}\right)$$

or $$\mu_l = \left(\frac{2x-y}{x}\right)$$ ½

[CBSE Marking Scheme 2018]

Detailed Answer :

Given, Radius of curvature of convex lens is R and $\mu = 1.5$

When lens is placed on a layer of water then focal length of combination is f. Thus the first measurement gives the focal length of combination *i.e.* $f = x$.

In second measurement, we get the focal length f_1 of convex lens *i.e.*, $f_1 = y$, therefore the focal length of plano convex lens of water f_2 is given as

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

$$\Rightarrow \quad \frac{1}{f_2} = \frac{1}{f} - \frac{1}{f_1} = \frac{1}{x} - \frac{1}{y} = \frac{y-x}{xy}$$

$$\Rightarrow \quad f_2 = \frac{xy}{y-x} \quad ....(i)$$

For plano convex lens of liquid of refractive index μ_l,

$$\frac{1}{f_2} = (\mu_l - 1)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) = (\mu_l - 1)\left(-\frac{1}{R} - \frac{1}{\infty}\right)$$

$$\Rightarrow \frac{1}{f_2} = -\frac{(\mu_l - 1)}{R}$$

$$\Rightarrow \mu_l = 1 - \frac{R}{f_2} \quad ....(ii)$$

Now from eqn. (i) and (ii),

$$\mu_l = 1 - \frac{R}{xy/(y-x)} = 1 - \frac{R(y-x)}{xy} \quad ....(iii)$$

Now again for plano convex lens of air, if image coincide at $2f_1$ then for case II we have

$$\Rightarrow \quad 2f_1 = R$$

$$\Rightarrow \quad f_1 = \frac{R}{2}$$

again $$y = 2f_1 = 2 \times \frac{R}{2}$$

$$\Rightarrow \quad y = R \quad ...(iv)$$

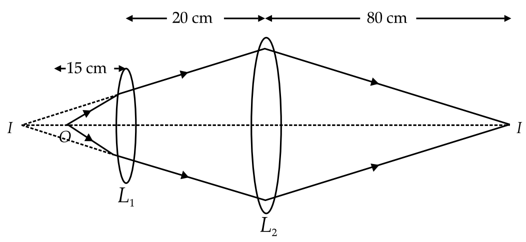
Now from eqn. (iii) and (iv),

$$\mu_l = 1 - \frac{y(y-x)}{xy} = 1 - \frac{y-x}{x}$$

$$\mu_l = \frac{2x-y}{x}$$

This is the required expression for the refractive index of liquid.

Q. 5. In the following diagram, an object 'O' is placed 15 cm in front of a convex lens L_1 of focal length 20 cm and the final image is formed at 'I' at a distance of 80 cm from the second lens L_2. Find the focal length of the lens L_2.



[Foreign 2016]

Ans. For lens L_1

$$u = -15 \text{ cm}$$
$$f = +20 \text{ cm}$$

Using lens formula

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

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

$$\frac{1}{v} = -\frac{1}{15} + \frac{1}{20} = -\frac{1}{60} \quad \mathbf{1}$$

$$v = -60 \text{ cm}$$

This image will act as object for lens L_2

Hence for lens L_2

$$u = -20 - 60 = -80 \text{ cm}$$
$$v = +80 \text{ cm} \quad \mathbf{1}$$

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

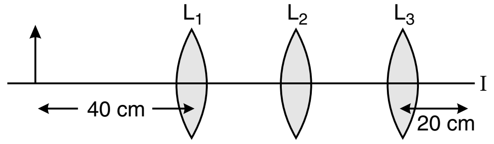
$$\frac{1}{80} + \frac{1}{80} = \frac{1}{f}$$

$$\frac{1}{f} = \frac{1}{40}$$

or $$f = 40 \text{ cm} \quad \mathbf{1}$$

[CBSE Marking Scheme 2016]

Q. 6. You are given three lenses L_1, L_2 and L_3 each of focal length 20 cm. An object is kept at 40 cm in front of L_1. The final real image is formed at the focus I of L_3. Find the separations between L_1, L_2 and L_3.



[O.D. I, II, III 2012]

$$f_3 = +20 \text{ cm}, v_3 = 20 \text{ cm}$$

$$\frac{1}{20} = \frac{1}{20} + \frac{1}{u_3}$$

$$\Rightarrow \quad u_3 = \infty$$ ½

It shows that L_2 must render the rays parallel to the common axis. It means that the image (I_1), formed by L_1, must be at a distance of 20 cm from L_2 (at the focus of L_2) ½

Therefore, distance between L_1 and L_2 (= 40 + 20) = 60 cm and distance between L_2 and L_3 can have any value. **[CBSE Marking Scheme 2012]** ½

Detailed Answer :

Given, $f_1 = f_2 = f_3 = 20$ cm

For lens, L_1,

$$u = -40 \text{ cm}$$

$$f = 20 \text{ cm}$$

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

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

$$\frac{1}{v} = -\frac{1}{40} + \frac{1}{20}$$

$$\frac{1}{v} = \frac{1}{40}$$

$$v = 40 \text{ cm}$$

(+ve sign shows it is right hand side of lens L_1)

Now for L_3, the final image is at its focus, that means $v_3 = +20$ cm. Hence $u_3 = \infty$

Now, since image of the object AB formed by convex lens L_2 is virtual object for L_3, therefore $v_2 = \infty$.

Hence for lens L_2, $u_2 = ?$, $f_2 = 20$ cm and $v_2 = \infty$. Using the lens formula,

$$\frac{1}{v_2} - \frac{1}{u_2} = \frac{1}{f_2}$$

$$\Rightarrow \quad \frac{1}{\infty} - \frac{1}{u_2} = \frac{1}{20}$$

$$u_2 = -20 \text{ cm}$$

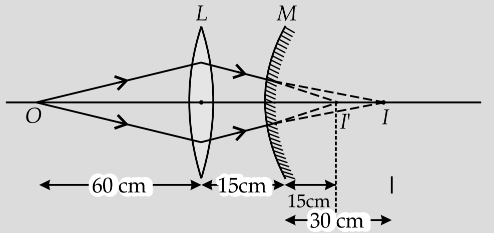
So, the separation between L_1 and L_2

$$= 40 + 20 = 60 \text{ cm}$$

As $v_2 = \infty$ and $u_3 = \infty$, therefore the distance between L_2 and L_3 does not matter it may take any value because image by L_2 is formed at infinity.

AI **Q. 7. A convex lens of focal length 20 cm is placed co-axially with a convex mirror of radius of curvature 20 cm. The two are kept at 15 cm from each other. A point object lies 60 cm in front of the convex lens. Draw a ray diagram to show the formation of the image by the combination. Determine the nature and position of the image formed. [O.D. I, II, III 2014]**

Ans.



1

For the convex lens, $u = -60$ cm, $f = +20$ cm

$$\frac{1}{v} - \frac{1}{u} = \frac{1}{f} \text{ gives } v = +30 \text{ cm} \quad ½$$

For the convex mirror,

$$u = +(30 - 15) \text{ cm} = 15 \text{ cm}, f = +\frac{20}{2} \text{ cm} = 10 \text{ cm} \quad ½$$

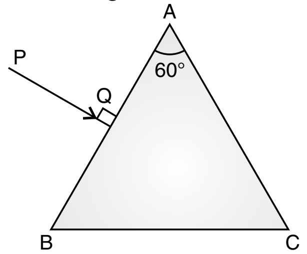
$$\frac{1}{v} + \frac{1}{u} = \frac{1}{f} \text{ gives } v = +30 \text{ cm}$$

The final image is formed at the distance of 30 cm from the convex mirror (or 45 cm from the convex lens) to the right of the convex mirror. ½

The final image formed is a virtual image. ½

[CBSE Marking Scheme 2014]

AI **Q. 8. A ray PQ is incident normally on the face AB of a triangular prism of refracting angle of 60°, made of a transparent material of refractive index $\frac{2}{\sqrt{3}}$, as shown in the figure. Trace the path of the ray as it passes through the prism. Also calculate the angle of emergence and angle of deviation.**



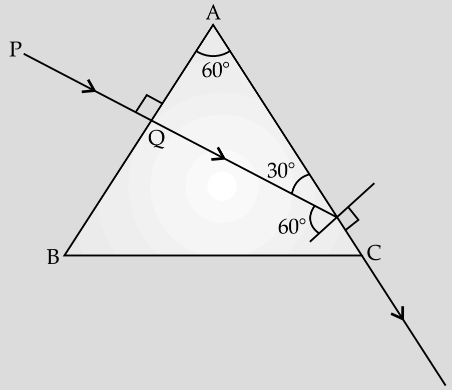
[Delhi Comptt. I, II, III 2014]

Ans. If i_c is the critical angle for the prism/material,

$$\mu = \frac{1}{\sin i_C}$$

$$\therefore \quad \sin i_C = \frac{1}{\mu} = \frac{\sqrt{3}}{2} \quad ½$$

$$\Rightarrow \quad i_C = 60° \quad ½$$



1

Angle of incidence at face AC of the prism = 60° ½

Hence, refracted ray grazes the surface AC.

⇒ Angle of emergence = 90° ½

⇒ Angle of deviation = 30°

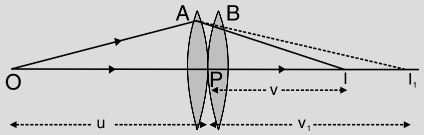
[CBSE Marking Scheme 2014] ½

Long Answer Type Questions (5 marks each)

Q. 1. (i) Draw a ray diagram to show the image formation by a combination of two thin convex lenses in contact. Obtain the expression for the power of this combination in terms of the focal lengths of the lenses.

(ii) A ray of light passing from air through an equilateral glass prism undergoes minimum deviation when the angle of incidence is $\frac{3}{4}$ th of the angle of prism. Calculate the speed of light in the prism. U [OD I, 2017]

Ans. (i)



1

Two thin lenses, of focal length f_1 and f_2 are kept in contact. Let O be the position of object and let u be the object distance. The distance of the image (which is at I_1), for the first lens is v_1.

This image serves as object for the second lens. ½

Let the final image be at I. We then have

$$\frac{1}{f_1} = \frac{1}{v_1} - \frac{1}{u} \quad ½$$

$$\frac{1}{f_2} = \frac{1}{v} - \frac{1}{v_1} \quad ½$$

Adding, we get

$$\frac{1}{f_1} + \frac{1}{f_2} = \frac{1}{v} - \frac{1}{u} = \frac{1}{f} \quad ½$$

$$\therefore \quad \frac{1}{f} = \frac{1}{f_1} + \frac{1}{f_2}$$

$$\therefore \quad P = P_1 + P_2 \quad ½$$

(ii) At minimum deviation

$$r = \frac{A}{2} = 30° \quad ½$$

We are given that, $i = \frac{3}{4}A = 45°$ ½

$$\therefore \quad \mu = \frac{\sin 45°}{\sin 30°} = \sqrt{2}$$

$\therefore$ Speed of light in the prism $= \frac{c}{\sqrt{2}}$ ½

($\cong 2.1 \times 10^8$ ms^{-1})

[Award ½ mark if the student writes the formula :

$$\mu = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\left(\frac{A}{2}\right)}$$

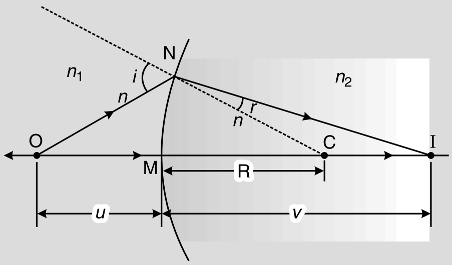
but does not do any calculations.]

[CBSE Marking Scheme 2017]

AI **Q. 2. (i) A point object is placed on the principal axis of a convex spherical surface of radius of curvature *R*, which separates the two media of refractive indices n_1 and n_2 ($n_2 > n_1$). Draw the ray diagram and deduce the relation between the object distance (*u*), image distance (*v*) and the radius of curvature (*R*) for refraction to take place at the convex spherical surface from rarer to denser medium.**

(ii) A converging lens has a focal length of 20 cm in air. It is made of a material of refractive index 1·6. If it is immersed in a liquid of refractive index 1·3, find its new focal length. U [Foreign 2017]

Ans. (i)



1

For small angles

$$\tan \angle NOM = \frac{MN}{OM}$$

$$\tan \angle NCM = \frac{MN}{MC}$$

and $$\tan \angle NIM = \frac{MN}{MI}$$

For ΔNOC, i is exterior angle, therefore

$$i = \angle NOM + \angle NCM$$

$$= \frac{MN}{OM} + \frac{MN}{MC} \quad ½$$

Similarly, $$r = \frac{MN}{MC} - \frac{MN}{MI} \quad ½$$

For small angles, Snell's law can be written as

$$n_1 i = n_2 r$$

$$\therefore \quad \frac{n_1}{OM} + \frac{n_2}{MI} = \frac{n_2 - n_1}{MC} \quad ½$$

$$\therefore \quad OM = -u, MI = +v$$

$$MC = +R$$

(using sign convention)

$$\therefore \quad \frac{n_2}{v} - \frac{n_1}{u} = \frac{n_2 - n_1}{R} \quad ½$$

(ii) Lens maker's formula is

$$\frac{1}{f} = \left(\frac{n_2}{n_1} - 1\right)\left(\frac{1}{R_1} - \frac{1}{R_2}\right) \quad ½$$

Focal length of lens is = 20 cm

$$\frac{1}{20} = (1.6-1)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$\therefore \quad \left(\frac{1}{R_1}-\frac{1}{R_2}\right) = \frac{1}{20\times 0.6} = \frac{1}{12} \qquad \frac{1}{2}$$

Let f' be the focal length of the lens in water

$$\therefore \quad \frac{1}{f'} = \left(\frac{1.6-1.3}{1.3}\right)\left(\frac{1}{R_1}-\frac{1}{R_2}\right)$$

$$= \frac{0.3}{12\times 1.3} \qquad \frac{1}{2}$$

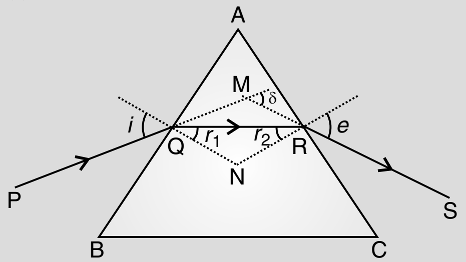
$$\text{Or} \quad f' = \frac{120\times 1.3}{3} = 52 \text{ cm} \qquad \frac{1}{2}$$

[CBSE Marking Scheme 2017]

Q. 3. (i) Draw the ray diagram showing refraction of light through a glass prism and hence obtain the relation between the refractive index μ of the prism, angle of prism and angle of minimum deviation.

(ii) Determine the value of the angle of incidence for a ray of light travelling from a medium of refractive index $\mu_1 = \sqrt{2}$ into the medium of refractive index $\mu_2 = 1$, so that it just grazes along the surface of separation. R **[Foreign 2017]**

Ans. (i)



1

From fig $\angle A + \angle QNR = 180°$ ...(i)

From triangle ΔQNR, $r_1 + r_2 + QNR = 180°$ ...(ii)

Hence from eqn. (i) & (ii)

$$\therefore \quad \angle A = r_1 + r_2 \qquad \frac{1}{2}$$

The angle of deviation

$$\delta = (i - r_1) + (e - r_2)$$
$$= i + e - A \qquad \frac{1}{2}$$

At minimum deviation $i = e$ and $r_1 = r_2$

$$\therefore \quad r = \frac{A}{2} \qquad \frac{1}{2}$$

$$\text{And} \quad i = \frac{A+\delta_m}{2} \qquad \frac{1}{2}$$

Hence, refractive index,

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+\delta_m}{2}\right)}{\sin\frac{A}{2}} \qquad \frac{1}{2}$$

(ii) From snell's law, $\mu_1 \sin i = \mu_2 \sin r$ ½

Given $\mu_1 = \sqrt{2}, \mu_2 = 1$

and $r = 90°$ (just grazing) ½

$$\Rightarrow \quad \sin i = \frac{1}{\sqrt{2}}$$

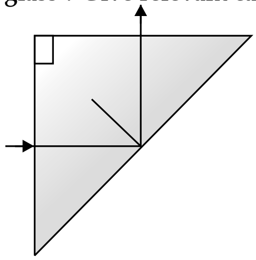
or $i = 45°$ ½

[CBSE Marking Scheme 2017]

AI **Q. 4. (i) Plot a graph to show variation of the angle of deviation as a function of angle of incidence for light passing through a prism. Derive an expression for refractive index of the prism in terms of angle of minimum deviation and angle of prism.**

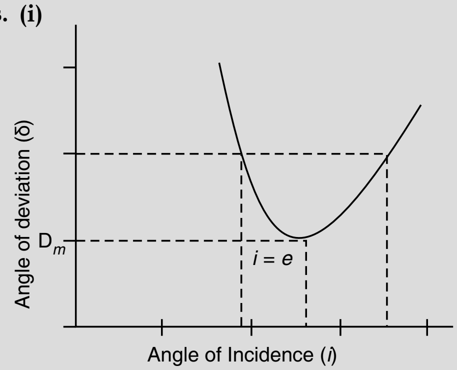
(ii) What is dispersion of light ? What is its cause ?

(iii) A ray of light incident normally on one face of a right isosceles prism is totally reflected as shown in fig. What must be the minimum value of refractive index of glass ? Give relevant calculations.



R **[Delhi I, II, III 2016]**

Ans. (i)



1

From figure $\delta = D_m$, $i = e$ which implies $r_1 = r_2$

$$2r = A, \text{ or } r = \frac{A}{2} \qquad \frac{1}{2}$$

Using

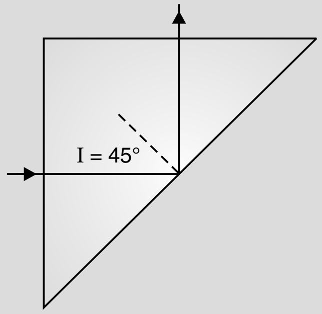
$$\delta = i + e - A$$
$$D_m = 2i - A$$
$$i = \frac{A + D_m}{2}$$

$$\mu = \frac{\sin i}{\sin r} = \frac{\sin\left(\frac{A+D_m}{2}\right)}{\sin\frac{A}{2}} \qquad \frac{1}{2}$$

(ii) The phenomenon of splitting of white light into its constituent colours. ½

Cause : Refractive index of the material is different for different colours. According to the equation, δ (deviation) = (μ – 1)A, where, A is the angle of prism, different colours will deviate through different amount. ½

(iii)



1

For total internal reflection,

$\angle i \geq \angle i_c$ (critical angle) ½

$\Rightarrow$ $45° \geq \angle i_c$, *i.e.*, $\angle i_c \leq 45°$ ½

$$\sin i_c \leq \sin 45°$$

$$\leq \frac{1}{\sqrt{2}}$$

$$\frac{1}{\sin i_c} \geq \sqrt{2}$$

$\Rightarrow$ $\mu \geq \sqrt{2}$

Hence, the minimum value of refractive index must be $\sqrt{2}$.

[CBSE Marking Scheme 2016]

TOPIC-3
Optical Instruments

Revision Notes

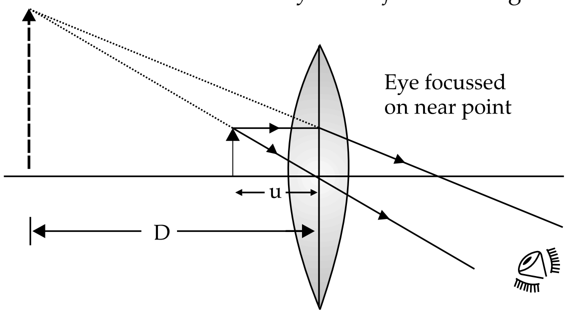
- Based upon phenomenon of reflecting and refracting properties of mirrors, lenses and prisms, a number of optical devices and instruments have been designed.
- **Microscope** is an optical instrument which help us to see and study micro objects or organism. It forms magnified image of the object.
- **Telescope** is an optical instrument which help us to see and study far off objects magnified and resolved (with clarity).
- We generally set these instruments at two different image vision positions
  - **Image at least distance of distinct vision :** This is the least distance from eye where we able to see objects distinctly. For normal human eye this distance is 25 cm from our eye.
  - **Image at relaxed vision :** This is the distance from eye where we able to see objects distinctly in relax vision (no strain to eye) . For normal human eye this distance is infinity from our eye.
  - Magnification at distinct vision is always greater than magnification at relaxed vision.

Simple Microscope : Convex lens behaves as simple microscope.

The magnifying power of the simple microscope

(i) For least distance of distinct vision $m = 1 + \dfrac{D}{f}$

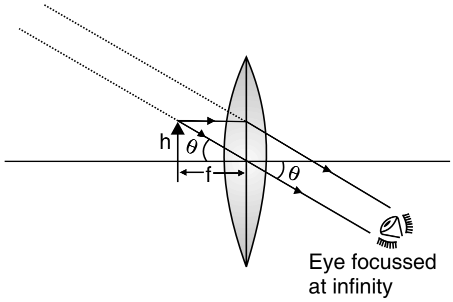
where, D is the least distance of distinct vision of the eye. And f is focal length of the lens.



(ii) For relaxed eye

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

from above formulae, it is clear that for larger magnifying power, the focal length of the convex lens should be small.



Please note that angular magnification by optical instruments is the linear magnification by lenses only. It means magnification of an instrument means how many times it enlarges the image of object. So this is just as

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

where, h is size of object (in one dimension) and h' is the size of image.

Compound Microscope : For much large magnification, compound microscope is used. It is a combination of two convex lenses hence the magnification of each lens is compounded.

- These two lenses are placed co-axially and the distance between them is adjustable.
- The lens towards the object is called objective and that towards the eye is called eyepiece.
- The final image formed by the compound microscope is magnified and inverted.
- Total magnification by compound lens

$$m = m_o \times m_e$$

where, m_o is magnification by objective lens and m_e is magnification by eyepiece.

- For least distance of distinct vision magnification by objective lens is

$$m_o = \frac{v_o}{u_o} \approx \frac{L}{f_o}$$

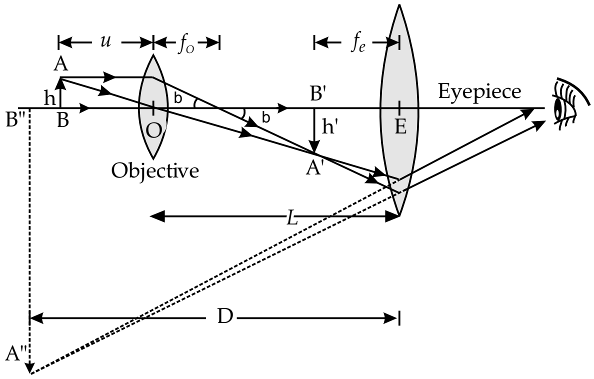
where, L is the distance between the second focal point of the objective and the first focal point of the eyepiece (focal length f_e). It is called the tube length of the compound microscope.

Eyepiece lens will act as simple microscope.

Magnification by eyepiece lens is

$$m_e = 1 + \frac{D}{f_e}$$

Hence, Magnification by compound lens $= \frac{L}{f_o}\left(1 + \frac{D}{f_e}\right)$



➢ **For Relaxed eye (normal adjustment)**

For relaxed eye the magnification by objective lens remain same, the magnification by eyepiece will be $+\frac{D}{f_e}$

Hence, the total magnification of compound microscope in relaxed eye condition is

$$m = \frac{L}{f_o} \times \frac{D}{f_e}$$

➢ **Properties of Compound Microscope**

- For large magnification of a compound microscope, both f_0 and f_e should be small.
- If the length of the microscope tube increases, then its magnifying power increases.
- Generally f_o is much smaller. So that objective is placed very near to principal focus.

- The aperture of the eyepiece is generally small so that whole of the light may enter the eye.
- The aperture of the objective is also small so that the field of view may be restricted.

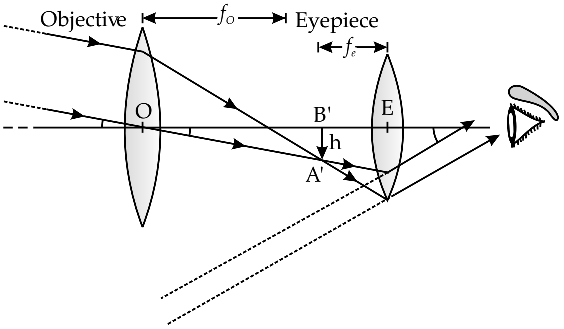
➢ **Magnification by Telescope**

- Telescope is an instrument to magnify and resolve far off objects.
- Far off objects make much smaller angle at our eye. Telescope makes that angle bigger without much intensity loss.
- To maximise the intensity aperture size of objective lens is quite large. It will focus a bright point size image at its focal plane.
- Now with eyepiece, we will form this point size image to final inverted magnified image. This type of telescope is known as astronomical telescope.
- For least distance of distinct vision

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

➢ **For relaxed eye (normal adjustment)**

$$m = \frac{\alpha}{\beta} = -\frac{f_o}{f_e}$$



➢ **Properties of astronomical telescope**

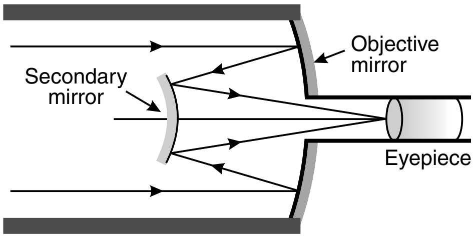
- For larger magnifying power, f_o should be large and f_e should be small.
- The length of the tube of an astronomical telescope is $L = f_o + f_e$ for relaxed vision adjustment.
- When the length of the tube of the telescope increases, f_o increases and hence the magnifying power also increases.

➢ **Limitations of refractive telescope**

- Large objective lens makes the telescope very heavy. So it is difficult to handle it by hand.
- It has spherical and chromatic aberrations.

➢ **Modern Telescope (Reflective Telescope)**

- Reflecting telescope consists of a concave mirror of large radius of curvature in place of objective lens
- A secondary convex mirror is used to focus the incident light, which now passes through a hole in the objective primary mirror .
- The magnifying power of the reflecting telescope is $m = \frac{f_o}{f_e}$



➢ **Advantages of reflective telescope**

- Very sharp point image by objective mirror removes spherical aberrations.
- As it is very light so large aperture of parabolic mirror can be used for desired magnification.
- This is based on the principle of reflection hence there will be no chromatic aberrations.

Know the Formulae

➢ Magnification by Simple Microscope

$$m = 1+\frac{D}{f} \text{ (for distinct vision)}$$

$$m = \frac{D}{f} \text{ (For relaxed eye)}$$

➢ Magnification by Compound Microscope

$$\frac{L}{f_o}\left(1+\frac{D}{f_e}\right) \text{ or } \frac{v_o}{u_o}\left(1+\frac{D}{f_e}\right) \text{ (for distinct vision)}$$

$$\frac{L}{f_o}\times\frac{D}{f_e} \text{ or } \frac{v_o}{u_o}\times\frac{D}{f_e} \text{ (for relaxed eye)}$$

➢ Magnification by Telescope

➢ $m = -\frac{f_o}{f_e}\left(1+\frac{f_e}{D}\right)$ (for distinct vision)

➢ $m = -\frac{f_o}{f_e}$ (for relaxed eye)

Very Short Answer Type Questions (1 mark each)

AI **Q. 1. Does the magnifying power of a microscope depend on the colour of the light used ? Justify your answer.** U **[Foreign 2017]**

Ans. Justification, $m \propto \frac{1}{f_o f_e}$ ½

And focal length depends on colour/μ. ½

[CBSE Marking Scheme 2017]

Detailed Answer :

Magnifying power of microscope $\propto \frac{1}{f_o f_e}$

Where f_o and f_e are the focal lengths of objective lens and eyepiece lens respectively.

Focal length of a lens depends upon the refractive index and different colour of light has different refractive index with respect to the medium of lens material. Hence, magnifying power of a microscope depends on the colour of the light used.

Q. 2. Define visual angle. Does it vary with distance of the object from the eye ? U

Ans. It is the angle subtended an object or image at the eye. It decreases with increasing distance of the object or image from the eye. ½+½ = **1**

Short Answer Type Questions-I (2 marks each)

Q. 1. Why should the objective of a telescope have large focal length and large aperture ? Justify your answer. U **[Delhi II 2017]**

Ans. Large focal length : to increase magnifying power

$$\left(\because m = \frac{f_o}{f_e}\right)$$ ½

Large aperture : to increase resolving power

$$\left(\because RP = \frac{2a}{1.22\lambda}\right)$$ ½

[**Note for students :** Resolving power of instruments is covered in chapter-10]

[CBSE Marking Scheme 2017] 1

Commonly Made Error

- Many students did not know the correct formula of resolving power of telescope.

Q. 2. Define the magnifying power of a compound microscope when the final image is formed at infinity. Why must both the objective and the eyepiece of a compound microscope have short focal lengths ? Explain. U **[Delhi I, 2017]**

Ans. Magnifying power is defined as the angle subtended by the image to the angle subtended (at the unaided eye) by the object. 1

(**Alternatively :** Also accept this definition in the form of formula)

$$m = m_0 \times m_e = \frac{L}{f_o}\times\frac{D}{f_e}$$

To increase the magnifying power both the objective and eyepiece must have short focal lengths $\left(\text{as } m = \frac{L}{f_o}\times\frac{D}{f_e}\right)$ ½+½

[CBSE Marking Scheme 2017]

Commonly Made Error

- Students wrote correct definition of magnifying power of the microscope but wrote wrong formula.

AI Q. 3. (i) State the condition under which a large magnification can be achieved in an astronomical telescope.

(ii) Give two reasons to explain why a reflecting telescope is preferred over a refracting telescope.

U **[CBSE 2017, Foreign set]**

Ans. (i) $m = \frac{f_o}{f_e}$ ½

By increasing f_o or decreasing f_e ½

(ii) (a) No chromatic aberration.

(b) No spherical aberration.

(c) Mechanical advantage – low weight, easier to support.

(d) Mirrors are easy to prepare.

(e) More economical. **(Any two)** ½+½

[CBSE Marking Scheme 2017]

AI Q. 4. You are given two converging lens of focal lengths 1.25 cm and 5 cm to design a compound microscope. If it is desired to have a magnification of 30, find out the separation between the objective and the eyepiece. A **[OD 2015]**

Ans. Given, $f_o = 1.25$ cm, $f_e = 5$ cm

Magnification, $m = 30$,

If we set these lens for minimum distance for distinct vision , then for

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

$m = 30$

$L = 6.25$ cm **1**

Hence, distance between two lenses is

$= f_o + 6.25 + f_e$

$= (1.25 + 6.25 + 5.0)$ cm

$= 12.5$ cm

This is a required separation between the objective and the eyepiece. **1**

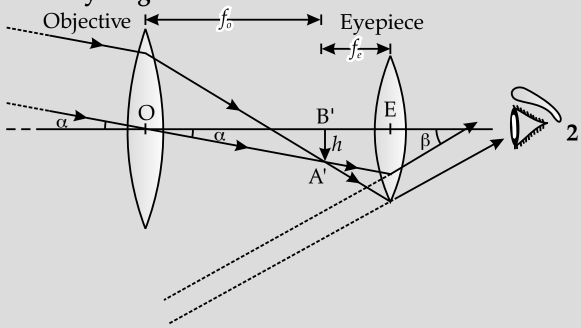
Short Answer Type Questions-II

(3 marks each)

AI Q. 1. Draw a labelled ray diagram to show the image formation in a refracting type astronomical telescope in the normal adjustment position. Write two drawbacks of refracting type telescopes.

A **[CBSE SQP 2018-19]**

Ans. Ray diagram :



2

Drawbacks :

(i) Large sized lenses area heavy and difficult to support. ½

(ii) Large sized lenses suffer from chromatic and spherical aberration. ½

[CBSE Marking Scheme 2018]

Q. 2. (i) Draw a ray diagram depicting the formation of the image by an astronomical telescope in normal adjustment.

(ii) You are given the following three lenses. Which two lenses will you use as an eyepiece and as an objective to construct an astronomical telescope ? Give reason.

Lenses	Power (D)	Aperture (cm)
L_1	3	8
L_2	6	1
L_3	10	1

A **[OD 2017]**

Ans. (i) Try yourself similar Q.1 SAT Question-II

(ii) Objective Lens : Lens L_1 ½

Eyepiece Lens : Lens L_2 ½

Reason :

The objective should have large aperture and large focal length while the eyepiece should have small aperture and small focal length. ½

[CBSE Marking Scheme, 2017]

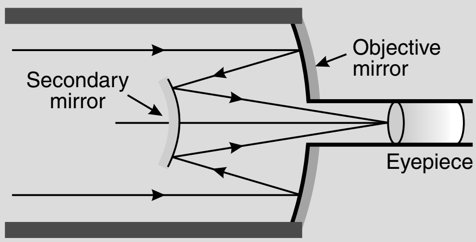
Commonly Made Error

- Most of the students could not draw correct labelled ray diagram of the astronomical telescope.

AI Q. 3. Draw a schematic ray diagram of reflecting telescope showing how rays coming from a distant object are received at the eye-piece. Write its two important advantages over a refracting telescope.

U **[Delhi 2016]**

Ans.



2

Advantages :

(i) Large gathering power

(ii) Large magnifying power

(iii) No chromatic aberration

(iv) Spherical aberration is also removed

(v) Easy mechanical support

(vi) Large resolving power **(Any two) ½ + ½**

[CBSE Marking Scheme 2016]

Q. 4. (i) A giant refracting telescope has an objective lens of focal length 15 m. If an eye piece of focal length 1.0 cm is used, what is the angular magnification of the telescope ?

(ii) If this telescope is used to view the moon, what is the diameter of the image of the moon formed by the objective lens ? The diameter of the moon is 3.48×10^6 m and the radius of lunar orbit is 3.8×10^8 m.

A [Delhi I, II, III 2015]

Ans. $|m| = \left|\frac{f_o}{f_e}\right|$

f_o → focal length of objective

f_e → focal length of eyepiece

$|m| = \frac{15 \times 100}{1} = 1500$

∵ image formed is inverted

$\boxed{\therefore \text{ angular magnification} = +1500}$

$|m| = \left|\frac{f_o}{f_e}\right|$

f_o → focal length of objective

f_e → focal length of eyepiece

$|m| = \frac{15 \times 100}{1} = 1500$

∵ image formed is inverted

$\boxed{\therefore \text{ angular magnification} = +1500}$

ii) ~~angle im~~ angle subtended by moon at obj = angle of img at objective.

$$\frac{D}{R} = \frac{d}{f_o}$$

$$\frac{3.4 \times 10^6}{3.8 \times 10^8} = \frac{d}{15}$$

$$d = \frac{3.4}{3.8} \times 10^{-2} \times 15 \text{ m}$$

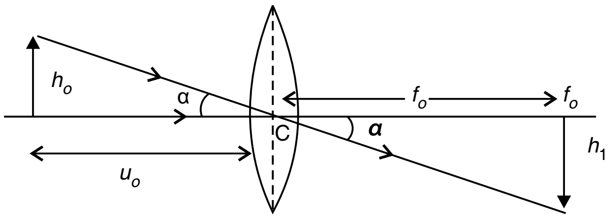
$$\boxed{d = 13.4 \text{ cm}} \rightarrow \text{Ans}$$

[Topper's Answer 2015]

Detailed Answer :

(i) $m = \frac{-f_o}{f_e}$; ignoring –ve sign as it only shown that image is inverted.

$$f_o = 1500 \text{ cm}$$
$$f_e = 1 \text{ cm}$$
$$m = \frac{1500}{1} = 1500 \qquad 1$$



(ii) Angular size of the moon,

$$\tan \alpha = \frac{h_o}{u_o}$$

Angular size of the moon's image by objective lens is also,

$$\tan \alpha = \frac{h_1}{f_o}$$

Hence,

$$\frac{h_o}{u_o} = \frac{h_1}{f_o}$$

$$h_o = 3.48 \times 10^6 \text{ m}$$
$$u_o = 3.8 \times 10^8 \text{ m.}$$
$$f_o = 15 \text{ m}$$
$$\frac{3.48\times10^6}{3.8\times10^8} = \frac{h_1}{15}$$
$$h_1 = \frac{3.48\times10^6}{3.8\times10^8}\times15$$
$$= 13.7 \text{ cm} \qquad 2$$

Answering Tip

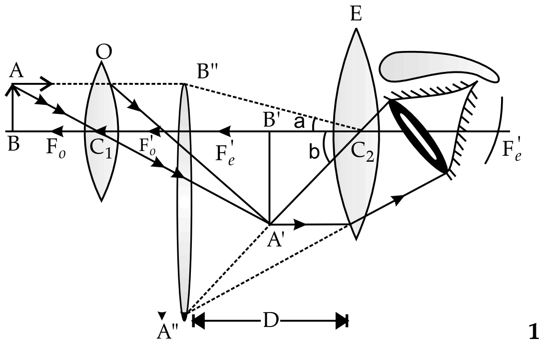
- Learn all the formulae of Telescope carefully. Do practice to solve the numericals by taking care of their sign convention.

Q. 5. (i) Draw a labelled ray diagram showing the formation of a final image by a compound microscope at the least distance of distinct vision.

(ii) The total magnification produced by a compound microscope is 20. The magnification produced by the eye piece is 5. The microscope is focussed on a certain object. The distance between the objective and eyepiece is observed to be 14 cm.

If the least distance of distinct vision is 20 cm, calculate the focal length of the objective lens and the eye piece. A **[Delhi I, II, III 2014]**

Ans. (i) Labelled ray diagram of a compound microscope for formation of image at the near point of the eye :



1

(ii) Given, $m = 20$, $m_e = 5$, D = 20 cm

For eyepiece,

$$m_e = \frac{D}{u_e}$$
$$5 = -\frac{20}{u_e}$$
$$u_e = -4 \text{ cm} \qquad ½$$
$$u_e = -4 \text{ cm}, v_e = D = -20 \text{ cm}$$
$$\frac{1}{f_e} = \frac{1}{v_e} - \frac{1}{u_e}$$
$$= \frac{1}{-20} + \frac{1}{4}$$
$$\frac{1}{f_e} = \frac{-1+5}{20}$$
$$\frac{1}{f_e} = \frac{4}{20} \qquad ½$$
$$\Rightarrow \quad f_e = 5 \text{ cm}$$

Hence, focal length of eyepiece, $f_e = 5$ cm

$$m = m_o \times m_e$$
$$m_o = \frac{m}{m_e} = \frac{20}{5} = 4$$
$$v_o = 14 - 4 = 10 \text{ cm} \qquad ½$$

For objective lens,

$$m_o = -\frac{v_o}{u_o}$$
$$4 = -\frac{10}{u_o} \quad (\because m_o = 4)$$
$$\Rightarrow \quad u_o = -\frac{10}{4} = -2.5 \text{ cm}$$

Now,

$$\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o}$$
$$\frac{1}{f_o} = \frac{1}{10} - \frac{1}{-2.5}$$
$$\frac{1}{f_o} = \frac{1}{10} + \frac{10}{25}$$
$$\frac{1}{f_o} = \frac{1}{2}$$
$$\Rightarrow \quad f_o = 2 \text{ cm}$$

Hence, focal length of objective, $f_o = 2.0$ cm. ½

Long Answer Type Questions **(4 marks each)**

Q. 1. (i) Draw a labelled schematic ray diagram of astronomical telescope in normal adjustment.

(ii) Which two aberrations do objectives of refracting telescope suffer from ? How are these overcome in reflecting telescope ? U **[Foreign 2016]**

Ans. (i) Refer the diagram of Q.No. 3 in LATQ

(ii) The two aberrations that objectives of refracting telescope suffer from are

(a) Spherical aberrations : Because of the surface geometry of the lens, sharp point image of star is difficult to obtain on a point.

(b) In reflecting telescope, we use parabolic mirror to remove this aberration. **1½**

(c) Chromatic aberrations : Different colours of light have different refractive index with respect to glass. Hence different colours would focus at different points. Hence image of white object would appear as different colour point images. This is known as chromatic aberrations.

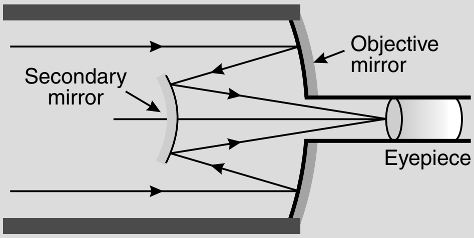
(d) In reflecting telescope, image is formed with reflected rays hence this aberration is removed. **1½**

Q. 2. (i) Draw a labelled ray diagram of an astronomical telescope to show the image formation of a distant object. Write the main considerations required in selecting the objective and eyepiece lenses in order to have large magnifying power and high resolution of the telescope.

(ii) A compound microscope has an objective of focal length 1.25 cm and eyepiece of focal length 5 cm. A small object is kept at 2.5 cm from the objective. If the final image formed is at infinity, find the distance between the objective and the eyepiece. U **[Foreign 2014]**

Ans. (i) Try yourself, Similar to Q. 1, Short Answer Type Questions-II **1½**

Alternatively,



1

For a large magnifying power, f_o should be large and f_e should be small. ½

For a higher resolution, the diameter of the objective should be large. ½

(ii) $$\frac{1}{v_o} - \frac{1}{u_o} = \frac{1}{f_o} \qquad ½$$

$$\frac{1}{v_o} = \frac{1}{f_o} + \frac{1}{u_o} = \frac{1}{1.25} - \frac{1}{2.5} = \frac{1}{-2.5}$$

$$v_o = -2.5 \text{ cm}$$

$$L = |f_o| + |f_e| \qquad (\because v_o = f_o) \; ½$$

$$= (2.5 + 5.0) \text{ cm} = 7.5 \text{ cm} \qquad ½$$

[Note for students : You may draw refractive or reflective telescope].

[CBSE Marking Scheme 2014]

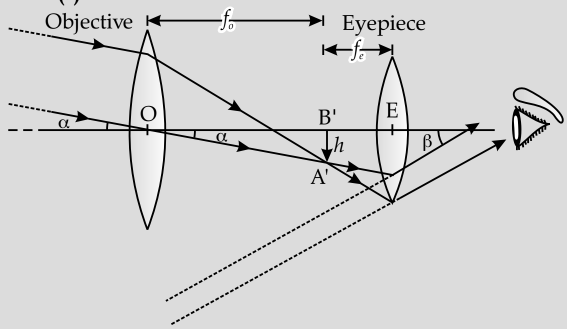
Q. 3. (i) Draw a labelled ray diagram showing the image formation of a distant object by a refracting telescope.

Deduce the expression for its magnifying power when the final image is formed at infinity.

(ii) The sum of focal lengths of the two lenses of a refracting telescope is 105 cm. The focal length of one lens is 20 times that of the other. Determine the total magnification of the telescope when the final image is formed at infinity.

U **[O.D. Comptt. I, II, III 2014, 2013]**

Ans. (i)



[Note : deduct ½ mark if not labelled] **1½**

Magnifying power,

$$m = \frac{\tan\beta}{\tan\alpha} \cong \frac{\beta}{\alpha} \qquad ½$$

$\because$ The angles are small

Final image is formed at infinity when the image $A'B'$ is formed by the objective lens at the focus of the eyepiece,

$$m = \frac{h}{f_e} \times \frac{f_o}{h} \qquad ½$$

$$m = \frac{f_o}{f_e} \qquad ½$$

(ii) Given,

$$f_o + f_e = 105, f_o = 20 f_e \qquad ½$$

$$20f_e + f_e = 105$$

$$f_e = \frac{105}{21} = 5 \text{ cm} \qquad ½$$

$$f_o = 20 \times 5 = 100 \text{ cm} \qquad ½$$

$\therefore$ Magnification, $$m = \frac{f_o}{f_e} = \frac{100}{5} = 20 \qquad ½$$

[CBSE Marking Scheme 2014]

Detailed Answer : (i)

Refer the diagram of Q. No. 3 in LATQ

Magnification

$$= \frac{\text{angle subtended by image at observer's eye}}{\text{angle subtended by object at observer's eye}} = \frac{\beta}{\alpha}$$

For small angle, $\beta = \tan\beta = \dfrac{-A'B'}{-f_e}$

(as eye is very near to eyepiece)

Angle $\alpha = \tan\alpha = \dfrac{-A'B'}{f_o}$

$$m = \frac{\dfrac{-A'B'}{-f_e}}{\dfrac{-A'B'}{f_o}} = \frac{-f_o}{f_e} \qquad 5$$

AI **Q. 4. (i) Draw a ray diagram showing the image formation by a compound microscope. Obtain expression for total magnification when the image is formed at infinity.**

(ii) How does the resolving power of a compound microscope get affected, when

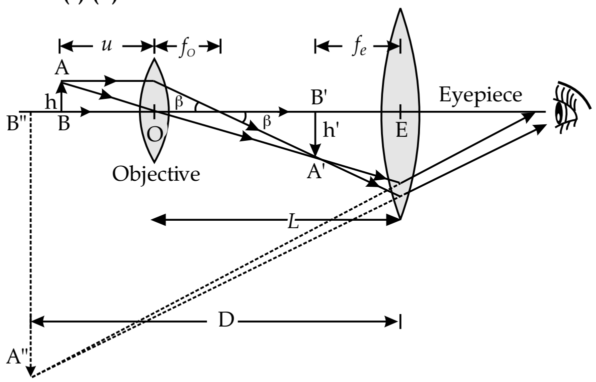
(a) focal length of the objective is decreased.

(b) the wavelength of light is increased ?

Give reasons to justify your answer.

U [O.D. I, II, III 2015]

Ans. (i) (a)



(ii) Magnification by objective lens = $\dfrac{\tan\beta}{\tan\alpha}$

$$\tan\beta = \frac{h'}{L} = \frac{h}{f_o}$$

$\dfrac{h'}{h} = \dfrac{L}{f_o}$ (where, the distance between the second focal point of the objective and the first focal point of the eyepiece is called the tube length of the compound microscope and is denoted by *L)*

Eyepiece will act as simple microscope, hence we may use the formula of magnification by simple microscope for normal adjustment.

$$m_e = \frac{D}{f_e}$$

Total magnification, $m = m_o \times m_e$

$$= \frac{L}{f_o} \times \frac{D}{f_e} \qquad 1$$

$$d_{min} = \frac{1.22 f\lambda}{D}$$

(a) From the equation, it is clear that resolving power increases when the focal length of the objective is decreased. This is because the minimum separation, d_{min} decreases when f is decreased. **1**

(b) Resolving power decreases when the wavelength of light is increased. This is because the minimum separation, d_{min} increases when λ is increased. **1**

AI **Q. 5. (i) Draw a labelled ray diagram to obtain the real image formed by an astronomical telescope in normal adjustment position. Define its magnifying power.**

(ii) You are given three lenses of power 0.5 D, 4 D and 10 D to design a telescope.

(a) Which lenses should be used as objective and eyepiece ? Justify your answer.

(b) Why is the aperture of the objective preferred to be large ? **A [O.D. I, II, III 2016]**

Ans. (i) Try yourself, Similar to Q. 1 (i), Long Answer Type Questions **2**

Definition : It is the ratio of the angle subtended at the eye, by the final image, to the angle which the object subtends at the lens, or the eye. **1**

(ii) (a) Objective = 0.5 D

Eye lens = 10 D

This choice would give higher magnification as

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

(b) High resolving power/brighter image/lower limit of resolution **(Any one) 2**

[CBSE Marking Scheme 2016]

Commonly Made Error

- Many students start correctly but get confused in between.
- Few students derived the expression for relaxed eye.

Q. 6. (i) Define magnifying power of a telescope.

(ii) Write its expression. A small telescope has an objective lens of focal length 150 cm and an eyepiece of focal length 5 cm. If this telescope is used to view a 100 m high tower 3×10^5 cm away, find the height of the final image when it is formed 25 cm away from the eye piece.

A [Delhi I, II, III 2012]

Ans. (i) Magnifying power is the ratio of the angle subtended at the eye by the image to the angle subtended at the unaided eye by the object. **1**

$$m = \frac{\beta}{\alpha} = \frac{f_o}{f_e}$$

(ii) Expression :

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

[Award 1 mark if student writes expression with –ve sign]

Using the lens equation for an objective lens, **1**

$$\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o}$$

$$\Rightarrow \quad \frac{1}{150} = \frac{1}{v_o} - \frac{1}{3 \times 10^5}$$

$$\Rightarrow \quad \frac{1}{v_o} = \frac{1}{150} - \frac{1}{3\times10^5} = \frac{2000-1}{3\times10^5} \quad \tfrac{1}{2}$$

$$\Rightarrow \quad v_o = \frac{3\times10^5}{1999}\text{ cm}$$

$$\approx 150\text{ cm}$$

Hence, magnification due to the objective lens

$$m_o = \frac{v_o}{u_o} = \frac{150\times10^{-2}\text{ m}}{3000\text{ m}} \quad \tfrac{1}{2}$$

$$m_o \approx \frac{10^{-2}}{20} = 0.05 \times 10^{-2}$$

Using lens formula for eyepiece,

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

$$\Rightarrow \quad \frac{1}{5} = \frac{1}{-25} - \frac{1}{u_e}$$

$$\Rightarrow \quad \frac{1}{u_e} = \frac{1}{-25} - \frac{1}{5} = \frac{-1-5}{25}$$

$$\Rightarrow \quad u_e = \frac{-25}{6}\text{ cm}$$

∴ Magnification due to eyepiece,

$$m_e = \frac{-25}{-\frac{25}{6}} = 6$$

Hence, total magnification, $m = m_e \times m_o$ ½

$$m = 6 \times 5 \times 10^{-4} = 30 \times 10^{-4}$$

Hence, size of the final image

$$= 30 \times 10^{-4} \times 100\text{ m}$$

$$= 30\text{ cm} \quad \tfrac{1}{2}$$

[CBSE Marking Scheme 2012]

Q. 7. How is the working of a telescope different from that of a microscope ? The focal lengths of the objective and eyepiece of a microscope are 1.25 cm and 5 cm respectively. Find the position of the object relative to the objective lens in order to obtain an angular magnification of 30 in normal adjustment. U **[Delhi I, II, III 2012]**

Ans. Working differences :

(i) The objective of a telescope forms the image of a very far off object at, or within, the focus of its eyepiece. The microscope does the same for a small object kept just beyond the focus of its objective.

(ii) The final image formed by a telescope is magnified relative to its size as seen by the unaided eye, while the final image formed by a microscope is magnified relative to its absolute size.

(iii) The objective of a telescope has large focal length and large aperture, while the corresponding for a microscope have very small values. **3**

Given : $f_o = 1.25$ cm, $f_e = 5$ cm

Angular magnification, $m = 30$

Now, $m = m_e \times m_o$

In normal adjustment, the angular magnification of an eyepiece

$$m_e = \frac{d}{f_e} = \frac{25}{5} = 5$$

Hence, $m_o = 6$

But $m_o = \frac{v_o}{u_o} \Rightarrow -6 = \frac{v_o}{u_o}$ ½

$$v_o = -6u_o$$

Applying lens equation to the objective lens :

$$\frac{1}{f_o} = \frac{1}{v_o} - \frac{1}{u_o} \quad \tfrac{1}{2}$$

$$\frac{1}{1.25} = \frac{1}{-6u_o} - \frac{1}{u_o} \quad \tfrac{1}{2}$$

$$\frac{1}{1.25} = \frac{-1-6}{6u_o}$$

$$6\,u_o = -1.25 \times 7$$

$$u_o = \frac{-1.25\times7}{6}\text{ cm}$$

$$|u_o| = 1.46\text{ cm} \quad \tfrac{1}{2}$$

[CBSE Marking Scheme 2012]