

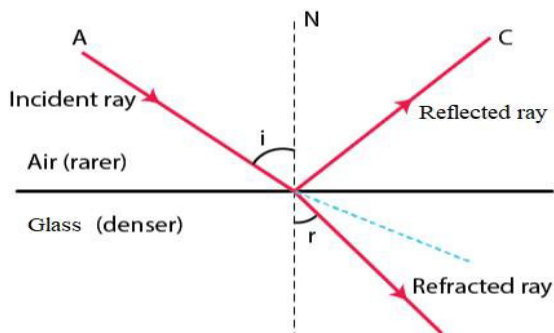
## Chapter 4 Refraction of Light at Plane Surfaces

### Solution:

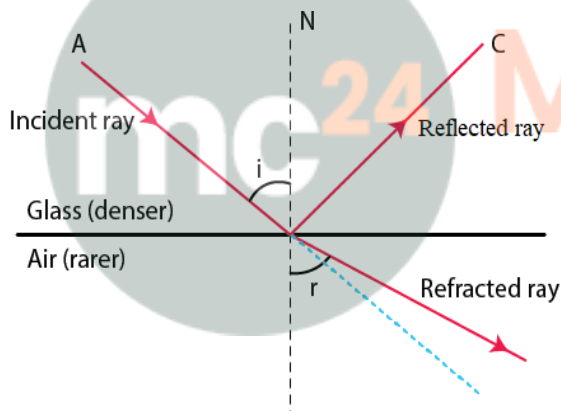
The change in the direction of the path of light, when it passes from one transparent medium to another transparent medium, is called refraction of light.

### Solution:

#### (i) Refraction of light from air to glass



#### (ii) Refraction of light from glass to air



## Chapter 4 Refraction of Light at Plane Surfaces

### **Solution:**

The ray of light incident normally on a plane glass slab passes undeviated, that means such rays suffers no bending at the surface because the angle of incidence is  $0^\circ$ . Hence, the angle of incidence  $\angle i = 0^\circ$ , then the angle of refraction  $\angle r = 0^\circ$ . Also the angle of deviation of the ray will be  $0^\circ$ .

### **Solution:**

Yes the ray have different speed in the other medium because when the medium changes, the speed of light changes.

### **Question: 5**

**What is the cause of refraction of light when it passes from one medium to another?**

### **Solution:**

Change in direction of path of light in other medium or the refraction of light occurs because light travels with different speeds in different media. When a ray of light passes from one medium to another medium, its direction or path (except  $\angle i = 0^\circ$  changes because of the change in speed of light.

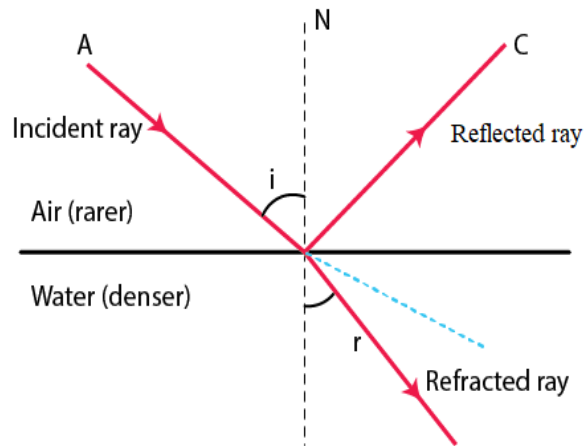
### **Question: 6**

**A light ray suffers reflection and refraction at the boundary in passing from air to water. Draw a neat labelled diagram to show it.**

### **Solution:**

Air is a rarer medium while water is denser medium than air with refractive index of 1:33. Therefore when a ray of light travels from air to water (i.e rarer to denser) it bends towards the normal.

## Chapter 4 Refraction of Light at Plane Surfaces



### Question: 7

A ray of light passes from medium 1 to medium 2. Which of the following quantities of the refracted ray will differ from that of incident ray: speed, intensity, frequency and wavelength?

#### Solution:

Speed, intensity and wavelength are the quantities in which refracted ray will differ from that of incident ray.

### Question: 8

State the Snell's laws of refraction of light.

#### Solution:

The Snell's laws of refraction of light are

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

$$\sin i / \sin r = \text{constant } {}_1\mu_2$$

where constant  ${}_1\mu_2$  is called the refractive index of the second medium with respect to the first medium

### Question: 9

Define the term refractive index of a medium. Can it be less than 1?

#### Solution:

The refractive index of second medium with respect to the first medium is defined as the ratio of the sine of the angle of incidence in the first medium to the sine of the angle of refraction in the second medium.

The refractive index of a transparent medium is always greater than 1 (it cannot be less

## Chapter 4 Refraction of Light at Plane Surfaces

than 1) because speed of light in any medium is always less than that in vacuum.

### Question: 10

(a) Compare the speeds of light of wavelength  $4000 \text{ \AA}$  (i.e. violet light) and  $8000 \text{ \AA}$  (i.e. red light) in vacuum.

(b) How is the refractive index of a medium related to the speed of light in it and in vacuum or air?

#### Solution:

(a) Speed of light depends on medium not on wavelength so, speed will be same for both.

(b) Denser medium has a higher refractive index and hence the speed of light in such medium is lower in comparison to the speed of light in a medium which has a lower refractive index.

### Question: 11

A light ray passes from water to (i) air, and (ii) glass. In each case, state how does the speed of light change.

#### Solution:

Refractive index of water,  $\mu_w = 1.33$

Refractive index of air,  $\mu_a = 1.0003$

Refractive index of glass,  $\mu_g = 1.5$

This shows that  $\mu_a < \mu_w < \mu_g$

The speed of light decreases when it enters from a rarer medium to denser medium and increases when it enters from a denser medium to rarer medium

Hence, the speed of light increases when light ray passes from water to air and the speed of light decreases when the light ray passes from water to glass.

### Question: 12

A light ray in passing from water to a medium (a) speeds up (b) slows down. In each case, (i) give one example of the medium, (ii) State whether the refractive index of medium is equal to, less than or greater than the refractive index of water.

#### Solution:

(a) A light ray in passing from water to a air speeds up

(b) A light ray in passing from water to a glass medium slows down

(c) It means that the refractive index of the medium is less than that of water when the speed increases.

(d) Similarly the refractive index of the medium is greater than that of water when the speed decreases.

## Chapter 4 Refraction of Light at Plane Surfaces

### Question: 13

What do you understand by the statement 'the refractive index of the glass is 1.5 for white light'?

#### Solution:

This statement indicates that white light travels in air 1.5 times faster than in glass.

### Question: 14

A monochromatic ray of light passes from air to glass. The wavelength of light in air is  $\lambda$ , the speed of light in air is  $c$  and in glass is  $v$ . If the refractive index of glass is 1.5, write down (a) the relationship between  $c$  and  $v$ , (b) the wavelength of light in glass.

#### Solution:

(a) The relation between speed of light in air  $c$  and in glass  $v$  is given by

$$c / v = \mu$$

or  $c = 1.5 v$

(b) The wavelength of light in glass ( $\lambda^1$ )

$$\begin{aligned} \mu &= \lambda / \lambda^1 \\ &= \lambda / 1.5 \end{aligned}$$

### Question: 15

In an experiment of finding the refractive index of glass, if blue light is replaced by the red light, how will the refractive index of glass change? Give reason in support of your answer.

#### Solution:

In glass, the speed of red light is more than that of blue light. The refractive index is  $c / v$ . Therefore the refractive index of glass for red light will decrease as compared to blue light.

### Question: 16

(a) For which colour of white light, is the refractive index of a transparent medium

(i) the least (ii) the most?

(b) Which colour of light travels fastest in any medium except air?

#### Solution:

(a)

(i) The refractive index of a transparent medium is least for red colour

(ii) The refractive index of a transparent medium is most for violet colour

(b) The wavelength of red colour is the highest. Hence, red colour travels fastest in any medium except air.

## Chapter 4 Refraction of Light at Plane Surfaces

### Question: 17

**Name two factors on which the refractive index of a medium depends? State how does it depends on the factor state by you.**

#### **Solution:**

The factors on which the refractive index of a medium depends are as follows

(i) Nature of the medium (e.g.  $\mu_g = 1.5$ ,  $\mu_w = 1.33$ ) : Less the speed of light in the medium as compared to that in air, more is the refractive index of the medium

(ii) Physical condition such as temperature: With increase in temperature, the speed of light in medium increases, so the refractive index of medium decreases.

### Question: 18

**How does the refractive index of a medium depend on the wavelength of light used?**

#### **Solution:**

Refractive index of a medium decreases with increase in wavelength of light.

Refractive index of a medium for violet light which has least wavelength is greater than that for red light which has greatest wavelength.

### Question: 19

**How does the refractive index of a medium depend on its temperature?**

#### **Solution:**

Refractive index decreases with the increase in temperature of medium.

The speed of light in that medium increases with increase in temperature. Hence, the refractive index = [velocity of light in vacuum / velocity of light in medium] decreases

### Question: 20

**Light of a single colour is passed through a liquid having a piece of glass suspended in it. On changing the temperature of liquid, at a particular temperature, the glass piece is not seen.**

**(a) When is the glass piece not seen?**

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

#### **Solution:**

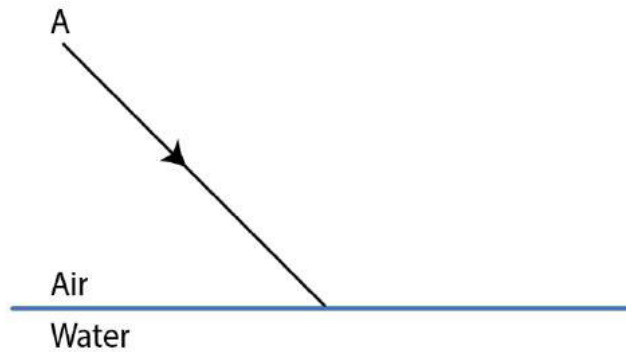
(a) The glass piece is not visible when the refractive index of liquid becomes equal to the refractive index of glass.

(b) The refractive index of a medium (glass or liquid) is different for the light of different colours. Hence, light of a single colour is used.

### Question: 21

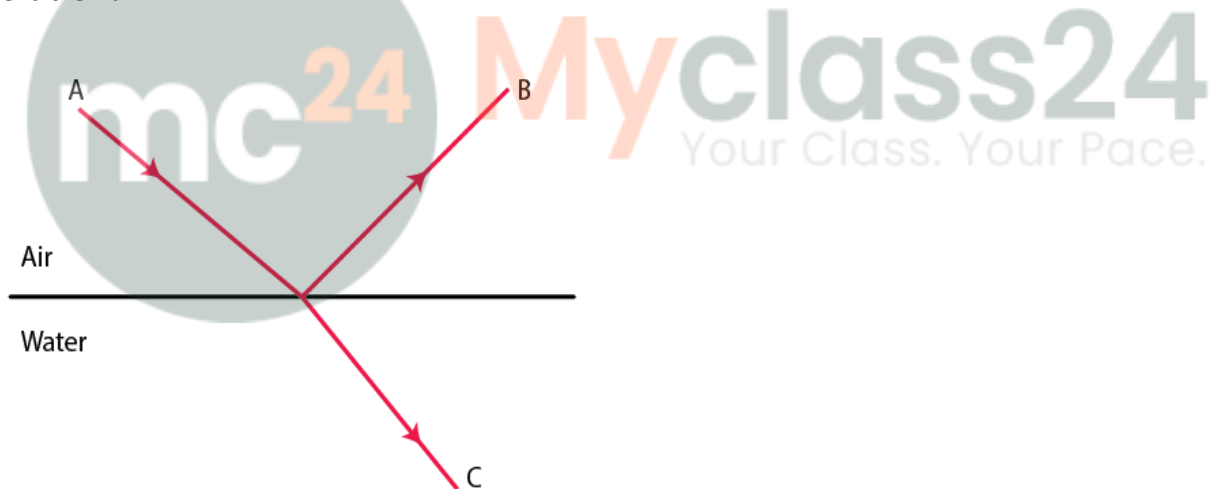
## Chapter 4 Refraction of Light at Plane Surfaces

In the figure below, a ray of light A incident from air suffers partial reflection and refraction at the boundary of water.



- (a) Complete the diagram showing (i) the reflected ray B and (ii) the refracted ray C.  
(b) How are the angles of incidence  $i$  and refraction  $r$  related?

**Solution:**



By Snell's law the angle of incidence and refraction are related to each other.

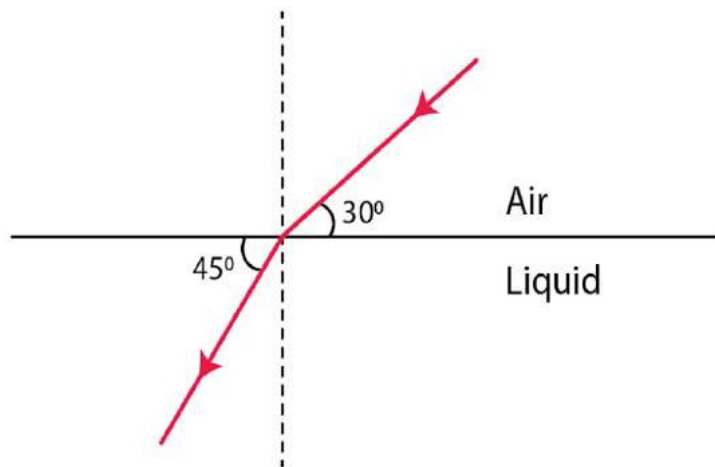
$$\sin i / \sin r = \mu_w$$

**Question: 22**

The diagram alongside shows the refraction of a ray of light from air to liquid.

- (a) Write the values of (i) angle of incidence, and (ii) angle of refraction.  
(b) Use Snell's law to find the refractive index of liquid with respect to air.

## Chapter 4 Refraction of Light at Plane Surfaces



**Solution:**

(a)

(i) The angle of incidence is the angle which the incident ray makes with the normal.

$$\text{Hence, } \angle i = 90^\circ - 30^\circ = 60^\circ$$

(ii) Angle of refraction is the angle which the refracted ray makes with the normal

$$\text{Hence, } \angle r = 90^\circ - 45^\circ = 45^\circ$$

(b) According to Snell's law

$$\begin{aligned} \text{air } \mu_{\text{liquid}} &= \sin i / \sin r \\ &= \sin 60^\circ / \sin 45^\circ \\ \text{air } \mu_{\text{liquid}} &= (\sqrt{3} / 2) / (1 / \sqrt{2}) \\ &= (\sqrt{3}/2) \\ &= 1.22 \end{aligned}$$

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**Question: 23**

The refractive index of water with respect to air is  ${}_a\mu_w$  and of glass with respect to air is  ${}_a\mu_g$ . Express the refractive index of glass with respect to water.

**Solution:**

The refractive index of glass with respect to water is given by

$${}_w\mu_g = {}_a\mu_g / {}_a\mu_w$$

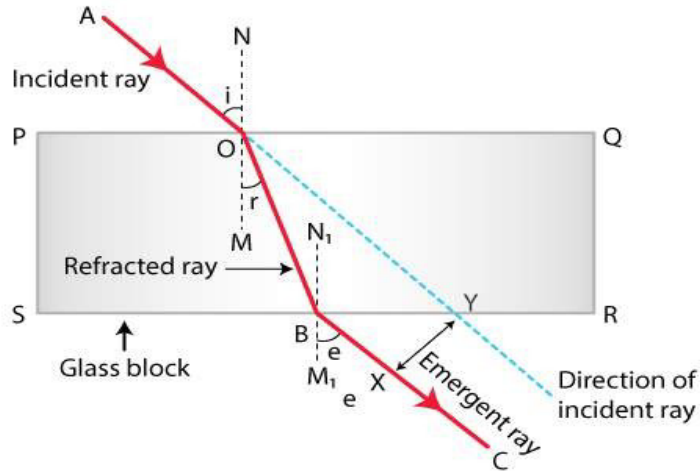
**Question: 24**

What is lateral displacement? Draw a ray diagram showing the lateral displacement of a ray of light when it passes through a parallel sided glass slab.

**Solution:**

The lateral displacement is the perpendicular distance between the path of emergent ray and the direction of the incident ray

## Chapter 4 Refraction of Light at Plane Surfaces



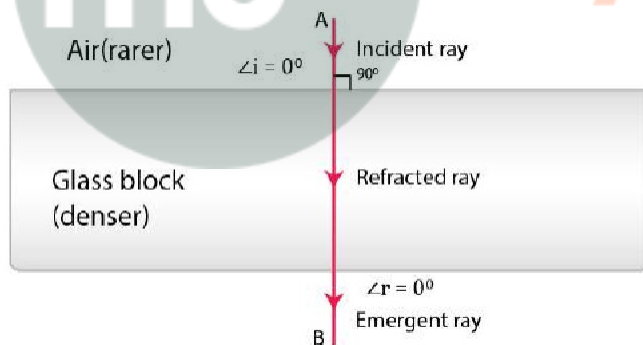
Here, XY is the perpendicular distance or the lateral displacement in the above figure

### Question: 25

A ray of light strikes the surface at a rectangular glass slab such that the angle of incidence is (i)  $0^\circ$ , (ii)  $45^\circ$ . In each case, draw diagram to show the path taken by the ray as it passes through the glass slab and emerges from it.

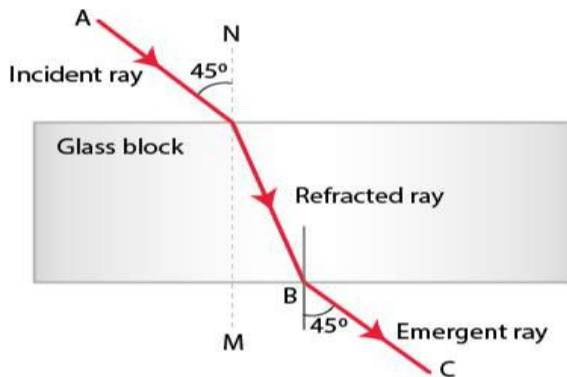
**Solution:**

(i) When angle of incidence is  $0^\circ$



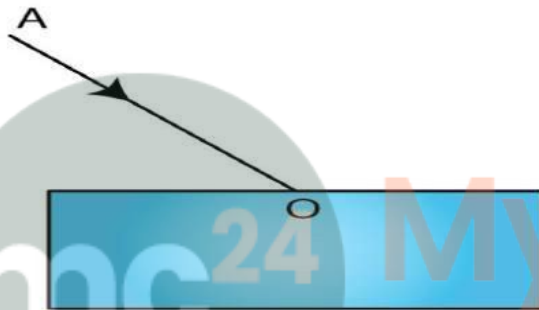
(ii) When angle of incidence is  $45^\circ$

## Chapter 4 Refraction of Light at Plane Surfaces



### Question: 26

In the adjacent diagram, AO is a ray of light incident on a rectangular glass slab.

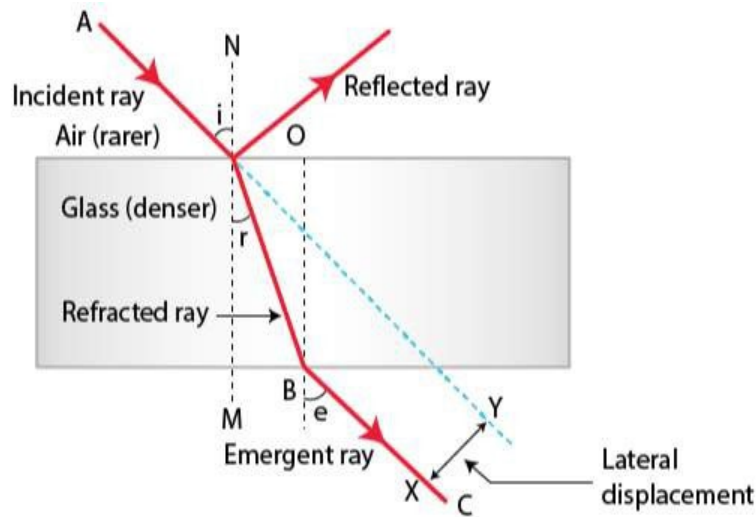


- Complete the path of the ray till it emerges out of the slab.
- In the ray diagram, mark the angle of incidence ( $i$ ) and the angle of refraction ( $r$ ) at the first interface. How is the refractive index of glass related to angles  $i$  and  $r$ ?
- Mark angle of emergence by the letter  $e$ . How are the angles  $i$  and  $e$  related?
- Which two rays are parallel to each other? Name them.
- Indicate in the diagram the lateral displacement between the emergent ray and the incident ray. State one factor that affects the lateral displacement.

**Solution:**

- The complete path of incident ray in glass block is given below

## Chapter 4 Refraction of Light at Plane Surfaces



(b) In part A, the angle of incidence ( $i$ ) and angle of refraction ( $r$ ) are marked.

Refractive index of glass is related to the angles  $i$  and  $r$  as

$$\sin i / \sin r = \mu$$

(c) Angle of emergence ( $e$ ) is marked in part (a)

The two angles  $i$  and  $e$  are related by the relation

$$\angle i = \angle e$$

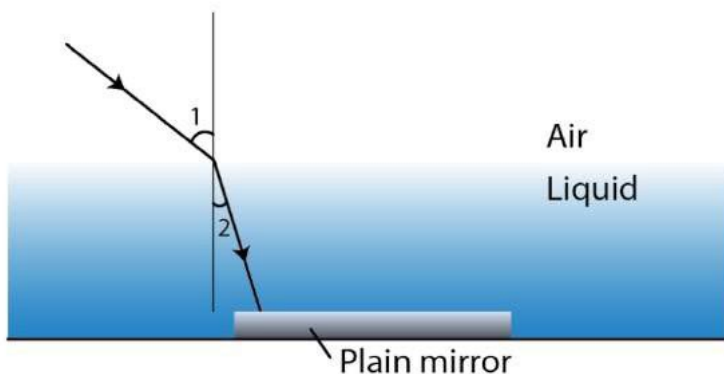
(d) The two rays which are parallel to each other are incident ray and emergent ray.

(e)  $XY$  is the lateral displacement between the incident ray and the emergent ray in the above figure.

More the thickness of the medium, more is the lateral displacement

### Question: 27

A ray of green light enters a liquid from air, as shown in the figure. The angle 1 is  $45^\circ$  and angle 2 is  $30^\circ$ .



(a) Find the refractive index of liquid.

(b) Show in the diagram the path of the ray after it strikes the mirror and re-enters in air. Mark in the diagram the angles wherever necessary.

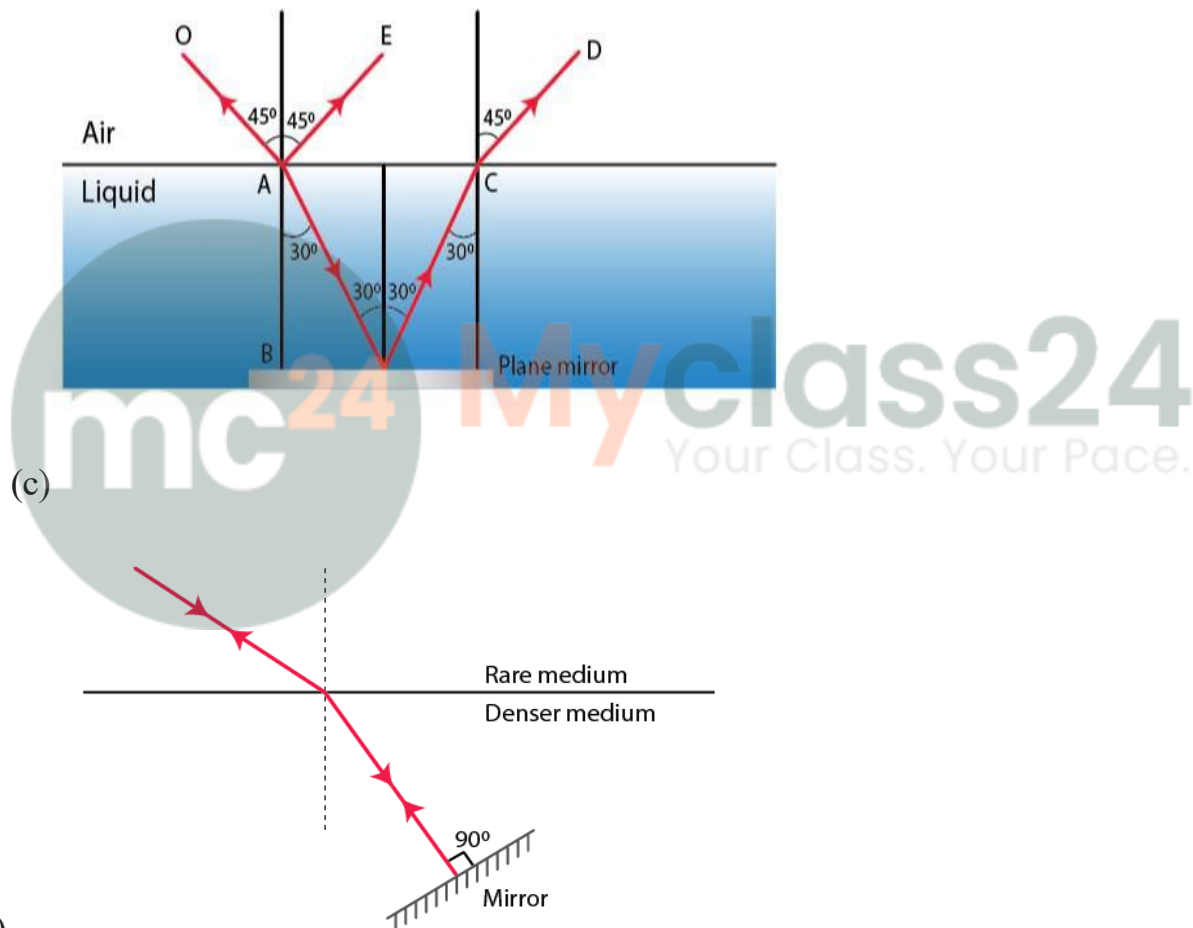
## Chapter 4 Refraction of Light at Plane Surfaces

(c) Redraw the diagram if plane mirror becomes normal to the refracted ray inside the liquid. State the principal used.

**Solution:**

(a) Refractive index of the liquid is given by

$$\begin{aligned} \mu_l &= \sin i / \sin r \\ \mu_l &= \sin 45^\circ / \sin 30^\circ \\ &= 1 / \sqrt{2} / 1 / 2 \\ &= \sqrt{2} \\ &= 1.414 \end{aligned}$$



(b)

The principle of reversibility is used here.

**Question: 28**

When an illuminated object is held in front of a thick plane glass mirror, several images are seen, out of which the second image is the brightest. Give reason.

**Solution:**

## Chapter 4 Refraction of Light at Plane Surfaces

When the ray of the light falls on the surface of the mirror from lighted candle, a small part of light (nearly 4%) is reflected forming a faint virtual image, while a large part of light (nearly 96%) is refracted inside the glass. Now this ray is strongly reflected back by the silvered surface inside the glass. This ray is then partially refracted in air and this refracted ray forms another virtual image. This image is the brightest image because it is due to the light suffering a strong first reflection at the silvered surface.

### Question: 29

Fill in the blanks to complete the following sentences:

- (a) When light travels from a rarer to a denser medium, its speed .....
- (b) When light travels from a denser to a rarer medium, its speed .....
- (c) The refractive index of glass with respect to air is  $\frac{3}{2}$ . The refractive index of air with respect to glass will be .....

**Solution:**

- (a) When light travels from a rarer to a denser medium, its speed decreases
- (b) When light travels from a denser to a rarer medium, its speed increases
- (c) The refractive index of glass with respect to air is  $\frac{3}{2}$ . The refractive index of air with respect to glass will be  $\frac{2}{3}$

### MULTIPLE TYPE CHOICE

#### Question: 1

When a ray of light from air enters a denser medium, it:

- a. Bends away from the normal
- b. Bends towards the normal
- c. Goes undeviated
- d. Is reflected back

**Solution:**

When a ray of light from air enters a denser medium, it bends towards the normal.

#### Question: 2

A light ray does not bend at the boundary in passing from one medium to the other medium if the angle of incidence is:

- a.  $0^\circ$
- b.  $45^\circ$
- c.  $60^\circ$
- d.  $90^\circ$

**Solution:**

A light ray does not bend at the boundary in passing from one medium to the other medium if the angle of incidence is  $0^\circ$

## Chapter 4 Refraction of Light at Plane Surfaces

### Question: 3

The highest refractive index is of:

- a. Glass
- b. Water
- c. Diamond
- d. Ruby

**Solution:**

Diamond has the highest refractive index

### NUMERICALS

#### Question: 1

The speed of light in air is  $3 \times 10^8 \text{ m s}^{-1}$ . Calculate the speed of light in glass. The refractive index of glass is 1.5.

**Solution:**

**Given**

Speed of light in air,  $C = 3 \times 10^8 \text{ m / s}$

Refractive index of glass,  $\mu = 1.5$

Speed of light in glass,  $v = ?$

Now,

$$c / v = \mu$$

Hence,  $v = c / \mu$

$$v = 3 \times 10^8 \text{ m / s} / 1.5$$

$$v = 2 \times 10^8 \text{ m / s}$$

#### Question: 2

The speed of light in diamond is  $125,000 \text{ km s}^{-1}$ . What is the refractive index? (speed of light in air =  $3 \times 10^8 \text{ m s}^{-1}$ ).

**Solution:**

**Given,**

Speed of light in diamond =  $125,000 \text{ km s}^{-1}$  i.e  $125 \times 10^6 \text{ m / s}$

Speed of light in air,  $c = 3 \times 10^8 \text{ m / s}$

Refractive index of diamond,  $\mu_D = ?$

We know that,

$$c / v = \mu$$

$$\mu = c / v$$

$$\mu = (3 \times 10^8) \text{ m / s} / (125 \times 10^6) \text{ m / s}$$

$$\mu = 2.4$$

## Chapter 4 Refraction of Light at Plane Surfaces

### Question: 3

The refractive index of water with respect to air is  $4/3$ . What is the refractive index of air with respect to water?

**Solution:**

Given,

The refractive index of water with respect to air is  $4/3$

$$\text{air } \mu_{\text{water}} = 4/3$$

Hence, the refractive index of air with respect to water is

$$\text{water } \mu_{\text{air}} = 1 / \text{air } \mu_{\text{water}}$$

$$\text{water } \mu_{\text{air}} = 1 / (4/3)$$

$$\text{water } \mu_{\text{air}} = 3/4$$

$$\text{water } \mu_{\text{air}} = 0.75$$

### Question: 4

A ray of light of wavelength  $5400 \text{ \AA}$  suffers refraction from air to glass. Taking  ${}_a\mu_g = 3/2$ , find the wavelength of light in glass.

Given,

Wavelength of light in air =  $5400 \text{ \AA}$

Refractive index of glass with respect to air is given by

$${}_a\mu_g = 3/2$$

Also,  ${}_a\mu_g = (\text{wavelength of light in air}) / (\text{wavelength of light in glass})$

$$3/2 = (\text{wavelength of light in air}) / (\text{wavelength of light in glass})$$

$$3/2 = 5400 \text{ \AA} / \text{wavelength of light in glass}$$

$$\text{Wavelength of light in glass} = 2/3 \times 5400 \text{ \AA}$$

$$\text{Wavelength of light in glass} = 3600 \text{ \AA}$$