Phenomenon of Refraction, Refraction Through A Glass Slab

Objectives

After going through this module, the learners will be able to:

- Understand Refraction
- Distinguish between mass density and optical density
- Define refractive index of a medium and relate refractive index of a medium with the speed of light in the medium
- Trace the path of an oblique ray of light through a rectangular glass slab.
- Predict the effects of change in
    - angle of incidence,
    - thickness of glass slab and
    - the refractive index of the material of the slab, on the lateral displacement produced in the incident ray

Content Outline

- Unit Syllabus
- Module wise distribution of unit syllabus
- Words you must know
- Introduction
- Optical density and mass density
- Incident ray, refracted ray and emergent ray, angle of incidence, angle of refraction and angle of emergence
- Refractive index
- Oblique incidence of light and Snell's law
- Refraction through a parallel sided glass slab, lateral displacement; factors affecting lateral displacement
- To observe refraction, and lateral displacement, of a beam of light incident obliquely on a glass slab
- Formation of image in a glass slab
- Intensity of refracted light -To use a LDR to study the variation in the intensity of light, emerging through different coloured transparent sheets

- Summary

Unit Syllabus

Unit 6

Chapter–9: Ray Optics and Optical Instruments

Ray optics Reflection of light; spherical mirrors; mirror formula; refraction of light; total internal reflection and its applications; optical; fibers; refraction at spherical surfaces; lenses; thin lens formula; lens maker's formula; magnification, power of a lens; combination of thin lenses in contact; refraction and dispersion of light through a prism.

Scattering of light – blue color of sky and reddish appearance of the sun at sunrise and sunset

Optical instruments – microscopes and astronomical telescopes (refracting and reflecting) and their magnifying powers

Chapter 10 Wave Optics

Wave optics: wavefront and Huygens's principle, reflection and refraction of plane wave at a plane surface using wave fronts, proof of laws of reflection and refraction using Huygens's principle. Interference, Young's double slit experiment and expression for fringe width, coherent sources and sustained interference of light; diffraction due to a single slit width of central maximum; resolving power of microscope and astronomical telescope. Polarisation, plane polarised light, Malus's law, Brewster's law, uses of plane polarised light and polaroid.

Unit Wise Module Distribution Of Unit Syllabus 15 Modules

Module 1	• Introduction • How we will study optics-plan • Light facts • Ray optics, beams • Light falling on surfaces of any shape texture • Peculiar observations
Module 2	• Reflection of light • Laws of reflection • Reflection of light by plane and spherical surfaces • Spherical Mirrors aperture, radius of curvature, pole principal axis • Focus, Focal length, focal plane

	● Image – real and virtual ● Sign convention ● The mirror equation, magnification ● To find the value of image distance v for different values of object distance u and find the focal length of a concave mirror ● Application of mirror formula
Module 3	● Refraction of light ● Optical density and mass density ● Incident ray, refracted ray emergent ray ● Angle of incidence, angle of refraction angle of emergence ● To study the effect on intensity of light emerging through different colored transparent sheets using an LDR ● Refractive index ● Oblique incidence of light, Snell's law ● Refraction through a parallel sided slab ● Lateral displacement, ● Factors affecting lateral displacement ● To observe refraction and lateral displacement of a beam of light incident obliquely on a glass slab ● Formation of image in a glass slab
Module 4	● Special effects due to refraction ● Real and apparent depth ● To determine the refractive index of a liquid using travelling microscope ● Total internal reflection ● Optical fibers and other applications
Module 5	● Refraction through a prism ● Deviation of light -angle of deviation ● Angle of minimum deviation ● Expression relating refractive index for material of the prism and angle of minimum deviation

	• To determine the angle of minimum deviation for given prism by plotting a graph between angle of incidence and angle of deviation • Dispersion, spectrum
Module 6	• Refraction at spherical surfaces • Radius of curvature • Refraction by a lens • Foci, focal plane, focal length, optical center, principal axis • Formation of images real and virtual • Lens maker's formula • Lens formula and magnification • Sign convention • Application of lens formula • Power of lens • Combination of thin lenses in contact

Module 7	• To study the nature and size of image formed by a
	    ○ convex lens
	    ○ concave mirror using a candle and a screen
	• To determine the focal length of convex lens by plotting graphs between u and v, between 1/u and 1/v
	• To determine the focal length of a convex mirror using a convex lens
	• To find the focal length of a concave lens using a convex lens
	• To find the refractive index of a liquid by using a convex lens and a plane mirror

Module 8	• Scattering of light – • Blue color of sky • Reddish appearance of the sun at sunrise and sunset • Dust haze • Clouds
Module 9	• optical instruments • human eye

	• microscope • astronomical telescopes reflecting and refracting • magnification • making your own telescope
Module 10	• wave optics • wave front • Huygens's principle shapes of wave front • plane wave front • Refraction and reflection of plane wavefront using Huygens's principle • Verification of Laws of refraction and reflection of light using Huygens's principle
Module 11	• Superposition of waves • Coherent and incoherent addition of waves
Module 12	• Interference of light • Young's double slit experiment • Expression for fringe width • Graphical representation of intensity of fringes • Effect on interference fringes in double slit experiment • Black and white or colored fringes
Module 13	• Diffraction • Diffraction at a single slit,width of the central maxima • Comparison of fringes in young's experiment and those in diffraction from a single slit
Module 14	• Diffraction in real life • Seeing the single slit diffraction pattern • Resolving power of optical instruments • Validity of ray optics • Fresnel distance
Module 15	• Polarisation • to observe polarization of light using two polaroid • Plane polarised light

	• Polariser analyser Malus law • Brewster/s law • Polarisation due to scattering • Uses of plane polarised light and polaroids

Words You Must Know

Let us remember the words and the concepts we have been using in our study of light

Light: Light is a form of energy which gives the sensation of vision when it falls on the retina of the eye.

Ray of light: The straight line path along which light travels is called a ray of light. Light rays start from each point of a source and travel along a straight line until they strike an object or a surface separating two media.

Beam of light: A group of rays of light is called a beam of light.

Parallel beam of light: If all the rays of light in the group are parallel to each other then the beam is said to be a parallel beam of light.

Converging beam of light: If the rays of light in the group come closer to each other i.e. converge to a point, then the beam is said to be a converging beam of light.

Diverging beam of light: If the rays of light in the group move away from each other i.e. diverge, then the beam is said to be a diverging beam of light.

Transparent medium: A medium through which light can pass freely over a large distance is called a transparent medium. Glass and still water are some examples of transparent objects

Opaque medium: A medium through which light cannot pass is called an opaque medium. Wood and metals are some examples of opaque objects.

Real image: If the rays of light after reflection from a mirror actually meet at a point i. e. the reflected beam is a converging beam, then the image is said to be a real image.

Virtual image: If the rays of light after reflection from a mirror do not actually meet at a point but seem to come from a point behind the mirror i.e. the reflected beam is a diverging beam, then the image is said to be a virtual image.

Ray diagram: A diagram that traces the path that light takes in order for a person to view a point on the image of an object. On the diagram, rays (lines with arrows) are drawn for the incident ray and the reflected ray or refracted

Spherical surface: any surface which is a part of a sphere

Pole: The geometrical center of the surface of the mirror is called its pole. It is marked as point (p) in the diagram.

Centre of curvature: It is the center of the hollow sphere of which the mirror is a part. It is marked as point (C) in the diagram.

Radius of curvature: It is the radius of the sphere of which the mirror is a part.

Principal axis: The line joining the pole and the center of curvature of the mirror is called its principal axis.

Aperture of a mirror: The diameter of the circular cross section of the sphere, used to form the spherical mirror is called its aperture

Focus point focal plane: A parallel beam of light parallel to the principal axis is incident on a concave or a convex mirror. The reflected rays are observed to converge to a point on the principal axis in case of a concave mirror or they appear to diverge from a point on the principal axis in case of a convex mirror. This point of convergence or apparent convergence is called the focus point (F)and the plane containing the focus perpendicular to the principal axis is called the focal plane.

Focal length the distance from the pole to the focus is called focal length.

Object distance (u) the distance of the object from the pole.

Image distance (v) the distance of the image from the pole.

Sign convention a universally accepted convention based on Cartesian coordinate system to indicate the location of object and image with respect to a mirror surface

Mirror formula An equation which expresses the quantitative relationship between the object distance (u), the image distance (v), and the focal length (f). The equation is stated as follows:

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

Magnification of the ratio of the image distance and object distance to the ratio of the image height (h`) and object height (h). The magnification equation is stated as follows:

$$m = \frac{height\ of\ image}{height\ of\ object} = \frac{image\ distance}{object\ distance}$$

Introduction

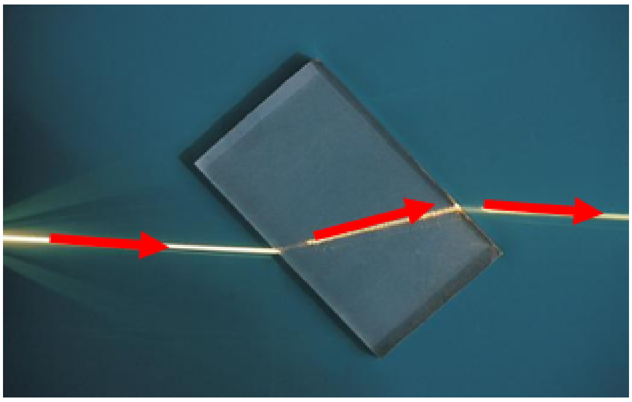
We have seen that when light falls on a surface it gets reflected and follows the laws of reflection of light.

Light seems to travel along straight-line paths in a transparent medium.

What happens when light enters from one transparent medium to another?

Does it still move along a straight-line path or change its direction? We shall recall some of our day-to-day experiences. Have you seen a pencil partly immersed in water in a glass tumbler? It appears to be displaced at the interface of air and water. You might have observed that a lemon kept in water in a glass tumbler appears to be bigger than its actual size, when viewed from the sides. How can you account for such experiences?

You might have observed that the bottom of a bucket, tank or a pond containing water appears to be raised. Similarly, when a thick glass slab is placed over some printed matter, the letters appear raised when viewed through the glass slab. Why does it happen?



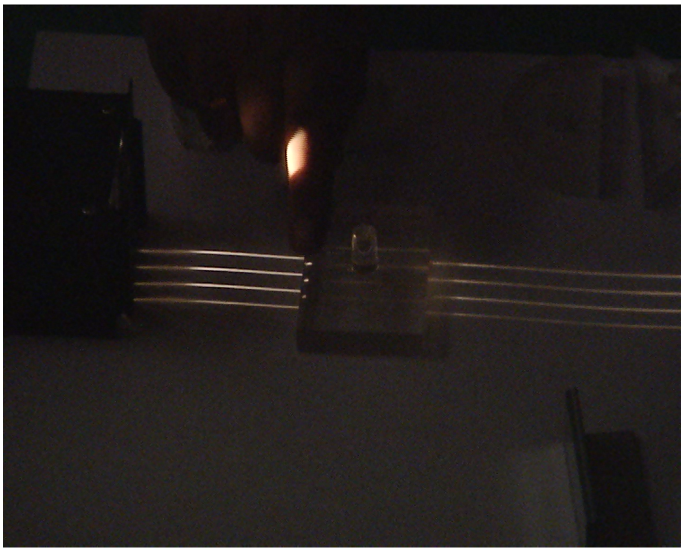
The red arrow shows the path of light as it propagates through the glass slab

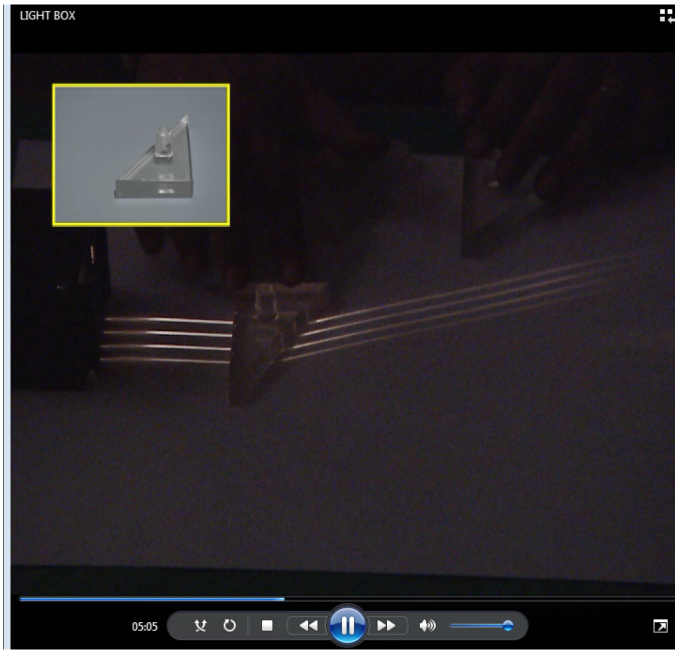
https://upload.wikimedia.org/wikipedia/commons/8/85/Refraction_photo.png

Now we will see what happens to the path of a ray of light when it goes from one transparent medium to another transparent medium.

Refraction of Light

Let a laser beam fall normally on a glass slab, you will see that it passes straight through the slab. Next increase the angle of incidence you will see that the beam of light has deviated from its path.





light box activities

The phenomenon of bending of incident light from its path when it goes from one transparent medium to another transparent medium is (usually) called the refraction of light.

This ‘bending’ takes place because of a change in the speed of light as it goes from one medium to another.

We may, therefore, (preferably) say:

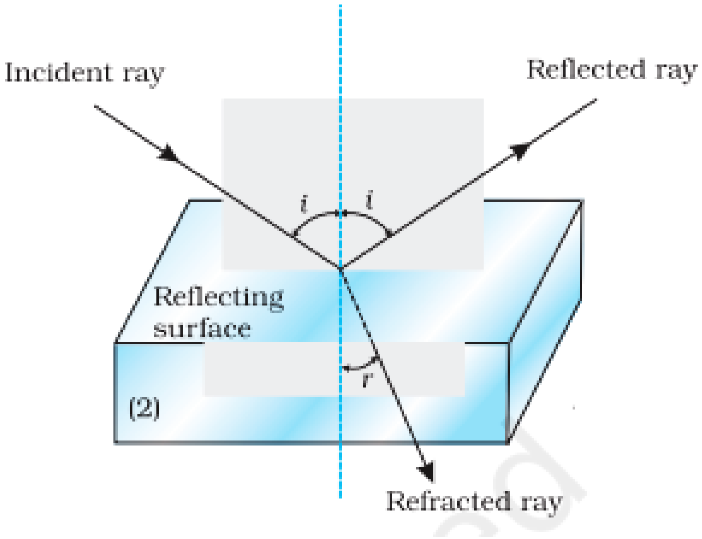
“The phenomena, associated with a ray of light, due to a change in its speed, make up the phenomena of refraction.

The bending of path, of an obliquely incident ray of light, in going from one transparent medium to another, is the most common, and easily observed, effect of refraction.

So to see both reflection and refraction of light consider the figure

Note

- At the point of incidence, the normal, reflected ray and refracted ray
- The refracted ray can be seen to bend towards the normal



In order to understand the cause of this **bending of light on refraction**, let us first understand the difference between mass density and optical density

Mass density and Optical Density

Mass density

Mass density is defined as mass per unit volume of the substance.

Mass density = $\frac{mass}{volume}$

Now, **what is meant by the statement density of water is 1000 kg per meter^3**

It means 1 m^3 of water contains 1000 kg of water

Optical Density

The ability of a medium to refract light is also expressed in terms of its optical density. Optical density has a definite connotation. It is not the same as mass density. We have been using the terms 'rarer medium' and 'denser medium'. It actually means 'optically rarer medium' and 'optically denser medium', respectively.

When can we say that a medium is optically denser than the other?

The **speed of light is higher in a rarer medium than a denser medium**.

Thus, a ray of light travelling from a rarer medium to a denser medium slows down and bends towards the normal. When it travels from a denser medium to a rarer medium, it speeds up and bends away from the normal.

So, as light travels from one transparent medium to another transparent medium its speed changes. If, on entering the second medium, the speed of light decreases then this second medium in which light has entered is said to have more optical density than that of the first medium.

In other words, an **increase in 'optical density' implies a decrease in speed of light and vice – versa.**

For a given pair of mediums, the medium in which light propagates faster is the optically rarer medium and the medium in which light propagates slower, is the optically denser medium of that pair.

Optical density, may, therefore, be regarded as determining the speed of light in a given medium.

Optical density should therefore, not be confused with mass density,which is mass per unit volume

It is quite possible that the mass density of an optically denser medium can be less than that of an optically rarer medium.

For example, turpentine has less mass density than water.

However, since light propagates slower in it than in water, i.e. it has more optical density than water. The phenomena of 'refraction'

Incident Ray, Refracted Ray and Emergent Ray, Angle of Incidence, Angle of Refraction and Angle of Emergence

Refraction through a rectangular glass slab

Incident ray: The ray of light which strikes the surface of separation of two media is called incident ray. .

Point of incidence: The point at which the incident ray strikes the interface of the two media is called point of incidence.

Angle of incidence: The angle which the incident ray makes with the normal drawn at the point of incidence is called the angle of incidence. Angle marked as i in the diagram is the angle of incidence.

Refracted ray: The ray of light which travels into the second medium is called refracted ray. It is represented by ray QR in the figure.

Angle of refraction: The angle, which the refracted ray makes with the normal drawn at the point of incidence is called the angle of refraction. Angle N'QR is angle of refraction; it is usually represented as angle r.

At point of first refraction

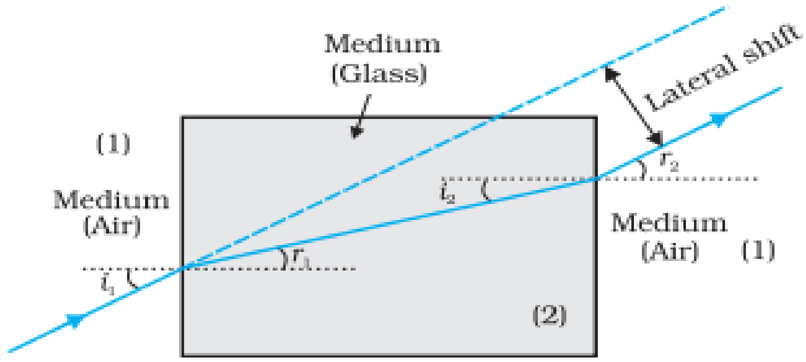
Angle of incidence $=i_1$

Angle of refraction $= r_1$

At the second point of refraction

Angle of incidence $=i_2$

Angle of refraction $= r_2$



An incident ray at the first surface undergoes refraction from air (medium 1) to glass (medium 2) or rarer to denser medium.The second refraction takes place at the point of emergence ray travels from denser to rarer medium.

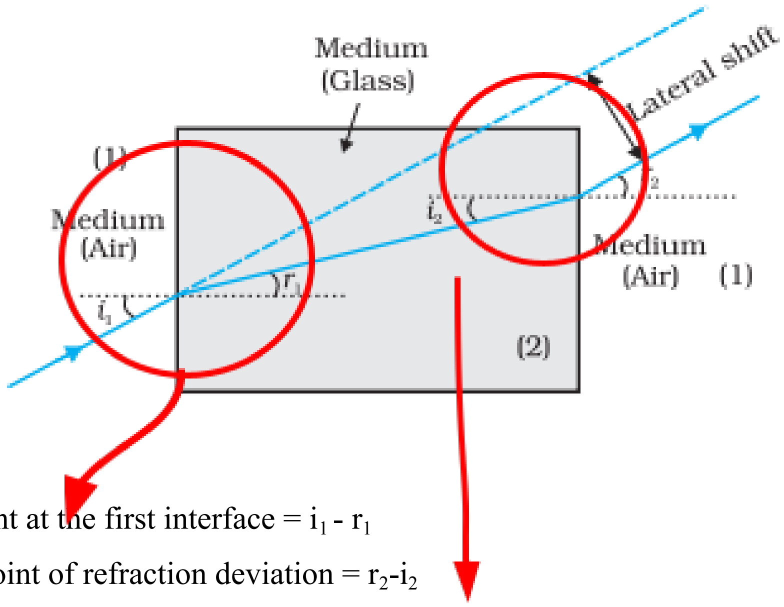
Emergent ray: the ray emerging from a medium is called emergent ray, it is the refracted ray emerging from a medium

Lateral shift or lateral displacement: light emerging from a parallel sided medium like a glass slab or water in a flat bottomed container (glass) held with the base horizontal, the emergent ray shifts from its original direction. The shift is sideways hence called lateral shift.

Deviation of emergent light-

Light its path on refraction the angle of deviation = angle of incidence - angle of refraction

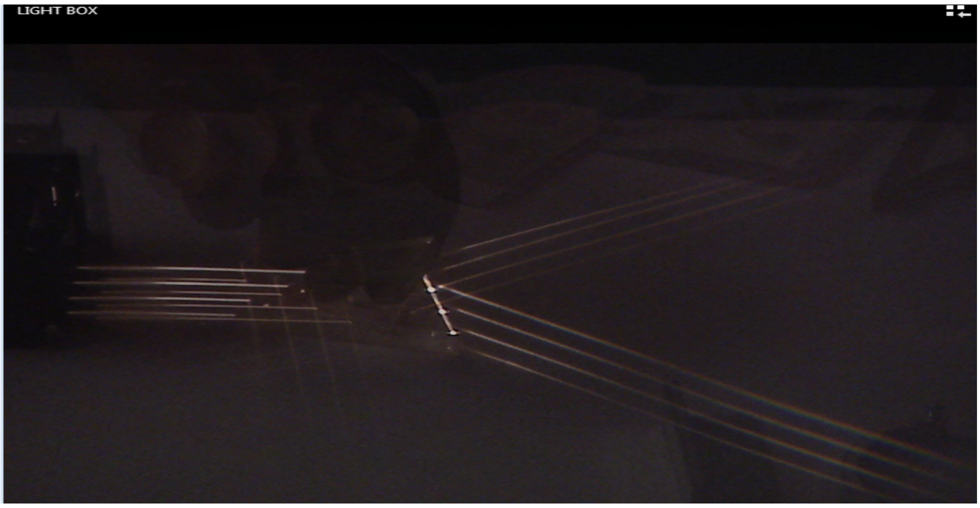
Light emerging from a non-parallel sided medium deviates from its original path



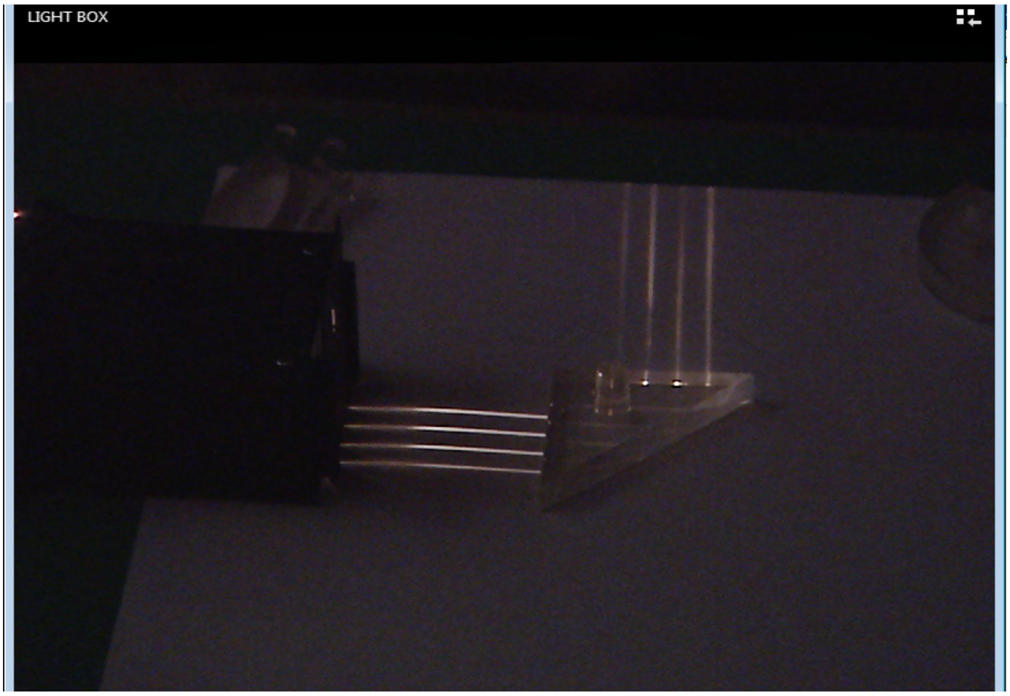
Deviation of light at the first interface = $i_1 - r_1$

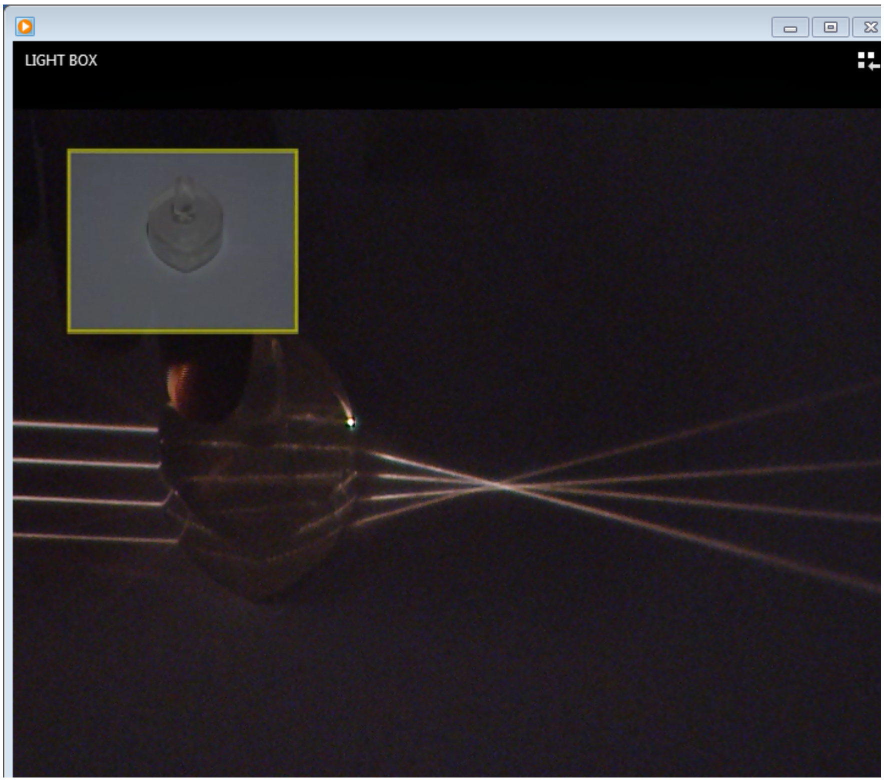
At the second point of refraction deviation = $r_2 - i_2$

Think About These



Check it out from the light box activity video





Watch the Video Light Box

Refractive Index

Speed of light in a medium depends upon the properties of that medium. We have seen above that it depends upon the optical density of the medium. The more optically dense a given medium is, the less is the speed of light in that medium. The optical density of a medium is indicated by a term called the refractive index of that medium.Refractive index of a medium is **a number** which indicates the factor by which the speed of light, in that medium, gets reduced with respect to its speed in vacuum. **In comparing two media, the one with the larger refractive index is optically denser medium than the other. The other medium of lower refractive index is optically rarer**.

We define it as follows:

Refractive index of a medium = n

$$= \frac{speed\ of\ light\ (c\ )in\ vacuum}{speed\ of\ light\ (v)in\ the\ medium}$$

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

Relative refractive index: - Consider light going from medium 1 to medium 2

Relative refractive index of medium 2 with respect to medium 1 is

$$n_{21} = \frac{n_2}{n_1}$$

$$\text{Or} \quad n_{21} = \frac{c/v_2}{c/v_1}$$

$$\text{or} \quad n_{21} = \frac{v_1}{v_2}$$

For example: refractive index of glass with respect to water =1.5

$$\frac{n_g}{n_w} = \frac{v_w}{v_g}$$

Velocity of light in water is greater than, that, in glass

Example

Refractive index of glass is 1.5. Find the speed of light in glass. Given: the speed of light in vacuum = 3×10^8 m/s)

Solution

$$\text{We have} \quad n = \frac{c}{v}$$

So $1.5 = 3\times10^8/v$

V = 2×10^8 m/s

Example

Refractive index of glass is 3/2 and the refractive index of water is 4/3.

- Find the refractive index of glass w.r.t. water.
- The ratio of speed in water as compared to speed in glass

Solution

Refractive index of glass with respect to water =

$$n_{gw} = \frac{n_g}{n_w} = \frac{v_w}{v_g}$$

= (3/2) / (4/3) = 9/8

If n_{21} is the refractive index of medium 2 with respect to medium 1 and n_{12} the refractive index of medium 1 with respect to medium 2, then it should be clear that

$$n_{21} = \frac{1}{n_{12}}$$

It also follows that if n_{32} is the refractive index of medium 3 with respect to medium 2

Then

$n_{32} = n_{31} \times n_{12}$,

Where, n_{31} is the refractive index of medium 3 with respect to medium 1.

Some elementary results based on the laws of refraction follow immediately, like the displacement from a parallel sided glass slab, **the bottom of a tank filled with water appears raised!**

Laws of Refraction of Light

When a beam of light encounters another transparent medium, a part of light gets reflected back into the first medium while the rest enters the other. A ray of light represents a beam. The direction of propagation of an obliquely incident ray of light that enters the other medium, changes at the interface of the two media.

Snell experimentally obtained the following laws of refraction:

- The incident ray, the refracted ray and the normal to the interface at the point of incidence, all lie in the same plane.
- The ratio of the sine of the angle of incidence to the sine of angle of refraction is constant. Remember that the angles of incidence (i) and refraction (r) are the angles that the incident and its refracted ray make with the normal, respectively. We have

$$n_{21} = \frac{\sin i}{\sin r}$$

$$\frac{n_2}{n_1} = \frac{\sin i}{\sin r}$$

$$n_1 \sin i = n_2 \sin r$$

Cause of Bending of Light Due to Refraction

We know that light propagates with different speeds in different media. When a ray of light goes from one medium to another it bends its path because of change in its speed. The more is the change in speed of light, as it goes from one medium to another; more will be the bending in its path.

According to Snell's law

$$\frac{n_2}{n_1} = \frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

When light goes from a **rarer medium to a denser medium**, its **speed decreases i.e. $v_2 < v_1$**.

Hence i > r

This means that **a ray of light, incident obliquely**, will bend towards the normal when it goes from an optically rarer medium to an optically denser medium.

When **light goes from an optically denser medium to an optically rarer medium**, its speed increases i.e. **$v_1 < v_2$.**

Hence i < r

This means that a ray of light, incident obliquely, will bend away from the normal when it goes from an optically denser medium to an optically rarer medium.

Note

- When a ray of light, incident obliquely, moves from an optically rarer medium to an optically denser medium it moves towards the normal.
- When a ray of light, incident obliquely, moves from an optically denser medium to an optically rarer medium it moves away from the normal.
- If light moves from rarer to denser medium, angle of refraction is less than angle of incidence

- If light moves from denser to rarer medium, angle of refraction is more than angle of incidence

Effect of refraction on the wavelength and frequency of the incident light

When a ray of monochromatic light (light of a single frequency) goes from one medium to another, its speed changes. However, **there is no change in its frequency, which may be regarded as a characteristic of the source**.

Now v= f λ (where λ is wavelength and f is frequency of light).

Hence for the two media

$$v_1 = f\lambda_1$$

$$v_2 = f\lambda_2$$

$$n_{21} = \frac{n_2}{n_1} = \frac{\sin i}{\sin r} = \frac{v_1}{v_2}$$

So the frequency remains the same but the wavelength changes. We will study this in greater detail in later modules of optics

Example

Refractive index of glass is 3/2 and the refractive index of water is 4/3. If the speed of light in water is 2.25 x 10^{8} m/s, find the speed of light in glass.

Solution

Refractive index of glass with respect to water $= \frac{n_g}{n_w} = \frac{v_w}{v_g}$

$$v_g = v_w\left(\frac{n_w}{n_g}\right) = \frac{4}{3} \times \frac{2}{3} \times 2.25\times10^{8} ms^{-1} = 1.95\times10^{8} ms^{-1}$$

Example

A ray of light is incident normally on a glass surface. Show that it will not bend from its path.

Solution

For the normally incident ray, we have angle i= 0

According to Snell's law

$n_1 \sin i = n_2 \sin r$

$n_1 \sin 0 = n_2 \sin r$

$0 = n_2 \sin r$

Since n_2 is not equal to zero

We would have

$$\sin r = 0$$

Thus $$r = 0$$

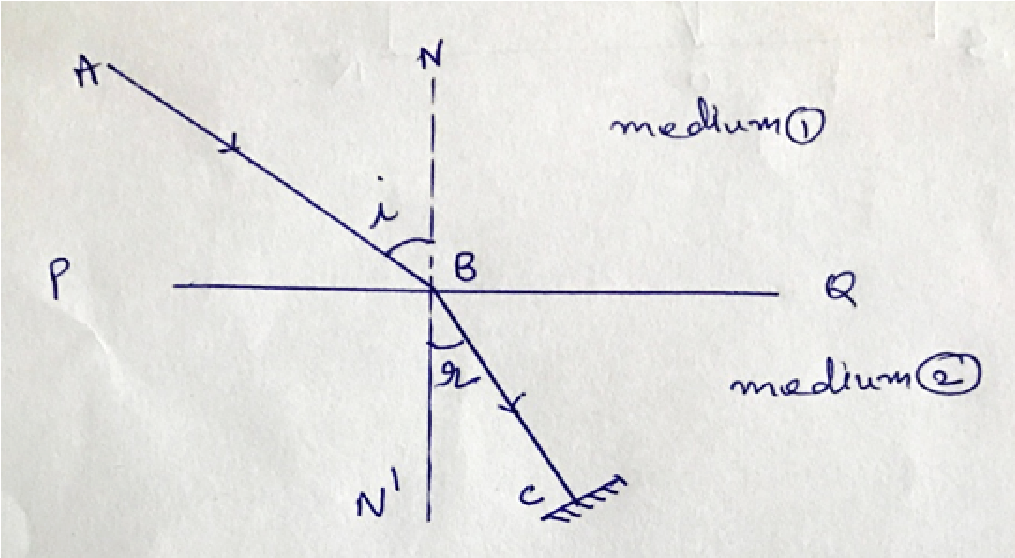
Hence there is no change in the path of the normally incident light ray. In other words, the ray of light will not bend when it is incident normally.

Example

Show that the refractive index of medium 2 w.r.t. medium 1 is reciprocal of the refractive index of medium 1 w.r.t. medium 2

Solution

Consider a ray of light AB going from medium 1 to medium 2. The ray AB is incident on a plane surface PQ separating the two media. Let the medium 1 be a rarer medium and the medium 2, a denser medium. It will bend towards the normal, so



BC is the refracted ray.

According to laws of refraction of light

$n_{21}=\frac{\sin i}{\sin r}$

Suppose the path of the ray BC is reversed by placing a plane mirror normal to BC.

Now angle of incidence = angle CBN' = r,

and angle of refraction = angle NBA= i

According to laws of refraction of light

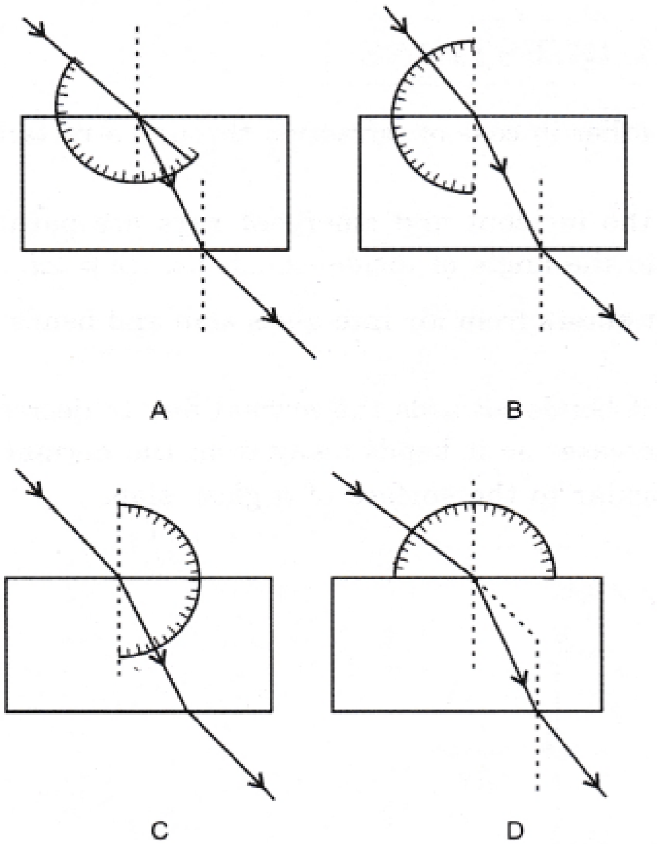
$n_{12} = \sin r / \sin i$

$n_{21} \times n_{12}$ = (sin i/sin r) ×(sin r /sin i) =1

Thus n_{21}= 1/ n_{12}

Example

Select the correct placing of the protractor to measure the angle of incidence on a glass slab



Solution

B, Angle of incidence is the angle between the incident ray and the normal

Refraction through a Parallel Sided Glass Slab, Lateral Displacement and Factors Affecting Lateral Displacement

Consider a rectangular glass slab of thickness (t). A ray of light PQ, propagating in air strikes the interface of air and glass at an angle of incidence 'i'. As light is going from a rarer to a denser medium, it bends towards the normal and moves along QR. The angle N'QR is the angle of refraction 'r'.

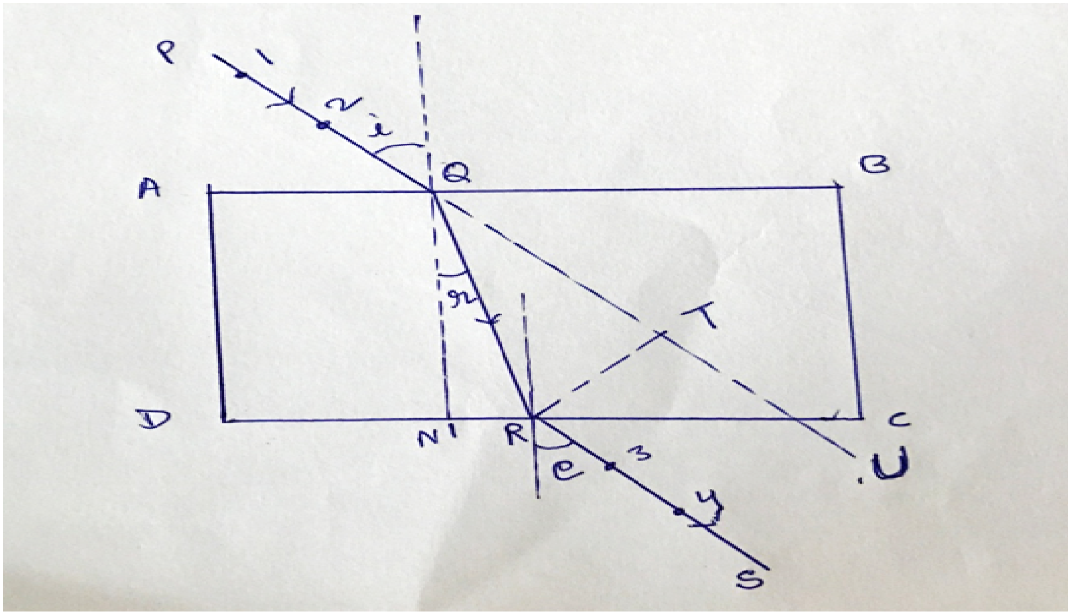
As the two opposite faces of the rectangular glass slab are parallel to each other, the refracted ray QR strikes the surface DC at an angle of incidence equal to 'r'. Now as light is going from glass to air i.e. from a denser medium to a rarer medium, it bends away from the normal. The ray of light QR which comes out of the glass slab after refraction is called the ‘emergent ray’. **The emergent ray QR is parallel to the incident ray as the two refracting surfaces are also parallel to each other.**

Thus the angle of incidence = angle of emergence

On producing the incident ray PQ, we will see that it is parallel to the emergent ray but displaced laterally. From the point R drop perpendicular RT on the produced incident ray. RT is called the lateral displacement produced by the glass slab placed in the path of the (obliquely incident -making an angle with the normal at the point of incidence) light ray.

The perpendicular distance, between the incident ray and the emergent ray, when light is incident obliquely on a parallel sided glass slab, is called lateral displacement or lateral shift.

Expression for Lateral Shift



In right angled triangle QTR,

$\angle TQR = (i - r)$

$Sin\,(i - r) = (RT/QR) = d/QR,$

Where **d = RT, is lateral displacement**

Thus $d = QR\,sin\,(i - r)$

In right angle triangle N’QR, we have

$cos\,r = (QN'/\,QR) = t/QR$

S0, $QR = (t/cos\,r)$

Substituting the value of QR we get

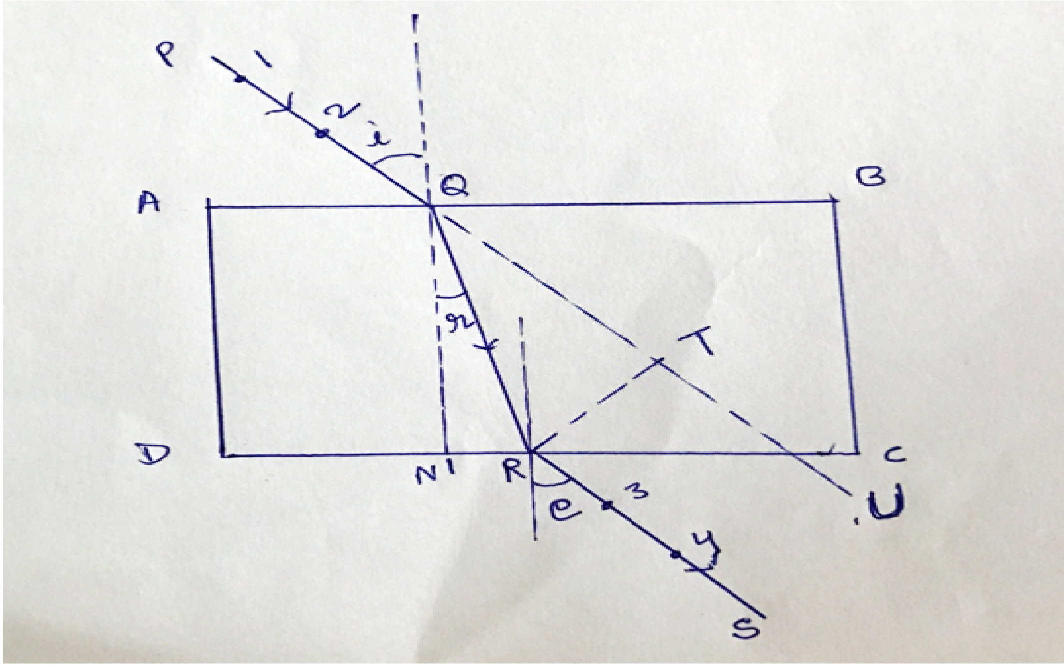
$d = t\,(sec\,r)\,sin\,(i - r)$

This expression leads us to conclude that the lateral shift, produced by a rectangular glass slab, increases with

- Increase in thickness of the glass slab
- Increase in angle of incidence
- Increase in refractive index of the glass used for making the slab

To Observe Refraction and Lateral Displacement of a Beam of Light Incident on a Glass Slab

- Fix a white sheet of paper on a drawing board. **To ensure that the paper does not move accidently and is firmly fixed**
- Draw a line parallel to the length of the paper, mark a point Q on it
  To get more space for the experiment
- Draw normal at Q ,NQN'
- Put the glass slab along the line adjusting the point Q to be about 2 cm from edge A and draw its boundary A B C D with a sharp pencil. **The boundary is marked so that we can place the glass slab on the same position.**
- Draw a line PQ, making an angle, say 45 ^{0}, with normal. This angle will be the angle of incidence.



- Fix two pins (pin 1 and 2), on the line PQ, 2 to 3 cm apart from each other, and also from the glass slab. Ensure that the pins are vertical.

- See the image of the lower ends of the pins from the face CD and fix two more pins (pin 3 and pin 4) such that the lower ends of all the four pins lie along a straight line.
- Ensure that these two pins are also 2 to 3 cm apart from each other and also the glass slab. This is to ensure that you see along the line joining the two pins, this line is the ray represented by the pins and you see through the slab

The images of the pins should be seen and not the pins

To trace the emergent ray, we need to see along the line through the glass slab, we must also close one eye and trace the rays with only one eye

- Remove the pins and encircle the pin pricks.

  This is done to mark the location of the fine hole created by the pin.
- Remove the glass slab and join the pin pricks (3) and (4).

  This line/ray will represent the emergent ray; the point of emergence is R
- **Join QR to represent the refracted ray**.
- Draw normal at the point R on the face CD
- Measure the angle of refraction N'QR = r
- Measure the angle of emergence e.
- Produce PQ. Draw RT perpendicular to QU.
- **RT is the lateral displacement**
- We will see that

  $\angle i = \angle e$

  $\angle I > \angle r$

Incident ray PQ is laterally displaced.

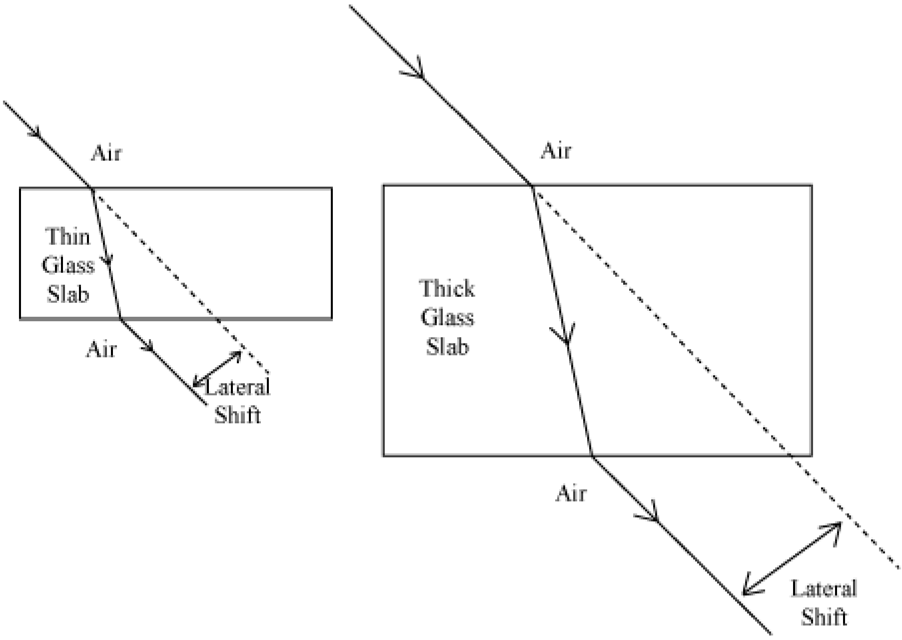
- Find the value of the ratio (sin i/ sin r).

This gives the refractive index of the glass used for making the given slab.
https://www.youtube.com/watch?v=KuCUaE6e1Oo

Example

Draw ray diagrams to show that the lateral shift produced by a thick glass slab is greater than a thin glass slab

Solution



Formation of Image in a Glass Slab

When we look through a glass bottle filled with water you see images of objects and not the objects.

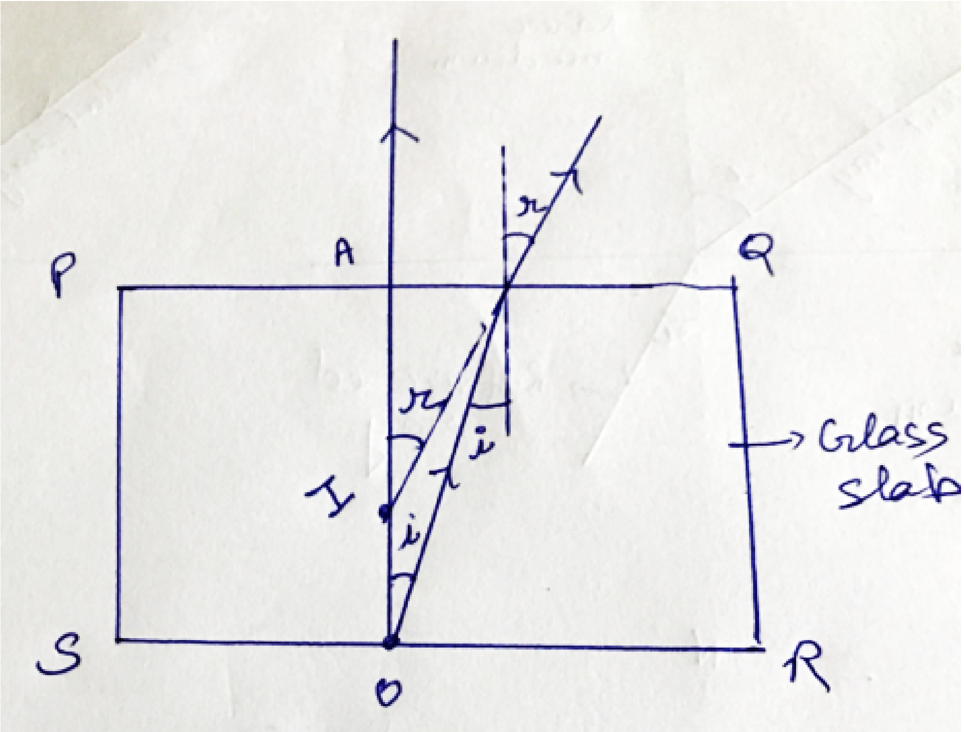
We see the image of the fish in a glass bowl

Let us use ray optics to show the formation of image

Consider a glass slab PQRS of thickness t placed on a thick white paper kept on a look from above almost normally, we will see the image I.Let us first try to understand the formation of image.The ray of light OA strikes normal to the surface and goes straight without bending as its angle of incidence is zero degree.The ray of light OB, which strikes the interface obliquely, will go away from normal as it is going from denser medium to a rarer medium.

Both the refracted rays appear to come from the point I;The point I is the virtual image of the object O.

We see that the object point O seems to be raised, when viewed through a glass slab.



Example

A light ray goes from the air into the water. If the angle of incidence is 34^0

What is the angle of refraction?

Solution

$$n_{wa} = \frac{\sin i}{\sin r} = \frac{\sin 34}{\sin r}$$

$$sinr = \frac{\sin 34}{1.33} = \frac{0.529}{1.33} = 0.397$$

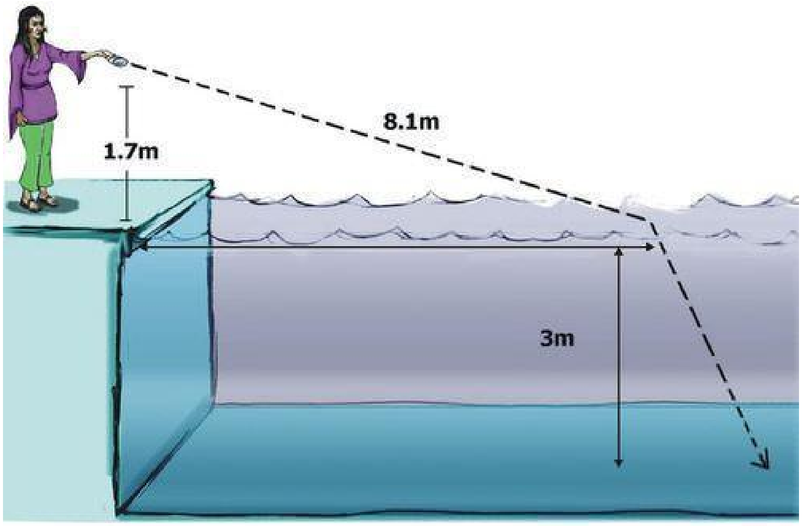
angle of refraction r = $\sin^{-1}$ 0.397 = 23.3^0

Example

Reena stands at the edge of a swimming pool 3.0 m deep. She shines a laser at a height of 1.7m. The laser beam strikes the water surface of the pool 8.1 m from the source.

- Draw a diagram of this situation. Label all known lengths.
- How far from the edge of the pool will the light hit the bottom?

Solution



Hint- Calculate the angle of incidence

Angle of refraction

Distance of point of strike of laser beam on the base of the pool

Try This

You are to design an experiment to **determine the index of refraction of an unknown liquid.** You have a small square container of the liquid, the sides of which are made of transparent thin plastic. In addition you have a screen, laser, ruler and protractors. Design the experiment. Give a detailed procedure; include a diagram of the experiment. Tell which equations you would use and give some sample calculations. Finally, tell in detail what level of accuracy you can expect and explain the causes of lab error.

Use a LDR to Study the Variation in the Intensity of Light, Emerging through Different Transparent Sheets of Different Colours

Apparatus required

- LDR(Light Dependent Resistance)
- multimeter,
- 100W bulb,
- transparent colourless sheet,
- transparent sheets of different colours (cellophane paper)

Principle The intensity of light decreases on refraction as the medium absorbs some energy

Procedure

- Set the multimeter to measure resistance.
- Connect the given LDR to the multimeter.
- Fix the bulb at a distance of about 50cm from the LDR.
- Switch the bulb on,and note down the resistance from the multimeter.
- Insert the colourless transparent sheet in between the bulb and the LDR.
- Again note down the value of resistance from the multimeter.
- Do you see any change in the value of the resistance?
- If yes, try to explain it.
- Replace the colourless transparent sheet with a blue colour transparent sheet of the same thickness as the colourless sheet and at the same position.
- Note down the value of the resistance from the multimeter.
- Repeat the steps 9 and 10 with transparent sheets of different colours.
- Prepare a table showing the colour of the thin sheet and the corresponding resistance.
- Analyze the data you have collected.

You may use the FUN activity as a project to also study the variation in intensity of light emerging from a glass slab with angle of incidence.

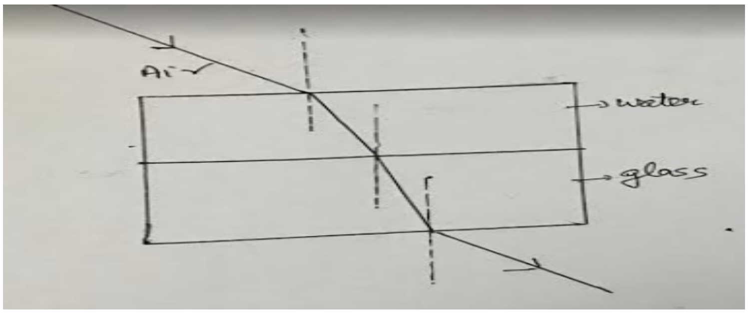
Summary

- The phenomenon of bending of incident light from its path when it encounters another transparent medium is called refraction of light.
- The phenomenon, associated with the change in speed of light as it goes from one medium to another.
- For a given pair of media, the medium in which light propagates faster, is called optically rarer medium and the medium in which light propagates slower, is called optically denser medium
- When a ray of light, incident obliquely, moves from an optically rarer medium to an optically denser medium, it bends towards the normal.
- When a ray of light, incident obliquely, moves from an optically denser medium to an optically rarer medium, it bends away from the normal.

- When a ray of light goes from an optically rarer to an optically denser medium, angle of refraction is less than the angle of incidence
- When a ray of light goes from an optically denser to an optically rarer medium, angle of refraction is more than the angle of incidence.
- Laws of refraction of light: -
  - The incident ray, the refracted ray, and the normal at the point of incidence, all lie in the same plane.
  - The ratio, of the sine of the angle of incidence to the sine of the angle of refraction r, for a given pair of two media is constant for a given wavelength of light; it is equal to the refractive index of the second medium with respect to the first medium. We call this law Snell's law.
- We can put Snell's law in the mathematical form:

$$n_1 \sin i = n_2 \sin r$$

- When a ray of light passes through a parallel sided glass slab,
  - The emergent ray is parallel to the incident ray, i.e., the angle of incidence = angle of emergence
- The emergent ray is laterally displaced. The lateral shift, produced by a glass slab increases with
  - Increase in thickness of the glass slab
  - Increase in angle of incidence
  - Increase in refractive index of the glass used for making the slab
- When a ray of light undergoes refraction through a combination of three media i.e. air, water and glass (all boundaries are parallel planes) , then



$$n_{wa} \times n_{gw} \times n_{ag} = 1$$

$$or\ n_{gw} = \frac{n_{ga}}{n_{wa}}$$