CHAPTER

4

Refraction of Light

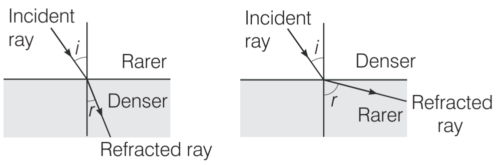
Chapter Objectives

- Laws of Refraction
- Refractive Index
- Refraction Through a Rectangular Glass Block
- Multiple Images in Thick Glass Plate/Mirror
- Simple Applications of Refraction of Light
- Some Consequences of Refraction of Light
- Prism
- Critical Angle
- Total Internal Reflection (TIR)

"Change in path of a light ray as it passes from one medium to another medium is called refraction of light."

When light travels from a rarer medium to a denser one, it bends towards the normal ($i > r$) and when travels from a denser medium to a rarer one, it bends away from the normal ($i < r$).

where, i = angle of incidence, r = angle of refraction.



Refraction of light

Some Important Terms Used in Refraction of Light

Some important terms used in refraction of light are as follow

(i) **Incident Ray** It is a ray of light which strikes the plane surface or a ray of light which travels towards the another optical medium.

(ii) **Point of Incidence** It is that point where an incident ray strikes the other optical medium.

(iii) **Normal** It is always perpendicular to the point of incidence.

(iv) **Angle of Incidence** It is an angle which an incident ray makes with the normal.

(v) **Refracted Ray** It is a ray of light which gets deviated from its path after entering in another optical medium.

(vi) **Angle of Refraction** It is an angle which the refracted ray makes with the normal.

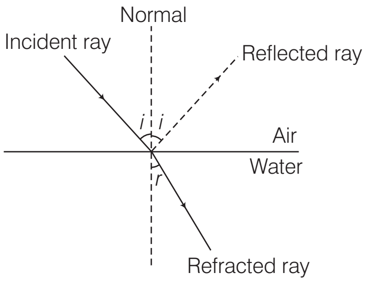
Causes of Refraction

The speed of light is different in different media. It is lesser in denser medium and greater in rarer medium. So, when light enters a denser medium its speed reduces and it bends towards the normal and when it enters rarer medium, its speed increases and it bends away from the normal.

Note When light is incident normally ($i = 0°$), the speed of light changes but the direction of light does not change.

Partial Reflection and Refraction due to Change in Medium

Partial reflection and refraction occurs when a wave is travelling between two mediums. Some of the wave is reflected back and the rest is refracted through the other medium.



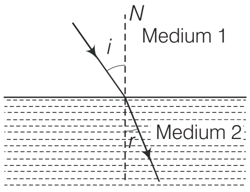
Note Partial reflection and refraction depends on angle of incidence. For 0° angle of incidence-mostly refraction, little or no reflection. For angle θ $(45° < \theta < 90°)$ little refraction, mostly reflection.

Laws of Refraction

There are two laws of refraction of light which are stated as below

First Law

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



Law of refraction

Second Law

The ratio of sine of angle of incidence to the sine of angle of refraction is constant for a given pair of media. This constant is known as **refractive index** of the second medium w.r.t. first medium. It is expressed as

$$\mu = \frac{\sin i}{\sin r} = \text{constant}$$

This relation is also known as **Snell's law.**

CHECK POINT 01

1. Define refraction.
2. Mention the cause of refraction of light, when it passes from one medium to another.
3. What do you mean by optically rarer medium?
4. During the refraction of light, the frequency of light remains constant. Explain the reason.
5. State second law of refraction.

Refractive Index

The extent of the change in direction that takes place in a given pair of media is expressed in terms of the refractive index.

${}_1\mu_2$ represents refractive index of medium 2 with respect to medium 1, when light is going from medium 1 to medium 2.

$$\boxed{{}_1\mu_2 = \frac{\mu_2}{\mu_1} = \frac{\sin i}{\sin r}}$$

The refractive index of a medium with respect to vacuum, is called **absolute refractive index of the medium**. The absolute refractive index of a medium is simply called its refractive index.

For glass/water pair,

$$\boxed{{}_w\mu_g = \frac{{}_a\mu_g}{{}_a\mu_w}}$$

Note Refractive index of air is minimum and refractive index of diamond is maximum.

Refractive Index and Speed of Light

If c is the speed of light in air and v is the speed of light in medium, then the refractive index of the medium is

$$\boxed{\mu = \frac{\text{Speed of light in vacuum / air}}{\text{Speed of light in medium}} = \frac{c}{v}}$$

Hence for any two media, the refractive index of second medium with respect to first medium is equal to the ratio of the velocities of lights in the medium.

Refractive index of glass with respect to air,

$${}_a\mu_g = \frac{\text{Velocity of light in air}}{\text{Velocity of light in glass}} = \frac{c}{v_g} \quad \text{...(i)}$$

Refractive index of water with respect to air,

$${}_a\mu_w = \frac{\text{Velocity of light in air}}{\text{Velocity of light in water}} = \frac{c}{v_w} \quad \text{...(ii)}$$

On dividing Eq. (ii) from Eq. (i), we get

$$\frac{{}_a\mu_w}{{}_a\mu_g} = \frac{v_g}{v_w} = {}_g\mu_w$$

Values of μ for common substances,

$$\mu \text{ of water} = 1.33$$
$$\mu \text{ of glass} = 1.52$$
$$\mu \text{ of diamond} = 2.47$$

Example 1. If refractive index of water is 1.33, then determine the speed of light in this medium, if the speed of light in vacuum is given by 3×10^8 ms^{-1}.

Sol. Since, refractive index of water can be given by

$$\mu_w = \frac{\text{Speed of light in vacuum}}{\text{Speed of light in water}}$$

$$\Rightarrow \quad 1.33 = \frac{3\times 10^8}{\text{Speed of light in water}}$$

$$\therefore \text{ Speed of light in water} = \frac{3\times 10^8}{1.33} = 2.25\times 10^8 \text{ ms}^{-1}$$

Example 2. Refractive indices of water and glass are 4/3 and 3/2 respectively. A ray of light travelling in water is incident on the water glass interface at 30°. Calculate the angle of refraction.

Sol. Given, refractive index of water, ${}^a\mu_w = \frac{4}{3}$

Refractive index of glass, ${}^a\mu_g = \frac{3}{2}$

Angle of incidence in water, $i = 30°$

Angle of refraction, $r = ?$

As, $${}^w\mu_g = \frac{{}^a\mu_g}{{}^a\mu_w} = \frac{3/2}{4/3} \Rightarrow {}^w\mu_g = \frac{9}{8}$$

According to Snell's law,

$$\frac{\sin i}{\sin r} = {}^w\mu_g \Rightarrow \frac{\sin i}{\sin r} = \frac{9}{8}$$

$$\sin r = \frac{8}{9}\sin i \Rightarrow \sin r = \frac{8}{9}\sin 30° = \frac{8}{9}\times\frac{1}{2} = 0.444$$

$$\sin r = 0.444$$

$$\Rightarrow \quad r = \sin^{-1}(0.444) = 26.38°$$

Factors Affecting the Refractive Index of Medium

There are following two factors on which the refractive index of medium depends

(i) **Wavelength of Incident Light** The refractive index of a medium decreases with increase in wavelength of incident light.

Since, the speed of light is different for different colours thus, the light travels slower in case of low wavelength which leads to increase in refractive index.

$$\therefore \quad \mu_{\text{red}} < \mu_{\text{violet}}$$

(ii) **Temperature** The refractive index of a medium decreases with increase in temperature of medium.

($\because$ velocity of light increases with increase in temperature of medium)

$$\therefore \quad \mu_{T_1} > \mu_{T_2} \text{ as } T_1 < T_2$$

(iii) **Optical Density of a Medium** Refractive index of a medium depends on optical density of a medium, more optical denser medium has larger value of refractive index and *vice-versa.*

Conditions for No Refraction

There are following two conditions under which a ray of light passes undeviated from medium 1 to medium 2

(i) When the refractive index of medium 2 is same as that of medium1.

(ii) When the angle of incidence at the boundary surface of the two media is zero ($i = 0°$).

Relation between Speed, Frequency and Wavelength of Light

The equation that relates wavelength and frequency is

$$v = f\lambda$$

where, v = speed of light in vacuum,

f = frequency of light and λ = wavelength of light.

Effect on Speed, Wavelength and Frequency Due to Refraction of Light

The effects due to refraction of light on speed, frequency and wavelength are given below as

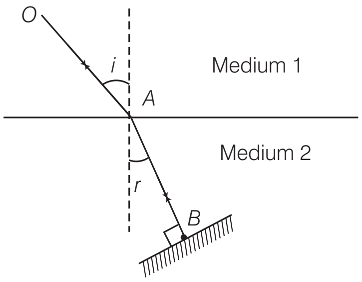
(i) Speed of light increases when light passes from denser to rarer medium and it decreases when light passes from rarer to denser medium.

(ii) Frequency is a characteristic light, therefore it remains same as light travels from one medium to another.

(iii) Wavelength of light increases when light passes from denser to rarer medium (as speed also increases) and it decreases when light passes from rarer to denser medium (as speed also decreases) but its frequency remains constant.

Principle of Reversibility of Light

When a light ray after suffering any number of reflections and refractions, its final path has reversed, it travels back along its entire initial path. This is called principle of reversibility of light.



Reversibility of light

In the given figure, OA is an incident ray in medium 1 and AB is the refracted ray in medium 2. By Snell's law, the refractive index of medium 2 relative to medium 1 is given by

$${}^1\mu_2 = \frac{\sin i}{\sin r} \quad \text{...(i)}$$

where, i and r are the angles of incidence and refraction respectively.

Suppose, the ray AB is reflected back by a plane mirror. Now, BA is the incident ray and AO is the refracted ray.

Correspondingly, r is angle of incidence and i is angle of refraction. Again by Snell's law, the refractive index of medium 1 relative to medium 2 is given by

$$^2\mu_1 = \frac{\sin r}{\sin i} \qquad \text{...(ii)}$$

Multiplying Eqs. (i) and (ii), we have

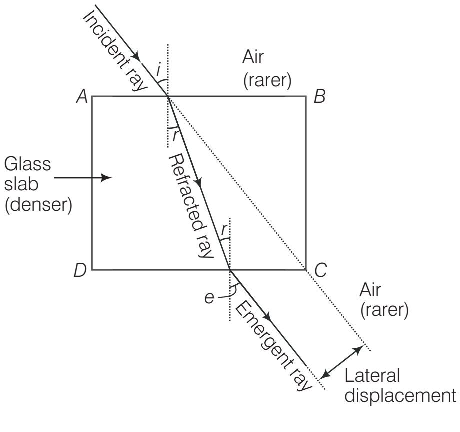
$$^1\mu_2 \times {}^2\mu_1 = \frac{\sin i}{\sin r} \times \frac{\sin r}{\sin i} = 1 \quad \text{or} \quad \boxed{^1\mu_2 = \frac{1}{^2\mu_1}}$$

Thus, the refractive index of medium 2 relative to medium 1 is equal to the reciprocal of the refractive index of medium 1 relative to medium 2.

Refraction Through a Rectangular Glass Block

When a light ray enters in a glass slab, then the emergent ray is parallel to the incident ray but it is shifted sideward slightly. In this case, refraction takes place twice, first when ray enters glass slab from air and second when exits from glass slab to air.

Both refractions have been shown in figure (here, glass slab is denser medium and air is rarer medium). The extent of bending of the ray of light at opposite parallel faces AB and CD of rectangular glass slab is equal and opposite. So, the ray emerging from face CD is parallel to incident ray but shifted sideward slightly.



Refraction of light through a glass block

where, i = angle of incidence, r = angle of refraction and e = angle of emergence.

Lateral Displacement

The perpendicular distance between the emergent ray and incident ray when the light passes out of a glass slab is called lateral displacement.

It can be calculated by the formula,

$$\text{lateral displacement} = \frac{t \sin (i - r)}{\cos r}$$

where, t = thickness of the glass block,
i = angle of incidence and r = angle of refraction.

The lateral displacement depends upon the following factors

(i) thickness of the glass block,
(ii) angle of incidence and
(iii) refractive index of glass.

Example 3. **A ray of light is incident at angle of 45° on one face of a rectangular glass slab of thickness** 10 cm **and refractive index 1.5. Calculate the lateral shift produced.**

Sol. Here, $i = 45°$, $t = 10\,\text{cm}$, $\mu = 1.5$

Lateral shift = ?

So, $\mu = \dfrac{\sin i}{\sin r} \Rightarrow \sin r = \dfrac{\sin i}{\mu}$

$$\sin r = \frac{\sin 45°}{1.5} \Rightarrow \sin r = \frac{0.707}{1.5}$$

$$\Rightarrow \sin r = 0.4713 \Rightarrow r = \sin^{-1}(0.4713)$$

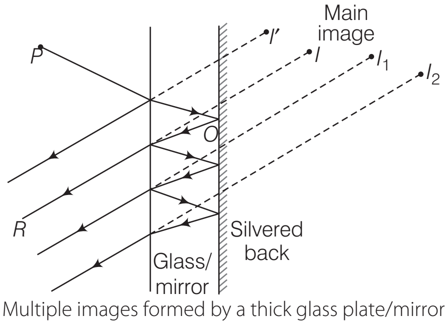
$$\Rightarrow r = 28.14°$$

$$\therefore \text{Lateral shift} = \frac{t \sin(i - r)}{\cos r} = \frac{10 \sin(45° - 28.14°)}{\cos 28.14°}$$

$$= \frac{10 \sin 16.86°}{\cos 28.14°} = \frac{10 \times 0.2900}{0.8818} = 3.3\ \text{cm}$$

Multiple Images in Thick Glass Plate/Mirror

When an object is placed in front of thick glass mirror, then its multiple images are formed. It happens due to multiple reflection from different layers (top and bottom surfaces). As only the second surface is silvered, therefore, the second image would be brightest.

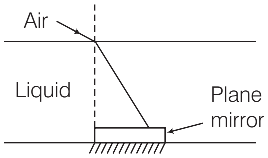


Multiple images formed by a thick glass plate/mirror

Further images would be formed due to multiple reflections. These images would become fainter due to absorption of light by medium.

CHECK POINT 02

1 Write the two factors on which the refractive index of a medium depends.
2 If a ray of light falls perpendicularly on a glass slab, what will be its angle of refraction? Give the reason in support of your answer.
3 State principle of reversibility.
4 A ray of monochromatic light enters a liquid as shown in diagram. i.e., $\angle i = 45°$, $\angle r = 30°$



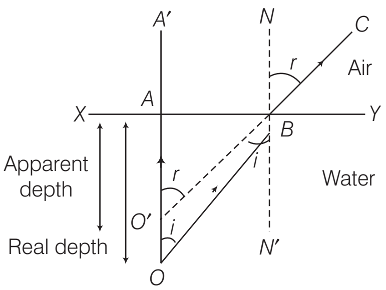
Show the path of ray after it strikes the mirror and goes into air.
5 Which image formed by the thick glass plate is brightest?

Simple Applications of Refraction of Light

Simple applications of refraction of light are givne below.

Real and Apparent Depth

An object placed in a denser medium when viewed from a rarer medium, appears to be at a depth lesser than its real depth. This is because of refraction of light. Consider an object is placed in water (denser medium) and is being seen from air (rarer medium). Let O be a point object at an actual depth OA below the free surface of water XY. A ray of light incident normally on XY, along OA passes straight along OAA'.



Real depth and apparent depth

Another ray of light from O incident at $\angle i$ on surface XY along OB deviates away from normal. It is refracted at $\angle r$ along BC. On drawing backwards CB meets OA at O′. Therefore, O′ is virtual image of O.

Hence, apparent depth = O′A

Real depth = OA

$$\therefore \quad \boxed{{}^a\mu_w = \frac{OA}{O'A} = \frac{\text{Real depth}}{\text{Apparent depth}}}$$

If x is the real depth of water surface and ${}^a\mu_w$ is the refractive index of water with respect to air, then the normal shift (d) in position of point object is given by

$$d = \text{Real depth} - \text{Apparent depth}$$

$$\therefore \quad d = x - \frac{x}{{}^a\mu_w}$$

$$\left(\because \text{Apparent depth} = \frac{\text{Real depth}}{{}^a\mu_w} = \frac{x}{{}^a\mu_w}\right)$$

or $$\boxed{d = x\left(1 - \frac{1}{{}^a\mu_w}\right)}$$

The shift by which an object seemed to be raised, depends upon

(i) refractive index of the medium,
(ii) thickness of the denser medium and
(iii) the colour of the incident light.

Note The apparent depth of an object lying in a denser medium is always less than its real depth for all angles of observation in a rarer medium.

Example 4. **A mark is made at the bottom of a beaker and a microscope is focused on it. The microscope is then raised through 0.015 m. To what height water must be poured into the beaker to bring the mark again at focus?**

$$\left(\text{Take, } {}^a\mu_w = \frac{4}{3}\right)$$

Sol. Given, ${}^a\mu_w = \frac{4}{3}$

Normal shift = 0.015 m

If x is the height upto which water must be poured into the beaker, then

normal shift, $d = x\left(1 - \frac{1}{{}^a\mu_w}\right)$

$$0.015 = x\left(1 - \frac{1}{4/3}\right) \Rightarrow 0.015 = x\left(\frac{1}{4}\right) \Rightarrow x = 0.060\text{m}$$

Example 5. **Velocity of light in glass is 2×10^8 m/s and that in air is 3×10^8 m/s. By how much would an ink dot appear to be raised, when covered by a glass plate 6 cm thick?**

Sol. Given, velocity of light in glass, $v = 2 \times 10^8$ m/s

Velocity of light in air, $c = 3 \times 10^8$ m/s

Thickness of glass plate, $x = 6$ cm

Normal shift, $d = ?$

Refractive index of glass with respect to air

$$\mu = \frac{c}{v} = \frac{3 \times 10^8}{2 \times 10^8} = 1.5$$

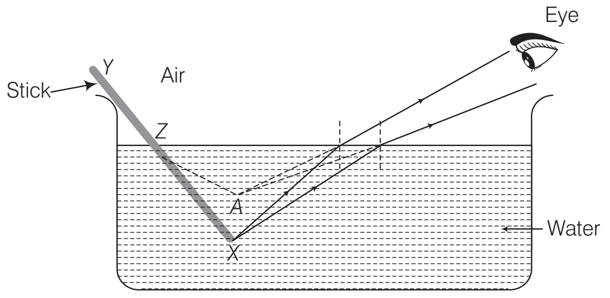
Normal shift, $d = x\left(1 - \frac{1}{\mu}\right)$

$$d = 6\left(1 - \frac{1}{1.5}\right) = \frac{6 \times 0.5}{1.5} = 2\,\text{cm}$$

Apparent Bending of Stick Under Water

A stick partially immersed in water appears to be bent because of the refraction of light coming from the part of stick that is under water.

If we consider a stick YX immersed obliquely in water, with its part ZX is submerged within the water. Consider a point X on the tip of the stick.



Apparent bending of stick under water

A divergent beam coming from it after refraction will bend away from the normal. So the moment, the refracted beam refracted the eye, the eye retraces back a straight line path.

Due to this, the rays appear to originate from point A,which is higher than X. Thus, it is true for any point between X and Y. So, the stick appears to be bent and short within the water. It appears magnified because the image is formed close to the eye.

Some Consequences of Refraction of Light

Some consequences of refraction of light are given below.

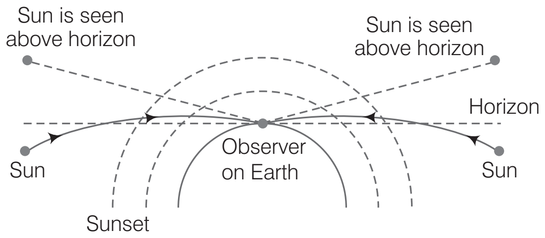
1. Advanced Sunrise and Delayed Sunset

The density of atmosphere around the earth is not uniform throughout due to which, it has layers of different densities which work as optically rarer and denser medium. The refraction of light due to these atmospheric layers is called **atmospheric refraction.**

The Sun is visible to us about two minutes before the actual sunrise and about two minutes after the actual sunset.

This is because of atmospheric refraction. When the Sun is slightly below the horizon, the sunlight coming from less dense to more dense air, is refracted downwards.

Because of this, the Sun appears to be raised above the horizon and so the rising of Sun can be seen about two minutes before actual sunrise. Similarly, due to atmospheric refraction, the Sun can be seen for about two minutes even after the Sun has set below horizon.



Note At sunrise and sunset, the Sun appears flattened. This apparent flattening of the Sun's disc is also due to atmospheric refraction.

2. Planets do not Twinkle

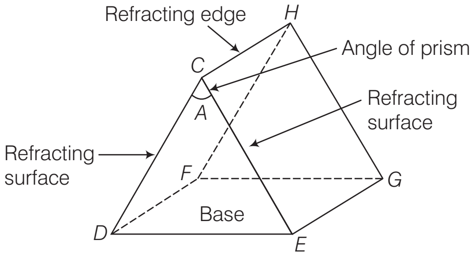
Planets are much closer to the Earth and hence appear larger in size as compare to stars. So, they can be taken as a collection of large number of point sized sources of light. The total variation in the amount of light entering our eye from all these individual point sized sources will average out to zero which nullify the twinkling effect of each other. So, planets do not twinkle.

3. Shimmering Effect Around a Camp Fire

During camping, when we sit around a camp fire, the face of the person sitting opposite to you, appears to shimmer. This occurs due to the refraction of light. The rays of light reflected from the face of the person sitting opposite to you on passing the hot fire get refracted. As, we know that the hot air is rapidly moving and its optical density is continuously changing, due to which the path of the refracted rays also changes. This gives rise to the shimmering effect.

Prism

A transparent refracting medium bounded by at least two lateral surfaces, inclined to each other at certain angle is called a **prism.** It has two triangular bases and three rectangular lateral surfaces. The angle between two lateral surfaces is called **angle of prism** (A).

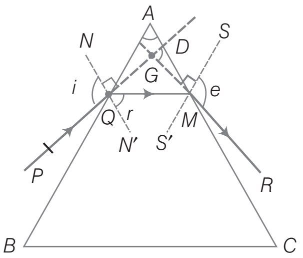


Prism

The two rectangular plane inclined surfaces through which the light passes, are known as **refracting surfaces**. The line along which the two surfaces (refracting) meet is called the **refracting edge**.

Refraction of Light through a Glass Prism

In the diagram given below, a ray of light PQ is entering from air to glass at the first surface AB. The light ray on refraction gets bent toward the normal. At the second surface AC, the light ray enters from glass to air, so it bents away from the normal.



Refraction of light through a triangular glass prism

The above diagram shows refraction through a prism, where,

PQ = incident ray, QM = refracted ray,

MR = emergent ray, $\angle A$ = angle of prism,

$\angle i$ = angle of incidence, $\angle r$ = angle of refraction,

$\angle e$ = angle of emergence and $\angle D$ = angle of deviation.

Note When a ray of light passes through a prism, it bends towards the thicker part of the prism.

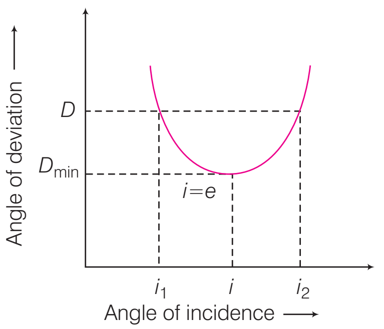
Angle of Deviation (D)

It is the angle at which the emergent ray (produced backward) makes with the incident ray (produced forward). It is given by $\angle D = \angle i + \angle e - \angle A$.

There are four factors on which the value of angle of deviation produced by the prism depends.

They are as follow

(i) **Dependence of Angle of Deviation on the Angle of Incidence (i)** Experimentally, it has been observed that with the increase in the incident angle, the angle of deviation first decreases, then reach a minimum value and then it also increases. This has depicted in (i-D) graph shown below.



The position of prism with respect to the incident ray at which the incident ray suffers minimum deviation is known as position of minimum deviation.

At this position of minimum deviation,

$$D = D_{\min}, \; i = e \text{ and } r_1 = r_2 = r$$

Hence, $A = 2r$

$$\therefore D_{\min} + 2r = 2i \Rightarrow D_{\min} = 2i - 2r \Rightarrow D_{\min} = 2i - A$$

As, refractive index of prism, $\mu = \dfrac{\sin i}{\sin r}$

$$\therefore \quad \boxed{\mu = \dfrac{\sin\left(\dfrac{D_{\min} + A}{2}\right)}{\sin\left(\dfrac{A}{2}\right)}}$$

(ii) **Dependence of Angle of Deviation on the Refractive Index (μ)** Experimentally, it is found that as the refractive index of the material decreases, the angle of deviation decreases.

(iii) **Dependence of Angle of Deviation on the Colour or Wavelength of Light (λ)** For a given prism deviates, the violet light most and the red light least.

(iv) **Dependence of Angle of Deviation on the Angle of Prism (A)** The angle of deviation (D) increases with increase in the angle of prism.

Example 6. **What should be the angle of incidence, if a ray of light incident on the refracting surface of a equilateral prism suffers a minimum deviation of 40°?**

Sol. We know from the relation, $A + D = i + e$

The minimum deviation can be calculated as

$$D = D_{\min} \text{ and } i = e$$

$$\Rightarrow \quad D_{\min} = 2i - A \quad \text{or} \quad i = \frac{D_{\min} + A}{2}$$

Given, $D_{\min} = 40°$ and $A = 60°$

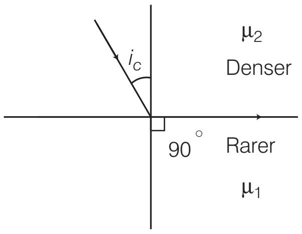
It is not true always, $i = \dfrac{40° + 60°}{2} = 50°$

CHECK POINT 03

1 What is the relation between real and apparent depth?
2 Define atmospheric refraction.
3 Why planets do not twinkle?
4 What are the different factors on which the angle of deviation depend?
5 Name the factors on which angle of deviation depends.
6 Does refractive index increases with the increase in angle of deviation?
7 Calculate refractive index of a equilateral glass prism for a light of red colour. Angle of minimum deviation for red colour is 30°.

Critical Angle

The angle of incidence in denser medium for which angle of refraction in rarer medium is 90° is called critical angle. Its value depends on the nature of two media in contact.



From Snell's law, $\mu_2 \times \sin i_c = \mu_1 \times \sin 90°$

$$\therefore \quad \frac{\mu_1}{\mu_2} = \frac{\sin i_c}{\sin 90°} \Rightarrow \frac{\mu_1}{\mu_2} = \sin i_c \Rightarrow \frac{\mu_2}{\mu_1} = \frac{1}{\sin i_c}$$

$$\Rightarrow \quad \boxed{{}^1\mu_2 = \frac{1}{\sin i_c} = \operatorname{cosec} i_c}$$

The critical angle for a given pair of media depends on their refractive index, which in turn depends on the following two factors.

(i) **Effect of Colour of Light** As violet light has the highest value of refractive index, while red light has the least value of refractive index. So, due to this reason, the critical angle for a pair of media is least for violet light and most for red light. Therefore, the critical angle increases with increase in the wavelength of light.

(ii) **Effect of Temperature** When the temperature of medium is increased, its refractive index decreases, due to which, the critical angle for that pair of media increases. Therefore, the critical angle increases with an increase in temperature.

Example 7. **If the refractive index of a glass is 1.5. Determine the critical angle for it.**

Sol. Since, we know that

$$^1\mu_2 = \frac{1}{\sin i_c} \quad \text{or} \quad ^a\mu_g = \frac{1}{\sin i_c}$$

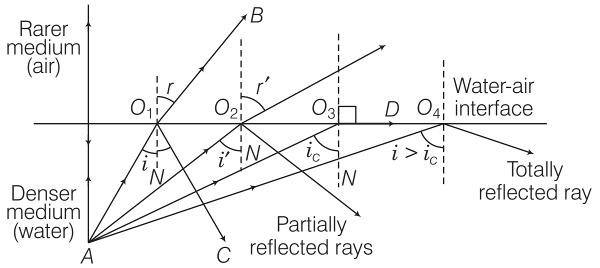
$$\therefore \quad 1.5 = \frac{1}{\sin i_c} \Rightarrow \sin i_c = \frac{1}{1.5} \Rightarrow i_c = \sin^{-1}\left(\frac{1}{1.5}\right)$$

$$\Rightarrow \quad i_c = \sin^{-1}(0.666) \Rightarrow i_c = 41.80° \approx 42°$$

Total Internal Reflection (TIR)

When a ray of light travelling from a denser medium to rarer medium, is incident at the interface of the two media at an angle greater than the critical angle for the two media, then the ray is totally reflected back to denser medium.

This phenomenon is called total internal reflection (TIR).



Refraction and internal reflection of rays from a point A in the denser medium (water) incident at different angles at the interface with a rarer medium (air)

Necessary conditions for total internal reflection to takes place are as follow

(i) The ray incident on the interface of two media should travel in the denser medium.

(ii) The angle of incidence should be greater than critical angle for the two media.

Total Internal Reflection in a Prism

The phenomenon of total internal reflection has been considered in three different prism which are given below as

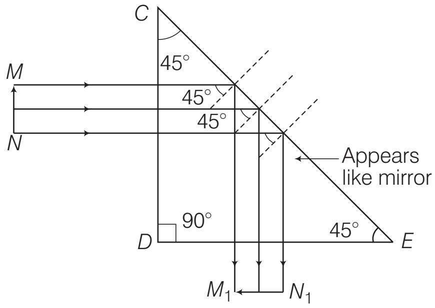
1. TIR in Prism of Angles (45°, 45° and 90°) i.e., Right-Angled is Isosceles Prism

When a prism has 90° angle between its two refracting surfaces and the two other angles each of 45°, then the prism is called **total reflecting prism.**

As, the light incident normally on any of its face, it then gets total internally reflected. Because of this property, this prism is used for the following three purposes.

(i) Deviation through 90° Angle

When a parallel beam of light strikes normally on the face DC, it does not suffer any refraction and then strikes the face CE at an angle of 45°.

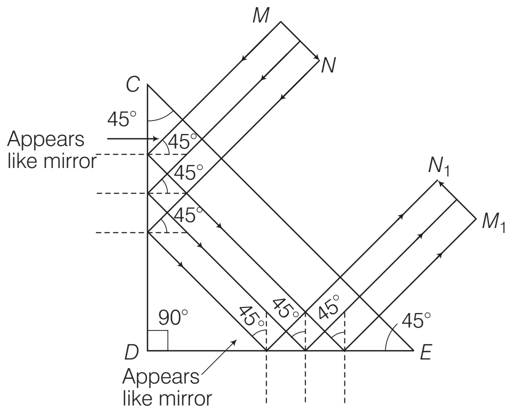


Deviation through 90° angle

As, we know that the critical angle for, the glass is 42°, so total internal reflection takes place. Due to this, the beam makes an angle of reflection of 45° and turns completely through 90°. It strikes the face DE normally and emerges out of the air and behaves like a mirror.

(ii) Deviation through 180°Angle

If a parallel beam of light is incident normally on the face CE of the right angled isosceles prism, the beam passes undeviated till it strikes the face CD at an angle of 45°.



Deviation through 180° angle

Then, total internal reflection takes place and the beam turns completely through an angle of 90° in order to strike the face DE at an angle of 45°.

Then at the face DE, another TIR takes place and again the beam turns through an angle of 90° in order to strike the face CE normally.

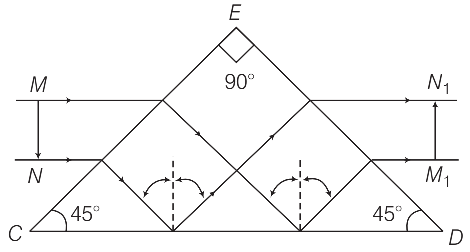
Finally, the beam comes out of the prism without suffering any refraction.

As a result, the beam turns through 180°.

(iii) No Deviation

The rays of light parallel to the hypotenuse (CD) strikes the surface EC.

These rays then suffers refraction and strike the face CD with an angle greater than 42°. Due to this, total internal reflection takes place. Then, the rays turn and strike the face ED.

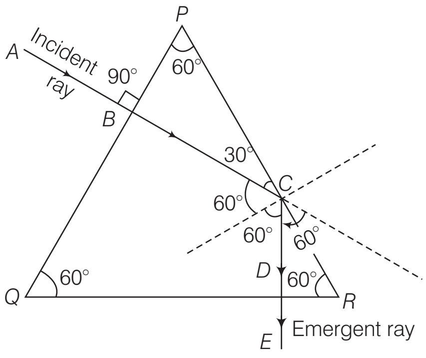


No deviation

On finally coming out from the face ED, these refracted rays suffer another refraction. During this, the rays revert themselves, i.e., the inverted image MN appears as N_1M_1.

2. TIR through a Prism where Each Angle is 60° i.e., Equilateral Prism

The figure given below shows an equilateral prism i.e., each angle of 60°. If a ray falls normally on the face PQ, then without any refraction it falls on the face QR at an angle 60° since, this angle is greater than the critical angle of glass. So, total internal reflection takes place. Thus, this prism can be used to deviate a ray of light by 60°.

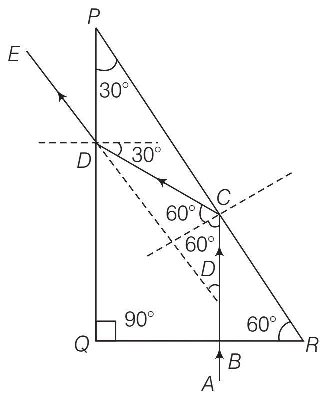


Total internal reflection through an equilateral prism

3. TIR through Prism of Angles (30°, 60° and 90°) i.e., Right-Angled Prism

The figure given below shows a prism with angles, 30°, 60° and 90° i.e., right angled prism. If a ray of light falls normally on the face QR, then it falls on the face PR without any deviation.

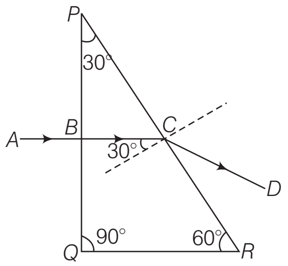
Since, the angle of incidence is 60° which greater than the critical angle of glass (42°) so TIR takes place, on reflection, the ray falls on the face PQ, where it gets refracted with an angle less than 60°. Therefore, this prism can be used to deviate a light ray through an angle less than 60° by TIR.

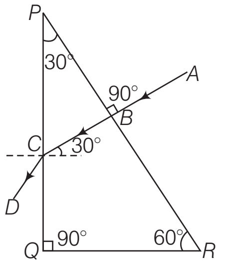


TIR through right angled prism

If the ray of light falls on other two faces i.e., PR and PQ, then the previous case does not take place i.e., no total internal reflection happens.

This has been depicted in the figures given below.





Comparison between Total Internal Reflection and Reflection from a Plane Mirror

Total Internal Reflection	Reflection from a Plane Mirror
This is the phenomenon in which light travels from denser to rarer medium at an angle greater than the critical angle for that pair of media, then the rays are totally reflected back.	In this light falls on plane mirror at any angle of incidence and then a little part of light gets reflected and rest get refracted and absorbed.
The energy of the reflected ray is same as that of incident ray i.e., no loss of energy.	The energy of the reflected rays is less than that of incident ray i.e., there is loss of energy.
The brightness of the image is very good and does not decrease even after a long use of TIR device.	The brightness of the image is not very good and decreases with the increase in time.

Some Consequences of Total Internal Reflection

Total internal reflection is also very prominent in our daily life also.

Some of these consequences are given below

(i) Optical fibre are used to transmit light over large distances without any loss of energy.

(ii) If a glass vessel is cracked, then it often shines like a mirror.

(iii) Brilliance of diamond.

(iv) In deserts, in daytime, a person often see a pool of water at a distance. It is because of the phenomenon of mirage.

CHECK POINT 04

1 Among the following substances, which one has the highest value of critical angle? Turpentine, glass, water, diamond.

2 How does the critical angle changes with the change in the temperature of surrounding?

3 State total internal reflection.

4 Name any two instruments in which total reflecting prism is used.

5 Mention one difference between refraction of light from a plane mirror or and total internal reflection from a prism.

SUMMARY

- The phenomenon of bending of light entering from one medium to another is called refraction of light.
- When a ray of light travels from a rarer medium to a denser medium, it bends towards the normal.
- When a ray of light travels from a denser medium to a rarer medium, it bends away from the normal.
- There are two laws of refraction.

  First Law The incident ray, the refracted ray and the normal at the point of incidence, all lie on the same plane.

  Second Law The ratio of sine of angle of incidence to the sine of angle of refraction is constant for a given pair of media.This is also called Snell's law.
- Refractive index (n) of a medium is the ratio of speed of light in vacuum (c) to the speed of light in the medium (v) and is given by

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

- Refractive index of one medium w.r.t to another medium is given by, ${}^1n_2 = \frac{\text{Speed of light in medium 1}}{\text{Speed of light in medium 2}}$
- When a light ray, after suffering many reflections and refractions, has its final path reversed and travels back along its initial path is called principle of reversibility of light.
- The perpendicular distance of separation between the incident ray and the emergent ray is called lateral displacement.
- The shift by which an object appears to be raised when it is immersed in water is called the apparent depth.

$$\text{Refractive index} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

- A transparent refracting medium bounded by five plane surfaces inclined at some angles is known as prism.
- The angle between two refracting surfaces is called angle of prism (A) and the angle between the incident ray and the emergent ray is called the angle of deviation (D).
- Critical angle for a pair of media is defined as the angle of incidence in denser medium for which the angle of refraction becomes 90°.
- When a ray of light is travelling from a denser medium to rarer medium, is incident at the interface of the two media at an angle greater than the critical angle, the ray is totally reflected back to the denser medium. This phenomenon is called total internal reflection.

EXAM PRACTICE

a 2 Marks Questions

1. When a ray of light does not change its path during refraction, state what will be the angle of incidence and refraction of this ray?

Sol. The moment, a ray of light is incident perpendicularly to the interface surface of the two medium, then it passes without any deviation. *[1]*

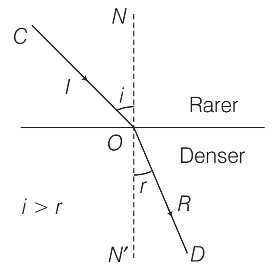
So, due to this reason, the angle of incidence and angle of refraction, both will be zero degree. *[1]*

2. With the help of a suitable diagram, represent the refraction of light rays from

(i) rarer to denser.

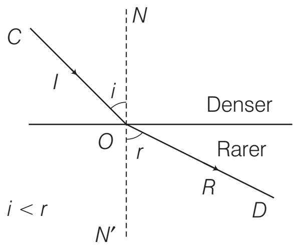
(ii) denser to rarer. Also, label each diagram.

Sol. (i) Rarer to denser



where, OC = incident ray, OD = refracted ray and NN' = normal. *[1]*

(ii) Denser to rarer



where, OC = incident ray, OD = refracted ray and NN' = normal. *[1]*

3. State the laws of refraction of light.

Sol. Refer to theory (Page 67).

4. How can you define the term "refractive index of a medium"? State whether it can be less than 1 or not?

Sol. The ratio of the velocity of light in vacuum to the velocity of light in a medium is known as the refractive index of that medium.

i.e., Refractive index of a medium

$$= \frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in that medium}}$$ *[1]*

The absolute refractive index of a substance cannot be less than one because it would mean that the speed of light is more in that substance than in free space, which is not possible. The relative refractive index can be less than one if the first medium is less denser than the second medium. *[1]*

5. If ${}^a\mu_g$ is refractive index of glass with respect to air and ${}^g\mu_a$ is refractive index of air with respect to glass. Express the refractive index of glass with respect to water (${}^w\mu_g$) in terms of refractive index of water and glass with respect to air.

Sol. As, we know that according to the definition of refractive index,

$${}^w\mu_g = \frac{v_w}{v_g}$$ *[1]*

Now, multiply and divide in numerator and denominator by v_a,

$$\Rightarrow \quad {}^w\mu_g = \frac{v_w . v_a}{v_g . v_a}$$

$$\Rightarrow \quad {}^w\mu_g = \frac{v_a / v_g}{v_a / v_w}$$

$$\left(\text{But } \frac{v_a}{v_g} = {}^a\mu_g \text{ and } \frac{v_a}{v_w} = {}^a\mu_w \right)$$

$$\therefore \quad {}^w\mu_g = \frac{{}^a\mu_g}{{}^a\mu_w}$$ *[1]*

6. "Refractive index of a medium is least for the red colour of light". Justify this statement.

Sol. Since, in prism the red colour of light is bent the least and its is a fact that the bending of light rays increases on increasing the refractive index of the medium. *[1]*

As, wavelength of red is maximum, refractive index of a medium is least for the red colour of light. *[1]*

7. If a light of a single colour is passed through a liquid having a piece of glass suspended in it, so on changing the temperature of the liquid, at a particular temperature, the glass piece is not seen.

(i) At what situation, the glass piece will not be seen?

(ii) Why is the light of a single colour used?

Sol. (i) The glass piece cannot be seen when the refractive index of the liquid becomes equal to refractive index of the glass. **[1]**

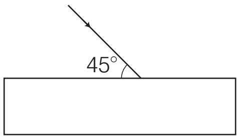
(ii) Since, the refractive index of medium is different for different colour of light.

So due to this, light of a single colour is used. **[1]**

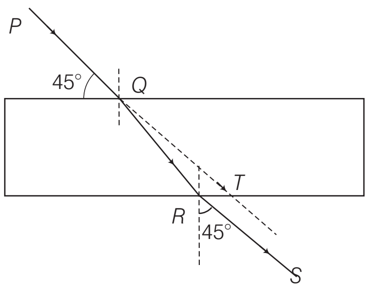
8. A boy uses blue colour of light to find the refractive index of glass. He then repeats the experiment using red colour of light. Will the refractive index be the same or different in the two cases? Give a reason to support your answer. **[2016]**

Sol. Since, the refractive index of the medium is always inversely proportional to the wavelength of light. Moreover, it is known that wavelength of the red colour is more than that of the blue colour. So, the refractive index in case of blue colour of light will be greater than that of red colour of light. **[2]**

9. Draw the diagram given below and clearly show the path taken by the emergent ray. **[2014]**

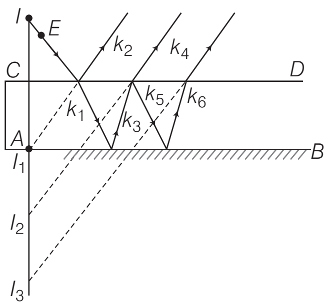


Sol. *The emergent ray RS is shown below as*



[2]

10. "If a lighted candle is placed in front of thick glass plane mirror, then several images can be observed, but the second image is brightest." Explain, the reason for this statement.



Sol. Since, first image is formed by reflected ray k_2 from the transparent surface CD.

The reflection from the transparent surface CD is very small due to which I_1 is not so much bright. Image I_2 is formed by the refracted ray k_4. As, most part of the incident ray E refract by refracted ray k_1, so a small part of k_1 can be absorbed by the mirror at the same time, the maximum part of k_1 is reflected by reflected ray k_3. **[1]** Some part of k_3 is reflected by ray k_5 but its most part is refracted by k_4. Other image is formed by ray k_5, which is less bright than by k_4. So, due to this reason I_2 is brightest than beyond I_2. **[1]**

11. How is the refractive index of a material related to

(i) real and apparent depth?

(ii) velocity of light in vacuum or air and the velocity of light in a given medium? **[2017]**

Sol. (i) When an object is placed under water (any other medium), then observing it from outside the water (or medium) it appears to be raised above.

The ratio of real depth and apparent depth is equal to the refractive index of the medium.

$$\text{Refractive index, } \mu = \frac{\text{Real depth}}{\text{Apparent depth}}$$ **[1]**

(ii) **Relation between Refractive Index and Velocity of Light**. The refractive index of the medium is the ratio of the velocity of light in vacuum (or air) to the velocity of light in that medium.

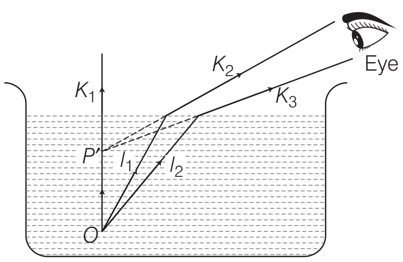
$$\mu = \frac{\text{Velocity of light in vacuum } (c)}{\text{Velocity of light in medium } (v)}$$ **[1]**

12. Does the depth of the tank of a water appear to change or remains the same when viewed normally from the above? **[2012]**

Sol. No, when the depth of a tank of water is viewed normally, no refraction takes place as the light rays passes through the medium undeviated. Thus, the depth of the tank remains the same because it is a case of normal incidence, where $\angle i = \angle r = 0°$. **[2]**

13. Fish swimming in a pond seems to be nearer than its actual depth. Explain why?

Sol. A fish can be seen by observer when the rays of light coming from the fish enters into observers eyes.



[1]

Consider the above figure, if I_1 and I_2 are the two rays coming from a point on fish O.

These rays passes water (denser) to air (rarer) and then deviate from the normal through path K_2, K_3 and form an image at P', which is virtual and above O. Due to this reason, fish in the water seems to be very nearer than its actual depth. ***[1]***

14. Light passes through a rectangular glass slab and through a glass prism. In what way does the direction of the two emergent beams differ? ***[2014]***

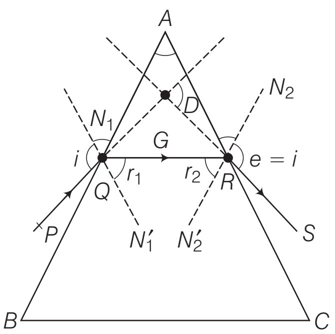
Sol. In a rectangular glass slab, the emergent ray is parallel to the incident ray but they are not along the same line, whereas in the prism, the emergent ray is not parallel to the incident ray. ***[1]***

This differ because in glass slab, the two surfaces at which refraction occurs is parallel to each other, but in prism they make some angle. ***[1]***

15. Draw a ray diagram to show the refraction of a monochromatic ray through a prism when it suffers minimum deviation. ***[2017]***

Sol. When a ray of light passes through a prism, it bends towards the thicker part of the prism.

Let the incident ray PQ falls on the face AB of prism and emerges out from the face AC as RS.



Sectional view of prism

Here, $PQ =$ incident ray, $QR =$ refracted ray

$RS =$ emergent ray, $\angle A =$ angle of prism

$\angle i_1 =$ angle of incidence,

$\angle r_1, \angle r_2 =$ angles of refraction,

$\angle e =$ angle of emergence and $\angle D =$ angle of deviation.

When the ray suffers minimum deviation, $e = i$. ***[2]***

16. State the dependence of angle of deviation.

(i) On the refractive index of the material of the prism.

(ii) On the wavelength of light. ***[2016]***

Sol. (i) Since, refractive index of the prism is directly proportional to the angle of deviation.

So, larger the refractive index, larger will be the deviation angle.

(ii) Since, refractive index of material is inversely proportional to the wavelength of light. So, smaller the wavelength of light larger will be the deviation angle. ***[2]***

17. Name the factors affecting the critical angle for the pair of media. ***[2014]***

Sol. *The main factors affecting the critical angle for the pair of media are*

(i) the refractive index of a medium. ***[1]***

(ii) the temperature of surrounding. ***[1]***

18. (i) State the relation between the critical angle and the absolute refractive index of a medium.

(ii) Which colour of light has a higher critical angle? Red light or Green light. ***[2018]***

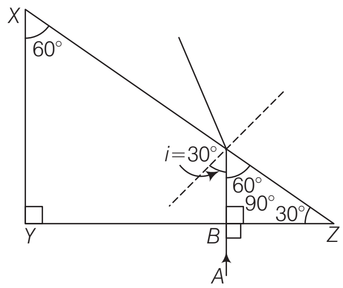
Sol. (i) The relation between the critical angle C and the absolute refractive index (μ) of medium is given by

$$\mu = \frac{1}{\sin C} \text{ or } \sin C = \frac{1}{\mu}$$ ***[1]***

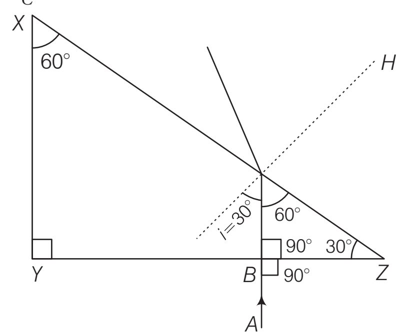
(ii) As $\mu_{\text{green}} > \mu_{\text{red}}$

Therefore, critical angle (C) for red colour is higher than green colour light. ***[1]***

19. The following diagram shows a 60°, 30°, 90° glass prism of critical angle 42°. Copy the diagram and complete the path of incident ray AB emerging out of the prism marking the angle of incidence on each surface. ***[2018]***



Sol. Given, $i_C = 42°$



[1]

As angle of incidence on face XZ is less than i_C so, ray is refracted. ***[1]***

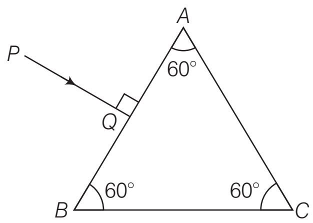
20. State the conditions required for total internal reflection of light to take place. ***[2017]***

Sol. *The necessary conditions for the total internal reflection are as follows*

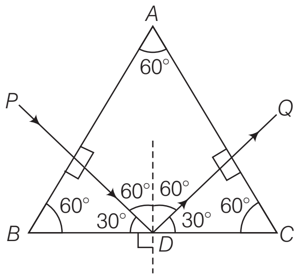
(i) The light must travel from a denser medium to a rarer medium.

(ii) The angle of incidence must be greater than the critical angle (i_c) for the pair of media. ***[2]***

21. Copy the diagram given below and complete the path of light ray till it emerges out of the prism. The critical angle of glass is 42°. In your diagram, mark the angles wherever necessary. ***[2016]***



Sol. *The ray diagram is given below*



[2]

b 3 Marks Questions

22. (i) Write a relationship between angle of incidence and angle of refraction for a given pair of media.

(ii) When a ray of light enters from one medium to another having different optical densities it bends. Why does this phenomenon occur?

(iii) Write one condition where it does not bend when entering a medium of different optical density.

Sol. (i) For a given pair of media, the relationship between the angle of incidence and angle of refraction is given by

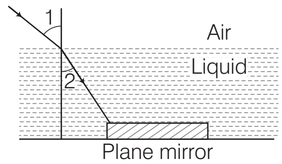
$$_1\mu_2 = \frac{\sin i}{\sin r}$$

where, i = angle of incidence, r = angle of refraction and $_1\mu_2$ = refraction index of the second medium with respect to the first medium. ***[1]***

(ii) The phenomenon of refraction occurs because light travels at different speeds in different medium. If a ray of light travels through air and enter a more dense medium, such as water, they slow down and bend towards the normal. ***[1]***

(iii) When a ray of light is incident normally to the surface, then it passes straight from one medium to another medium without any bending. ***[1]***

23. When a ray of monochromatic green light enters a liquid from air as shown in the figure given alongside.



The angle 1 is 45° and angle 2 is 30° .

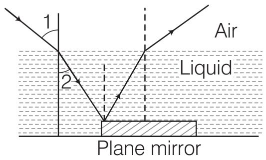
(i) Determine the refractive index of the liquid.

(ii) Represent in the diagram showing the path of the ray after it strikes the mirror and re-enters air. Mark in the diagram wherever necessary.

(iii) Draw the diagram again if plane mirror becomes normal to the refracted ray inside the liquid. Name the principle used.

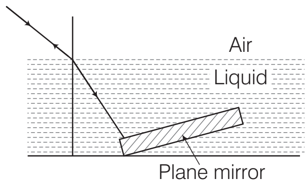
Sol. (i) Refractive index of liquid $= \frac{\sin 45°}{\sin 30°} = \frac{0.7}{0.5} = 1.4$ ***[1]***

(ii) *The path of the reflected and refracted ray is shown below.*



[1]

(iii) The principle used is the principle of reversibility of path of light.



[1]

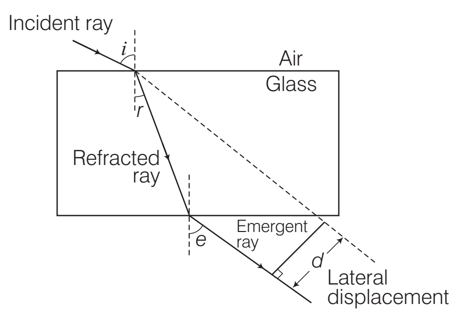
24. A ray of monochromatic light is incident from air on a glass slab. ***[2010]***

(i) Draw a labelled ray diagram showing the change in the path of the ray till it emerges from the glass slab.

(ii) Name the two rays that are parallel to each other.

(iii) Mark the lateral displacement in your diagram.

Sol. (i) **Ray diagram**



[1]

(ii) Two rays that are parallel to each other are incident ray and emergent ray. **[1]**

(iii) The perpendicular d istance between the incident ray and emergent ray is the lateral displacement, which is marked as d in the above diagram. **[1]**

25. If an obliquely incident light ray bends at the surface due to change in speed, when passing from one medium to another. While the ray does not bend when it is incident normally.

State with the reason, whether the ray will have the different speed in the other medium.

Sol. Definitely yes, the ray will have the different speed in the other medium because this is the case of no refraction (no bending) of light on going perpendicular from one medium to another. **[1½]**

All the parts of the ray will reach from one medium to another at the same time, enters the other medium at the same time, get slowed down or speed up at the same time. Due to this, no bending of light occurs but speed changes. **[1½]**

26. How does the value of angle of deviation produced by a prism change with an increase in the **[2009]**

(i) value of angle of incidence and

(ii) wavelength of incident light ?

Sol. (i) If the value of angle of incidence increases, then there is a corresponding decrease in the angle of deviation. For a particular value of angle of incidence, the angle of deviation becomes minimum after which it starts rising with further increase in the value of angle of incidence. **[1½]**

(ii) If the value of the wavelength of incident light increases, then angle of deviation decreases. **[1½]**

27. Explain the meaning of reversibility of light.

Sol. Refer to theory (Pages 68 and 69).

28. If the refractive index of air with respect to glass is expressed as ${}^g\mu_a = \dfrac{\sin i}{\sin r}$, answer the following:

(i) Express the similar expression for ${}^a\mu_g$ in terms of i and r.

(ii) If angle $r = 90°$, what is the corresponding angle (i) is called?

(iii) Write down the physical significance of angle (i) in part (ii).

Sol. (i) The similar expression for ${}^a\mu_g$ in terms of i and r can be expressed as

$$ {}^a\mu_g = \frac{\sin r}{\sin i} $$ **[1]**

(ii) If angle of refraction $r = 90°$, then the corresponding angle i is called critical angle. **[1]**

(iii) If angle of incidence is more than the critical angle, then the light gets reflected back into glass from the interface. This phenomenon is known as total internal reflection. **[1]**

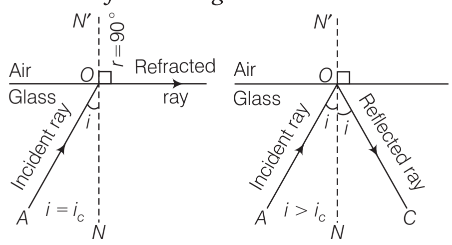
29. (i) Draw a labelled ray diagram to illustrate

(a) critical angle

(b) total internal reflection for a ray of light moving from one medium to another.

(ii) Write a formula to express the relationship between refractive index of the denser medium with respect to rarer medium and its critical angle for that pair of media. **[2008]**

Sol. (i) *The labelled diagram of critical angle and total internal reflection is given below* **[1]**



(a) Critical angle (b) Total internal reflection **[1]**

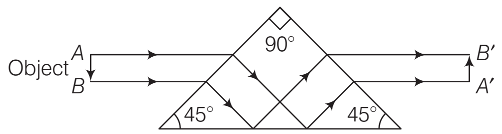
(ii) The formula to express the relationship between refractive index of the denser medium with respect to rarer medium and critical angle is given by

$$ \mu = \frac{1}{\sin i_c} = \operatorname{cosec} i_c $$

where, i_c is the critical angle. **[1]**

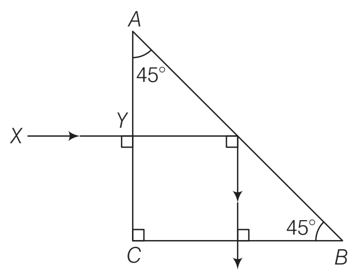
30. Draw the diagram of a right angled isosceles prism which is used to make an inverted image erect. **[2018]**

Sol.



[3]

31. A ray of light XY passes through a right angled isosceles prism as shown below.



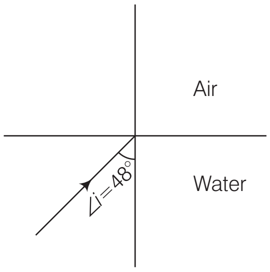
(i) What is the angle through which the incident ray deviates and emerges out of the prism?
(ii) Name the instrument where this action of prism is put into use.
(iii) Which prism surface will behave as a mirror? ***[2018]***

Sol. (i) 90°

(ii) Periscope

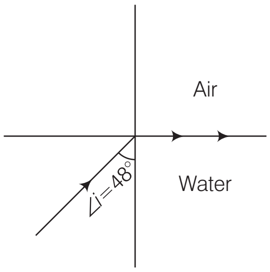
(iii) Surface AB behaves like a mirror. Because on this surface total internal reflection occurs. ***[3]***

32. A ray of light travels from water to air as shown in the diagram given below.



(i) Copy the diagram and complete the path of the ray. Given, the critical angle for water is 48°.
(ii) State the condition, so that total internal reflection occurs in the above diagram. ***[2017]***

Sol. (i)



[1½]

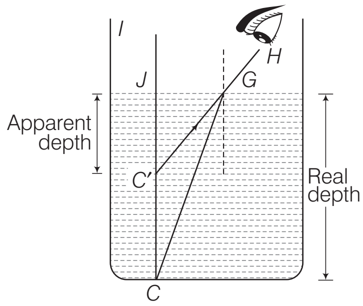
(ii) Required condition for TIR in the above diagram is angle of incidence should be greater for TIR than the critical angle, i.e., $\angle i > 48°$. ***[1½]***

C 4 Marks Questions

33. It has been observed that water in a pond appears to be only three quarters of its actual depth.
(i) Mention the property of light that is responsible for this observation.
(ii) Elaborate your answer with the help of a suitable diagram.

Sol. (i) Refraction of light is the property of light due to which the water in a pond appears to be only three quarters of its actual depth. ***[1]***

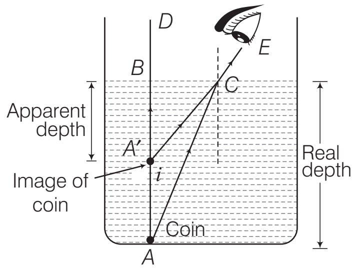
(ii) A ray from the bottom of the tank C on striking normally at J goes straight. Another ray from C strikes the interface at G is refracted towards GH and when produced back, it appears to come from C'. When JI and GH enter the eye, these form the image of C at C'. Therefore, the depth appears to be $C'J$ instead of actual depth CJ. ***[2]***



[1]

34. (i) With the help of a well-labelled diagram, show that the apparent depth of an object such as a coin in water is less than its real depth.
(ii) How is the refractive index of water related to the real depth and the apparent depth of a column of water? ***[2007]***

Sol. (i) A ray from bottom of the tank A (coin) is striking normally at B goes straight.



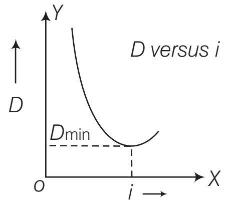
Another ray from A striking the interface at C is refracted towards E and when produced back, it appears to come from A'. When BD and CE enter the eye, these form an image of A (coin) at A' (coin). Thus, the depth appears to be at $A'B$ instead of the actual AB. ***[2]***

(ii) The refractive index of water related to the real depth and the apparent depth of a column of water is given by

$$\text{Refractive index, } \mu = \frac{\text{Real depth}}{\text{Apparent depth}}$$ ***[2]***

35. (i) In which manner, does the angle of deviation produced by a prism change with increase in the angle of incidence? With the help of a suitable diagram, show the variation in the angle of deviation with the angle of incidence at the prism surface.
(ii) Using the curve in part (i) above, how do you infer that for a given prism, the angle of minimum deviation D_{min} is unique for the given light?

Sol. (i) Angle of deviation decreases with increase in incidence angle but upto a certain extent. After reaching a minimum value, angle of deviation will increase again.



Here, it is shown graphically. ***[1 + 1]***

(ii) Since, we can see in the graph that in the position of minimum deviation.

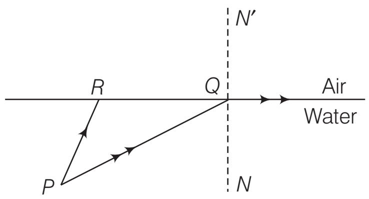
$$D = D_{\min} \quad \Rightarrow \quad i_1 = i_2 = i$$ ***[1]***

where, i_1 is the angle of incidence and i_2 is the angle of emergence.

Then, $D_{\min} = 2i - A$

For a given prism and given colour of light, $D_{\min}$ is unique. ***[1]***

36. PQ and PR are two light rays emerging from the object P as shown in the figure. ***[2006]***



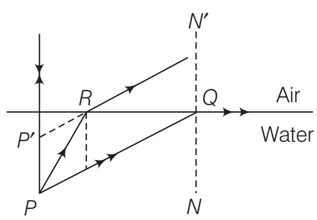
(i) What is the special name given to the angle of incidence ($\angle PQN$) of ray PQ?

(ii) Copy the ray diagram and complete it to show the position of the image of the object P, when seen obliquely from above.

(iii) Name the phenomenon that occurs, if the angle of incidence $\angle PQN$ is increased still further.

Sol. (i) The special name given to the angle of incidence $\angle PQN$ of ray PQ is critical angle. ***[1]***

(ii) *The complete diagram is shown below.*



The image of the object P will be formed at P' when seen obliquely from above. ***[2]***

(iii) Total internal reflection occurs, if the angle of incidence $\angle PQN$ is increased still further. ***[1]***

37. Answer the following questions.

(i) Write a note on "total reflecting prism".

(ii) State three actions that it can produce.

(iii) With the help of a diagram, show one action of total reflecting prism.

Sol. (i) A prism having an angle of 90° between its two refracting surfaces and the other two angles each equal to 45°, is known as total reflecting prism. It is because the light incident normally on any of its faces, suffers total internal reflection inside the prism. ***[1]***

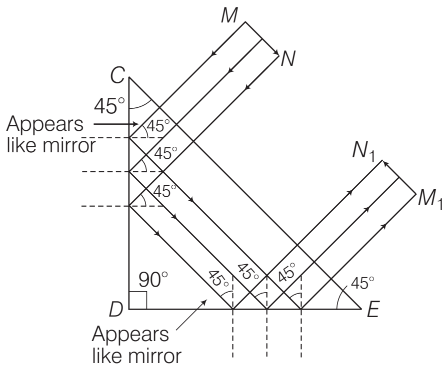
(ii) *Given below are the three actions produced by it,* i.e.,

(a) It can deviate a ray of light through 180° i.e., in prism binoculars.

(b) It can erect the image (inverted) without producing deviation in its path.

(c) It can deviate a ray of light through 90°. ***[2]***

(iii)

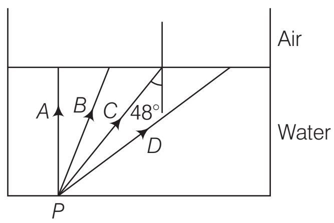


Deviation through 180° angle ***[1]***

38. Mention some differences between the reflection of light from a plane mirror and total internal reflection of light from a prism. ***[2007]***

Sol. Refer to theory (Page 75).

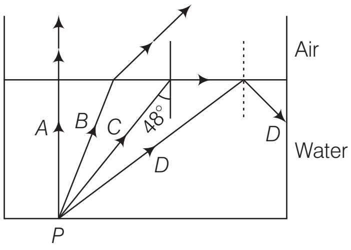
39. The diagram below shows a point source P inside a water container. Four rays A, B, C and D starting from the source P are shown upto the water surface.



(i) Show in the diagram, the path of these rays after striking the water surface. The critical angle for water-air surface is 48°.

(ii) Name the phenomenon which the rays B and D exhibit. ***[2017]***

Sol. (i) **Ray diagram**



[2]

(ii) Ray B exhibits refraction ray D exhibits total internal reflection. [2]

Numerical Based Questions

40. If the speed of light in air is $3\times10^8\ \text{ms}^{-1}$, determine the speed of light in glass. The refractive index of glass is 1.5. [2]

Sol. Given, speed of light, $c = 3\times10^8\ \text{ms}^{-1}$

Refractive index, $\mu = 1.5$

$$\because \quad \mu = \frac{c}{v} = \frac{\text{Velocity of light in air}}{\text{Velocity of light in a medium}} \quad [1]$$

$$\Rightarrow \quad 1.5 = \frac{3\times10^8}{v} \quad \Rightarrow \quad v = \frac{3\times10^8}{1.5}$$

$$\Rightarrow \quad v = 2\times10^8\ \text{m/s.} \quad [1]$$

41. The speed of light in diamond is 125000 km/s, if the speed of light in air is 3×10^8 m/s, then determine the refractive index of the diamond.

Sol. Velocity of light in air, $v_a = 3\times10^8$ m/s

Velocity of light in diamond, $v_d = 125\times10^6$ m/s [1]

$${}^a\mu_d = \frac{v_a}{v_d} = \frac{3\times10^8}{125\times10^6} = \frac{300\times10^6}{125\times10^6} \Rightarrow {}^a\mu_d = \frac{12}{5} = 2.4 \quad [1]$$

42. When a ray of light travelling in air is incident on the glass surface at angle of incidence 60°. Determine the angle of refraction in glass, if refractive index of glass is 3/2.

Sol. Given, $\angle i = 60° \quad \Rightarrow \quad {}^a\mu_g = \frac{3}{2}$

$$\text{As,} \quad {}^a\mu_g = \frac{\sin i}{\sin r} \quad \Rightarrow \quad \sin r = \frac{\sin i}{{}^a\mu_g} \quad [1]$$

$$\Rightarrow \quad \sin r = \frac{\sin 60°}{\frac{3}{2}} = \frac{\sqrt{3}\times2}{2\times3} \quad \Rightarrow \sin r = \frac{1}{\sqrt{3}} \quad [1]$$

$$\therefore \quad \sin r = \sin 35° \quad \Rightarrow \quad r = 35° \quad [1]$$

43. When a coil is placed at the bottom of a beaker containing water of refractive index $\frac{4}{3}$ to a depth of 12 cm, so by what height, does the coin appear to be raised when seen from vertically above?

Sol. Shift of image = Real depth of water $\left(1 - \frac{1}{\mu_w}\right)$

$\because$ Real depth of water = 12 cm (given)

$$\mu_w = \frac{4}{3} \quad \text{(given)} \quad [1]$$

$\therefore$ Shift of image of coin

$$= 12\left(1 - \frac{1}{4/3}\right) = 12\left(1 - \frac{3}{4}\right) = 12\left(\frac{1}{4}\right) \quad [1]$$

$\therefore$ Shift of coin = 3 cm

44. Determine the angle of incidence and emergence for a ray of light which suffers minimum deviation. Determine the angle of minimum deviation (D_{min}).

Sol. When ray suffers minimum deviation,

then angle of incidence, i = angle of emergence (e)

$$\Rightarrow \quad i = e = 48° \text{ and } \angle A = 60°$$

$$\because \quad D + A = i + e$$

$$D_{\text{min}} = 48° + 48° - 60°$$

$$= 96° - 60° \quad [1]$$

$$D_{\text{min}} = 36° \quad [1]$$

45. Determine the time taken by a ray of light when it passes through a glass sheet of thickness 2 m, ${}^a\mu_g = \frac{3}{2}$.

Sol. As we know, ${}^a\mu_g = \frac{v_a}{v_g}$

$$\Rightarrow \quad v_g = \frac{v_a}{{}^a\mu_g} = \frac{3\times10^8}{3/2}$$

$$\Rightarrow \quad v_g = 2\times10^8\ \text{m/s.} \quad [1]$$

$$\text{Time} = \frac{\text{Distance}}{\text{Speed}}$$

$$= \frac{2\ \text{mm}}{2\times10^8\ \text{m/s}} = \frac{2\times10^{-3}}{2\times10^8} = 10^{-11}\ \text{s}$$

$\therefore$ Time to pass in 2 mm glass $= 10^{-11}$ s. [1]

46. If a ray of light of wavelength 5400 Å suffers refraction from air to glass, determine the wavelength of light in glass. (Take, ${}^a\mu_g = 3/2$)

Sol. Given, $\lambda = 5400$, Å $= 5400 \times 10^{-10}$ m

$^a\mu_g = 3/2$

As, frequency remains same, $v = f\lambda$ **[1]**

$$\Rightarrow \quad 3 \times 10^8 = f \times 54 \times 10^{-8}$$

$$\Rightarrow \quad f = \frac{3 \times 10^8}{54 \times 10^{-8}} \Rightarrow f = \frac{3}{54} \times 10^{16}$$ **[1]**

$$\Rightarrow \quad f = \frac{300}{54} \times 10^{14} \Rightarrow f = 5.5 \times 10^{14}$$

$$\because \quad ^a\mu_g = \frac{3}{2} \Rightarrow {}^a\mu_g = \frac{\text{Velocity of light in vacuum}}{\text{Velocity of light in glass}}$$

$$\Rightarrow \quad v = \frac{c}{^a\mu_g} = \frac{3 \times 10^8}{3} \times 2 = 2 \times 10^8 \text{ ms}^{-1}$$ **[1]**

Now, $v = f\lambda \Rightarrow 2 \times 10^8 = 5.5 \times 10^{14} \times \lambda$

$$\Rightarrow \quad \lambda = \frac{2 \times 10^8}{5.5 \times 10^{14}} \Rightarrow \lambda = 3600 \text{ Å}$$ **[1]**

47. A coin placed at the bottom of a beaker appears to be raised by 4.0 cm. If the refractive index of water is 4/3, find the depth of the water in the beaker.

Sol. Since, we know that

$$\mu = \frac{\text{Real depth}}{\text{Apparent depth}} \Rightarrow \frac{4}{3} = \frac{\text{Real depth}}{\text{Apparent depth}}$$

Let real depth $= x$ **[1]**

Therefore, apparent depth $= x - 4$

$$\Rightarrow \quad \frac{4}{3} = \frac{x}{x-4}$$

$$\Rightarrow \quad 4x - 16 = 3x$$ **[1]**

$$\Rightarrow \quad x = 16 \qquad (\therefore \text{ real depth} = 16 \text{ cm})$$

48. If the refractive index of glass is $3/2$, determine the critical angle for glass-air surface.

(Take, $\sin 42° = 2/3$)

Sol. Given, $\mu = \frac{3}{2}$

If i_c is the critical angle, then

$$\sin i_c = \frac{1}{\mu} = \frac{1}{3/2} = \frac{2}{3}$$ **[1]**

$$\Rightarrow \quad \sin i_c = \sin 42°$$

$$\Rightarrow \quad i_c = 42°.$$ **[1]**

49. Determine the approximate value of critical angle for

(i) glass-air surface (ii) water-air surface.

Sol. (i) Since, $\sin i_c = \frac{1}{^a\mu_g}$

$$\because \quad ^a\mu_g = \frac{3}{2}$$

$$\therefore \quad \sin i_c = \frac{2}{3} \Rightarrow \sin i_c = 0.6667$$

$$\Rightarrow \quad \sin i_c = \sin 42° \Rightarrow i_c = 42°$$ **[1]**

So, critical angle for glass-air surface is 42°.

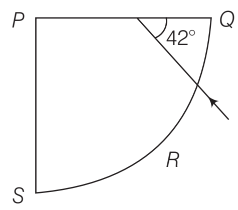
(ii) As, $^a\mu_w = \frac{4}{3}$, then critical angle for water-air surface can be calculated by

$$\sin i_c = \frac{1}{^a\mu_w} \Rightarrow \sin i_c = \frac{3}{4} \Rightarrow \sin i_c = \sin 48.6$$ **[1]**

$\Rightarrow i_c = 48.6°$

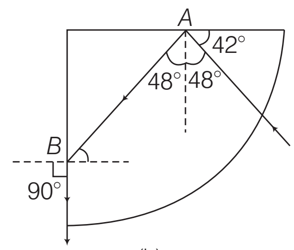
So, critical angle for water-air surface is 48.6°.

50. A ray of light enters a glass slab $PQRS$, as shown in the diagram. The critical angle of the glass is 42°. Copy the diagram and complete the path of the ray till emerges from the glass slab. Mark the angles in the diagram wherever necessary. ***[2011]***



(a)

Sol. At point A in fig. (b), $i = 48°$ and $i_c = 42° \Rightarrow i > i_c$



(b)

[1]

While at point B, $i = 42°$ and $i_c = 42° \Rightarrow i = i_c$

Therefore, $r = 90°$ **[1]**

CHAPTER EXERCISE

2 Marks Questions

1. How does the refractive index of a medium depend upon its temperature?

2. "The upper surface of water contained in the beaker and held above the eye level appear silvery". Justify the statement along with a reason.

3. The critical angle for glass-air is 45° for the yellow colour of light.

Mention whether it will be less than equal to or more than 45° for

(i) red light

(ii) blue light

4. What will be the change occurred in the angle of minimum deviation produced by a prism, if

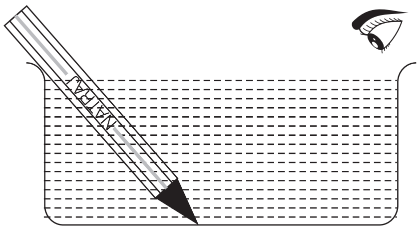
(i) the wavelength of the incident light and

(ii) the refracting angle of prism increases?

3 Marks Questions

5. If a girl puts her pencil into an empty trough and see the pencil from the position as given in the figure below.

(i) What kind of variation will be noticed in the appearance of pencil, when water is poured into the trough?



(ii) Mention the name of the phenomenon which accounts for the above stated observation.

(iii) Complete the given diagram to show how the girl's eye observes the pencil through water.

6. Explain the factors affecting the critical angle for a given pair of media.

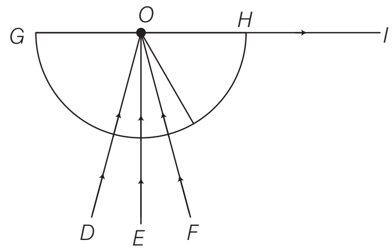
7. With the help of a suitable diagram, explain mathematically the refraction and total internal reflection of light rays at different angle of incidences.

8. If an object is viewed through a glass prism with its vertex pointing upwards, then it appears to be displaced upwards. Explain why?

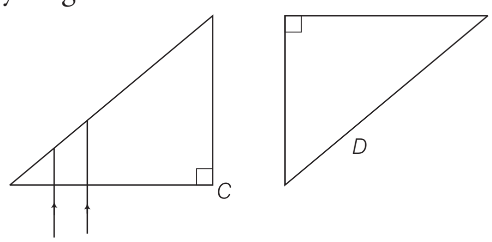
4 Marks Questions

9. Given below is a diagram showing the section of a semi-circular glass block having centre at O. D, E, F are the monochromatic rays of light of the same colour.

Mark the critical angle by i_c. Draw the path of rays F and D after they strike the edge GH. Name the phenomenon which the rays F and D exhibit.

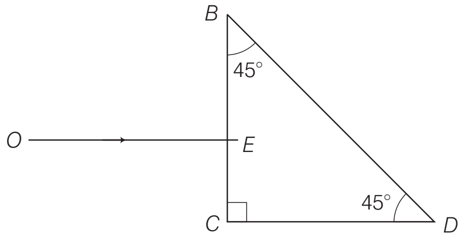


10. A diagram given below is to be completed in order to show the rays coming out of prism D. Mention the principle used for completing the ray diagram.



11. Briefly state, how is the angle of emergence related to the angle of incidence when prism is in the position of minimum deviation. Explain your answer with the help of a labelled diagram using an equilateral prism.

12. If a ray of light *OE* passes through a right angled prism as shown in the figure.

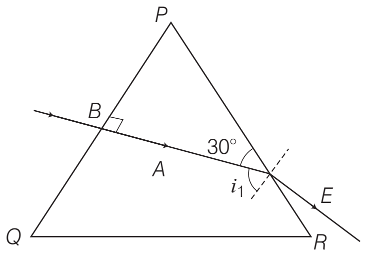


(i) Mention the angle of incidence at the faces *BD* and *CD*.

(ii) Give the name of phenomenon which the ray suffers at the face *BD*.

13. A water pond appears to be 2.7m deep. If the refractive index of water is 4/3. Determine the actual depth of the pond. ***Ans.*** 3.6 m

14. If a ray of light is incident normally on one face of the equilateral glass prism, answer the following questions.



(i) Determine the angle of incidence on first face of prism. ***Ans.*** 0°

(ii) Calculate the angle of refraction from first face of the prism. ***Ans.*** 0°

(iii) Find the angle of incidence (i_1) at the second face of the prism. ***Ans.*** 60°

(iv) Will the ray of light suffers minimum deviation by the prism? ***Ans.*** No

15. A ray of light incident at an angle of 48° on a prism of refracting angle 60° suffers minimum deviation. Determine the angle of minimum deviation. ***Ans.*** 36°