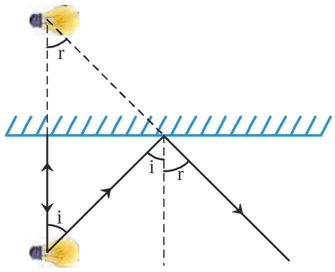
CHAPTER 10

LIGHT: REFLECTION AND REFRACTION FROM PLANE SURFACE



In class VII you have done several experiments using a light source, mirror(s) and black paper. All those experiments were done with light rays. You would have observed that an object casts a shadow when it blocks the path of the light ray. The properties of the shadow depend on the opacity of the object. Transparent objects do not cast shadows. However, in reality, most of the object are neither truly transparent nor truly opaque. When light falls on an object, some of the light gets reflected and some of it is refracted while the remaining is absorbed by the object.

You have also observed by doing experiments, that light travels in simple straight path. Is this the reason why we cannot see an object placed in the other room?

In this chapter, we will learn about reflection and refraction of light at plane surfaces. We will represent a light ray with a simple line and study the formation of shadows and images after reflection and refraction of light. We shall use geometry to find the position, shape and nature of the image. But, before that, let's do a simple experiment about the formation of shadow.

Activity-1

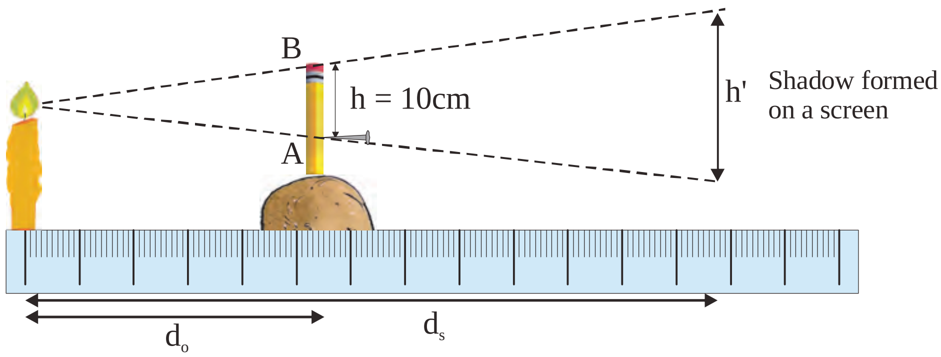


Figure-1

To measure the length of shadow of a pencil, insert the pencil perpendicular in a piece of potato. Insert a pin at a height 10 cm below the head of pencil as shown in the diagram. The pin should be attached perpendicular using glue or wax. Now, observe the change in the shadow varying the distance of light source and the screen from the pencil. What do you see?

- If we decrease the distance between the light source and the pencil or we increase the distance between the screen and pencil, then we will observe that the size of the shadow increases and vice versa.
- On keeping the pencil and screen fixed fixed and bringing the source near it, we will find that the shadow length increases.
- If we keep the pencil and source fixed, and move the screen away then the size of the shadow increases and it decreases when we move the screen close to the pencil.

The ratio between the size of the shadow and the distance between the shadow and source is equal to ratio of the size of the object and distance between the object and source.

i.e;

$$\frac{\text{Length of the object}}{\text{Distance between object and source}} = \frac{\text{Length of the shadow}}{\text{Distance between image and source}}$$

$$\frac{h}{d_o} = \frac{h'}{d_s} \Rightarrow h' = \frac{h d_s}{d_o}$$

Use the above activity to fill the following table - Size of object (h) = 10 cm

Formula for calculating size of shadow: $h' = \frac{h d_s}{d_o} = 10 \times \frac{d_s}{d_o} = 10 * (d_s/d_o)$

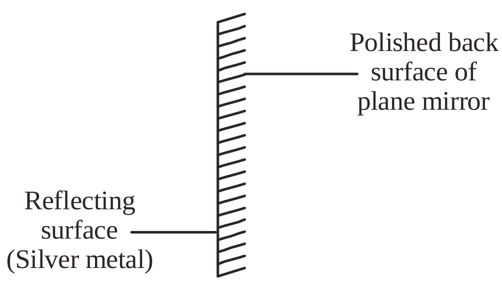
S. No.	Distance between object and source(d_0)	Distance between object and screen(d_s)	Size of shadow of object (h')	Size of shadow using formula
1.	20 cm.	10 cm.		
2.	20 cm.	20 cm.		
3.	30 cm.	10 cm.		
4.	30 cm.	20 cm.		
5.	40 cm.	10 cm.		
6.	40 cm.	20 cm.		

Did you verify the formula?

Now you can predict the size of shadow in any case.

10.1 Image formation on plane mirror by reflection

Any plain and shiny surface works as a plane mirror. A Plain mirror consists of a thin layer of silver sandwiched between a transparent glass on one side and a protective paint coating on the other side. Silver is a very good reflector of light. So, it acts as a reflecting surface in the mirror.



According to laws of reflection-

1. Angle of incidence is always equal to the angle of reflection.
2. Incident ray, normal and the reflected ray lie in the same plane.

Let's understand these laws through some activities.

10.1.1 Study of laws of reflection

1. Angle of incidence is always equal to the angle of reflection.

To understand this law, we will do practical number 1 given on at the end of the book.

2. Incident ray, normal and the reflected ray lie in the same plane.

The point, at which incident ray falls on the mirror is called the Incidence Point, where a line can be drawn perpendicular to the surface of the mirror. This line is known as a normal line. Reflected ray lies in the same plane as the incident ray and normal (in this case the plane of paper). This is the second law of reflection. In the figure given below, mirror is fixed vertically. Incident ray is shown in the red colour and the normal plane is shown in the yellow colour. According to the second law of reflection reflected ray (yellow colour) would also lie in the same plane.

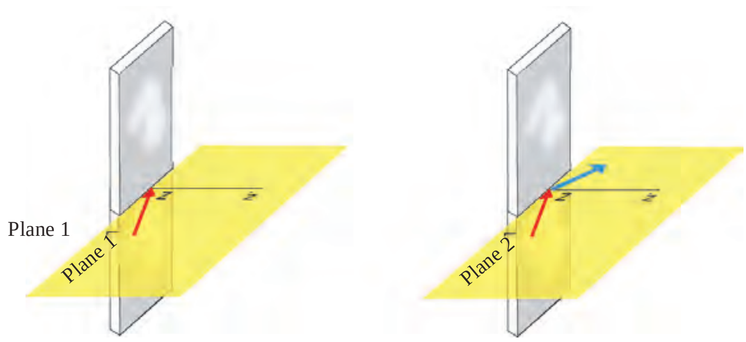


Figure-3 (a)

If we rotate the mirror as shown below then what would be its effect on the normal line?

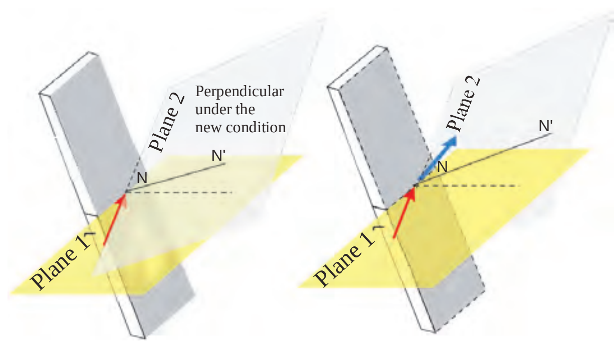


Figure-3 (b)

In order to understand the direction of the normal glue a matchstick to a plane mirror. Now rotate the mirror and observe the change in the direction of the matchstick.

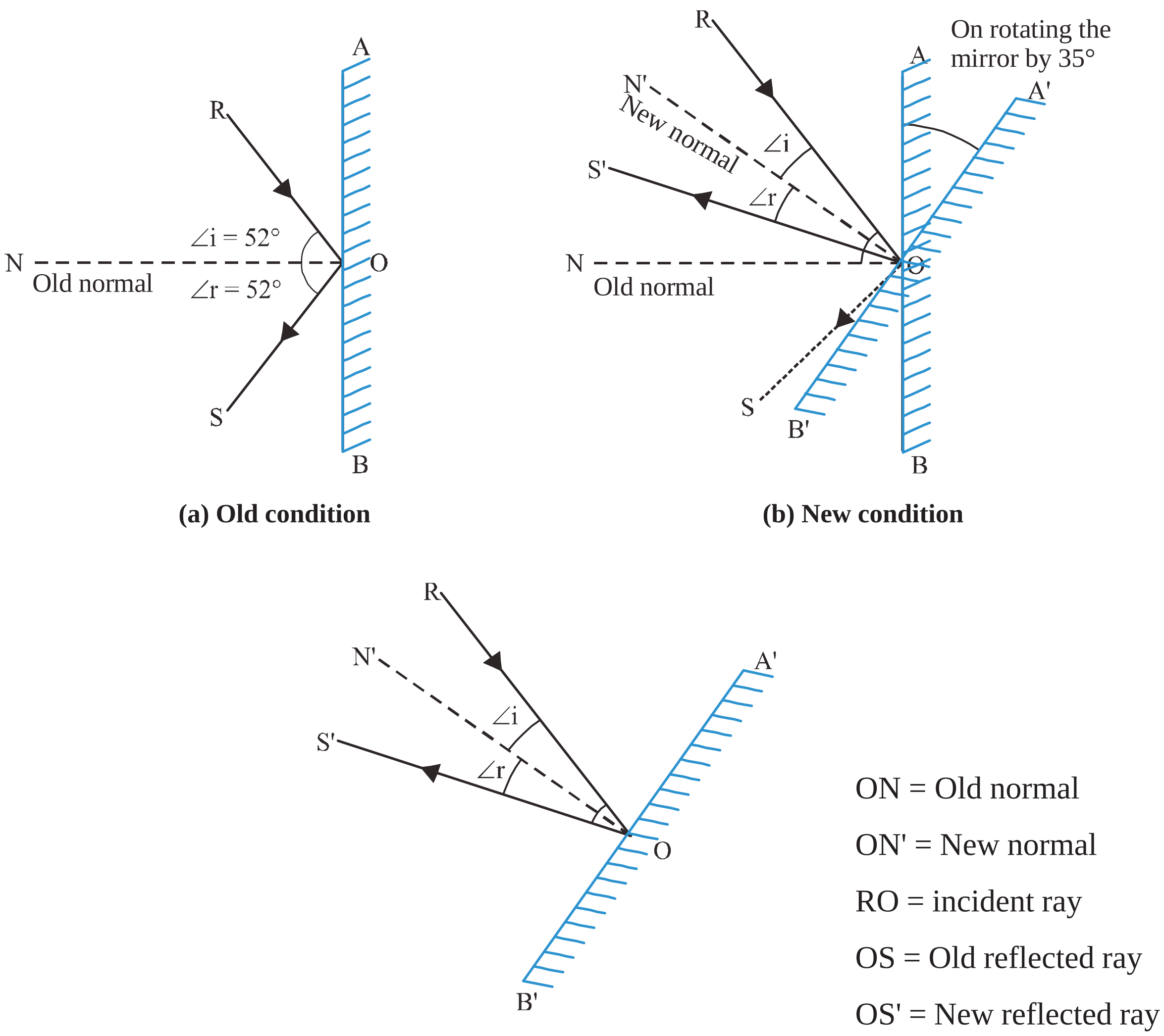
10.1.2 Effect of rotation of plane mirror on reflected rays

If we rotate the plane mirror by 35° then what would be the direction of normal on mirror? By how much angle reflected ray will rotate?

Question 1: A light ray falls on a plane mirror making an angle of 52° with normal AB. Now, keeping incident ray fixed, rotate the plane mirror byθ =35° at the point of incidence. The normal also gets rotated by an angle θ from its original direction at the point of incidence.

New position of mirror and normal will be A'B' and ON' respectively. As we can see, the angle of incidence decreases with respect to the initial condition.

Now can you tell, what will be the angle of reflection?



(a) Old condition

(b) New condition

(c) On moving by θ = 35°

Figure-4

Solution: Angle of incidence from new normal = $\angle i - 35° = 52° - 35° = 17°$

According to law of reflection, $\angle i = \angle r$

So, angle of reflection from new normal = 17°

Difference between ($\angle SON$) and ($\angle S'ON'$) = 52 + 35 – 17 = 70°

i.e; our new angle of reflection = 70° = 2 × 35°

Therefore, when the plane mirror is rotated by an angle θ, the reflected ray gets rotated by an angle of 2θ°.

Activity-2

S.No.	Angle of incidence	Rotating the mirror by θ°	Reflected angle in new condition

10.2 Formation of image of point object by plane mirror

Consider a point object O placed infront of a plane mirror. Light rays from the object are being reflected at the mirror. When we look through a mirror it appears as if the reflected rays are coming from the point I. Therefore, point I is the reflection of point O. Such images are called virtual image.

Virtual image can be drawn by producing the reflected rays in backward direction till these rays meet at a point.

The reflected rays reaching our eyes appear to emerge from a point behind the mirror. The image I is formed at the same distance as the object 'O' from the mirror. We will prove this using geometry.

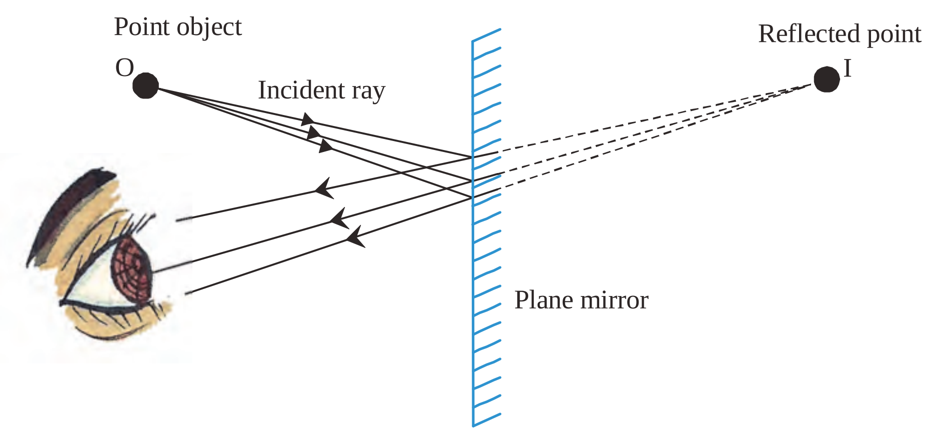


Figure-5: Point formed by plance mirror is virtual image of the objcts

10.2.1 Distance of image formed by plane mirror

If you stand in front of a plane mirror, then you will observe that your image is formed at same distance behind the mirror as you are from the mirror. To see this, place a meter scale between you and the mirror. At what distance from the meter scale is your image formed? When you move towards the mirror where does your image move? What happens when you move away from the mirror?

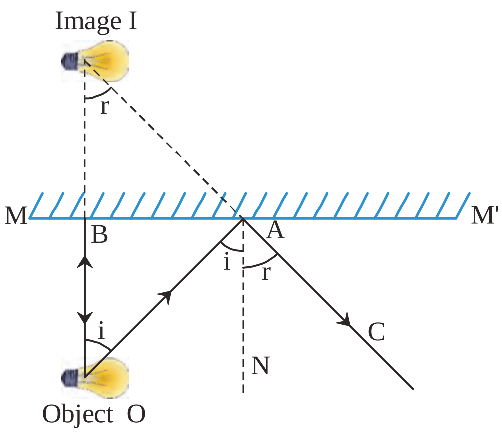


Figure-6

Consider an object, at a distance OB from the plane mirror MM'. AN is normal to the mirror.According to the law of reflection, light ray OA falls on the mirror and gets reflected in the direction AC. Another ray OB, falls normally on the mirror and after reflection it comes back in the same direction. If we produce the rays AC & OB backward behind the mirror, then they will meet at a point I. Therefore, the virtual image of O is formed at I.

According to the figure,

If angle of incidence is $\angle OAN = (\angle i)$

then $(\angle BOA) = (\angle i)$ (alternate interior angle) ....(1)

and if angle of reflection is (NAC) = $(\angle r)$

then $(\angle BIA) = (\angle r)$ (corresponding angles) ....(2)

according to law of reflection $(\angle i) = (\angle r)$ ......(3)

therefore from equation (1),(2) and (3)

in ΔBOA and ΔBIA

$(\angle BOA) = (\angle BIA)$ $[(\angle i) = (\angle r)]$

$(\angle OBA) = (\angle IBA)$ (90° formed by normal)

AB = AB (common side)

$(\angle OAB) = (\angle IAB)$ (since sum of all angles in a triangle is 180°)

so $(\angle OAB) \equiv (\angle IAB)$ and by theorem, corresponding parts of congruent triangles are congruent (CPCTC)

Therefore, OB = BI

Therefore, the distance of image from the plane mirror is same as the distance of object from the mirror.

Question 2: If an object is placed at a distance of 30 cm from a plane mirror. Then find the total distance between object and image formed by the plane mirror.

Solution: Distance of object from plane mirror = 30cm

Object after reflection from plane mirror forms image at a distance same as the distance between object and mirror from the mirror

So, the distance of image from the mirror = the distance of object from the mirror.

Distance between the object and the image: = 30 cm + 30 cm = 60 cm

Therefore, the total distance between the object and the image is 60 cm.

10.3 Image of Extended object at plane Mirror

Consider an object OO' placed in front of a mirror. According to the laws of reflection, incident and reflected rays would be as shown in the figure.

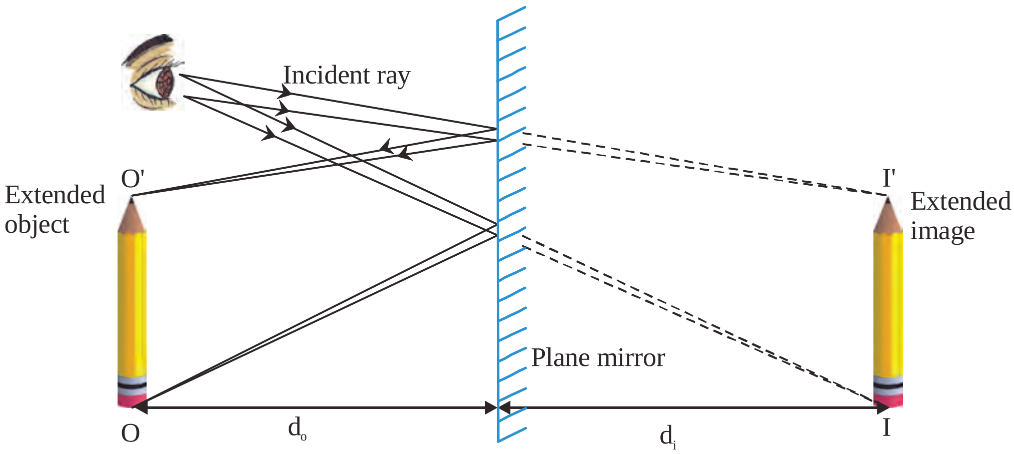


Figure-7: Virtual image I I' of object O O' formed by plane mirror

Light coming from O and O' gets reflected from the mirror and appears as if they are coming from I and I'. That means I is the image of O and I' is the image of O'. All the points between the O and O' will also form their image between I and I'.

When you look yourself in the mirror, do you see any difference in the size of the image and yourself? Is the height of the image same as your height?

Hold a pencil in your hand and look at the image in the mirror. Now move the pencil away from the mirror towards your eye. Now, can you see any difference in the size of the image?

In order to understand this let's consider an example.

An observer is standing at a point O and is looking at two trees of same height.

The Tree closer to the observer will look bigger than the one away from him. This is because the light from far away tree will make a smaller angle than the one closer to the observer. Our eyes determine the size of the object based on the angle made by the light from the object.

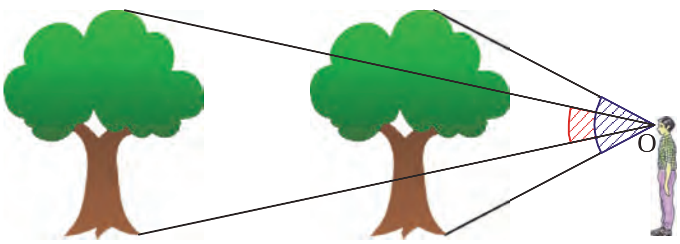


Figure-8 (a): The view angle in cross on coming closer to the object

Therefore, when we bring the pencil closer to us, its image is formed further behind the mirror. Because of this, distance between the image and our eye increases, which leads to decrease in the angle made by the image with our eye. This result is that the object looks smaller.

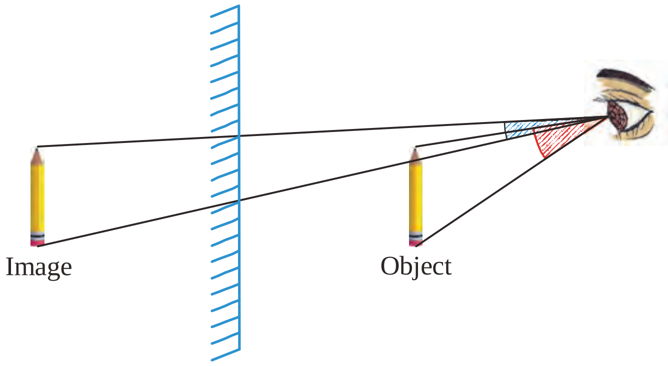


Figure-8 (b)

10.3.1 What is the Minimum Size of Mirror required to view a full Image?

In the given figure, we can see that PQ part of the mirror MM' is sufficient to show our full image if it is kept at a height of QM'.

Observe ΔHPE and ΔEQF.

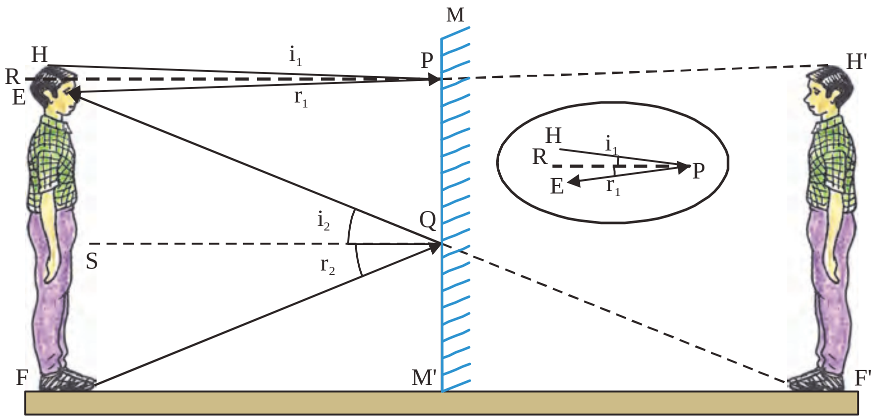


Figure-9

Light ray coming from our head H gets reflected at P and enters our eye E. We see the image of our head at H' behind the mirror. In the same manner, light coming from our leg F gets reflected at Q returns to our eye E and we see the image at F'. So, we can see, that in order to form our complete image, only PQ part of the mirror is used.

In (ΔHPE) and (ΔEQF) draw normal PR and QS on HF :

Since, $(\Delta i_1) = (\Delta r_1)$

And $(\Delta i_2) = (\Delta r_2)$ (according to laws of reflection)

Hence, $HR = RE = \dfrac{HE}{2}$ ...(1)

And $SF = SE = \dfrac{EF}{2}$ ...(2)

Now PQ = RS,

PQ = RE + ES

$$PQ = \frac{HE}{2} + \frac{EF}{2}$$

$$PQ = \frac{1}{2}\,[HE + EF]$$

$$= \frac{1}{2}\,[HF]$$

So, the useful part of the mirror is half the height of person who is standing infront of the mirror.

And since QM' = SF

$$QM' = \frac{EF}{2}$$

Therefore, the mirror needs to be placed at the level, half the level of eye.

Discussion:

Discuss the properties of image formed by a plane mirror.

Question 3: A person is 160 cm tall. What would be the length of mirror if he/she wants to see his/her full image.

Solution: Height of person = 160cm

As we have discussed earlier if a person wants to see his /her full image then the length of mirror will be half of the height of a person.

$$\text{So, length of mirror} = \frac{1}{2}\text{ height of a person}$$

$$= \frac{1}{2} \times 160$$

$$= 80 \text{ cm}$$

Therefore, a person whose height is 160 cm needs a mirror of 80 cm to see his/her full image.

10.4 Multiple reflections

We know that a single plane mirror can make only one image. What will happen if we combine two plane mirrors?

Place two mirrors at right angle to each other. Place a coin between these mirrors and see how many images are formed?

As shown in the figure, image of object O is formed at O_1 due to mirror 1. In the same way mirror 2 forms the image of O at O_2.

Mirror 2 gets reflected from mirror 1 and forms its image behind mirror 1. This is a virtual image of mirror 2. This virtual mirror will inturn reflect the image at O_1 to O_3. In the same manner virtual image of mirror 1, formed from mirror 2, will act as a virtual mirror and will reflect the virtual image O_2 to O_3.

Hence, virtual image of any object can act like a virtual object and can give virtual reflection. Kaleidoscope works on a similar principle.

Now arrange the mirror so that they form angles 30°, 45°, 60°, 120°, 180° etc. with each other. In each case, how many images are formed? How many are formed when mirrors are parallel to each other?

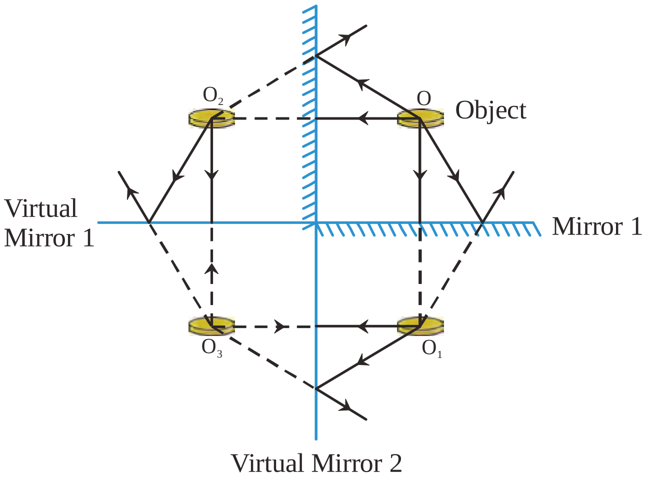


Figure-10

You will find in your observation that the number of reflections depends on the angle between the mirror.

$$\boxed{\text{Number of Images} = \frac{360}{\theta} - 1}$$

If the angle between both mirrors is 90° then $\frac{360}{90} - 1 = 1 = 4 - 1 = 3$ Images will be formed.

10.5 Refraction of light from plane surface.

In daily life, you must have seen many examples of refraction.

You have seen that the base of a vessel filled with water seems to be upraised. Do you know why this happens?

If, instead of water, we use another fluid like kerosene oil or turpentine oil, will the base of vessel seems to be upraised by same height as water?

Insert a pencil or spoon in a glass filled with water. Pencil appears to be bend. We will study the concept behind this by doing an activity.

Activity - 2

Put a bowl on a table. Put a coin on bottom of bowl. Ask your friend to stand near the table and watch the bowl. Now ask her to move away from the table so that the coin disappears, and stand at that point.

Now, pour water in the bowl without disturbing the coin.

Is your friend able to see the coin from that place now? How's that possible?

Due to refraction of light in water the coin seems to be upraised from its real position. Actually, a virtual image of the coin is seen by your friend.

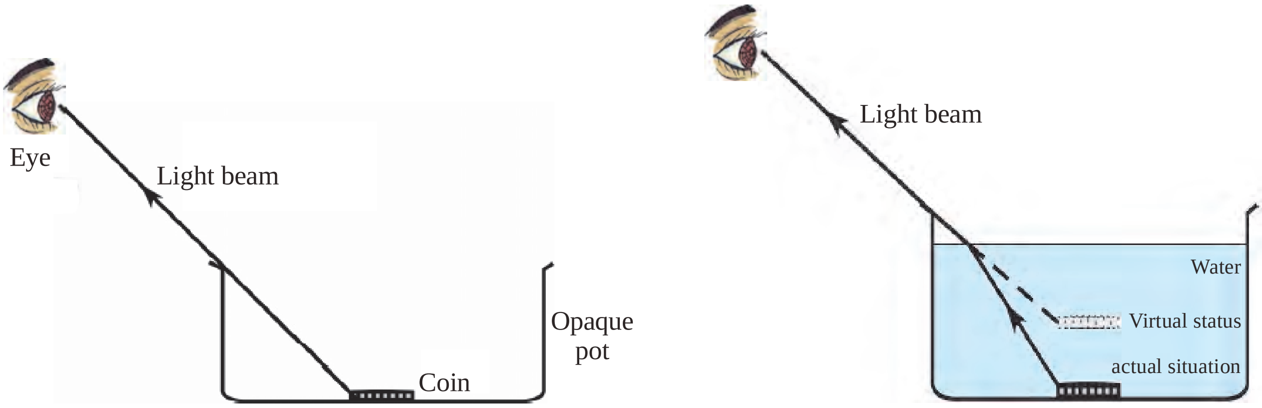


Figure-11: Coin appears upraised due to refraction of light

When light ray moves in a medium, it follows a straight line path. But what happens when light passes from one medium to another? What happens to the straight line path at the surface of two me diums? It seems that upon entering the second medium with some inclination, light changes its direction of propagation.

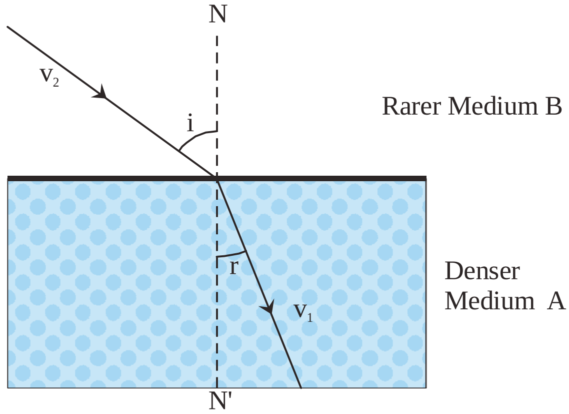


Figure-12 (a): Refracted ray bends towards normal on going from lighter to denser medium

Light ray changes its velocity at the boundary of two medium and bends from the straight line path. This is known as refraction of light. If light is incident normal to the surface, then there is no change after refraction.

When light ray passes from Optically rarer medium to Optically denser medium, then light bends towards the normal to the boundary of the media.

Can you tell which side the refracted ray will bend, towards the normal or away from the normal, going from denser to rarer medium? Tell by observing the given figure and discus the reason behind it.

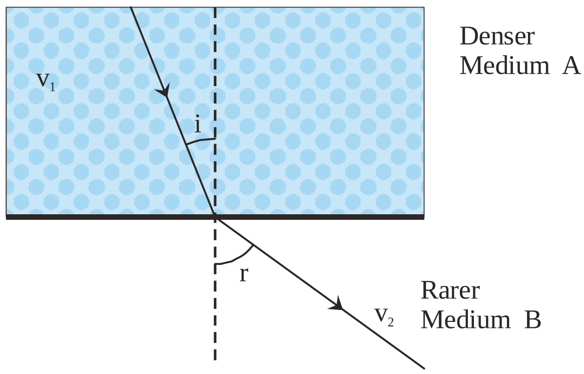


Figure-12 (b): Refracted ray bends way from the normal on going from denser to rarer medium

The angle of incidence ($\angle$i) is defined as the angle between the incident ray and normal, the angle between normal and the refracted ray is called angle of refraction ($\angle$r).

In this section we will are using "rarer medium" and "denser medium". This has reference to optical density. Optical is different from mass density. A medium of high refractive index has more optical density.

Can you tell while going from denser medium to rarer medium which angle will be greater ($\angle$i) or ($\angle$r) fig. 12(b).

Figure-12(a) Medium A is denser than medium B then speed of light in medium B (v_2) will be greater than speed of light in medium A (v_1).

10.5.1 Refractive index

We have seen that the speed of light is different in different transparent mediums. In a vacuum the speed of light is 3×10^8 m/s, which is greater than that in any other medium. In the air, the speed of light is little less than that in vacuum.

If the speed of light is 'v' in a medium and 'c' in vacuum, then, the ratio of the speed of light in vacuum to speed of light in the medium is called 'absolute refractive index' of that medium. We denote this by 'n'.

$$\text{Absolute refractive index} = \frac{\text{speed of light in vacuum}}{\text{speed of light in medium}}$$

ie. $n = c/v$

Question 4: If the absolute refractive index of water is $\frac{4}{3}$, then find the speed of light in water?

Solution: Refractive index of water = $\frac{4}{3}$

Speed of light in vacuum $c = 3\times10^8$ m/sec

Speed of light in water v = ?

We know that-

$$\text{Refractive index of medium} = \frac{\text{speed of light in vacuum}}{\text{speed of light in water}}$$

$$n_w = \frac{c}{v_w}$$

$$\frac{4}{3} = \frac{3\times10^8 m/s}{v_w}$$

$$v_w = \frac{3\times3\times10^8 m/s}{4}$$

$$v_w = \frac{9\times10^8 m/s}{4}$$

$$= 2.25\times10^8 \text{ m/s}$$

so speed of light in water will be 2.25×10^8 m/sec.

Refractive index of a material gives us the idea of how fast or slow the light is moving in that material. Speed of light will be less in the material of higher refractive index.

In the following table, the refractive index and the absolute density of different materials are given. Using $n = \frac{c}{v}$ we can calculate the speed of light in different mediums. Complete the table:

Table 1: refractive index and absolute density of some materials

S. No.	Material (medium)	Refractive index	Absolute density	Speed of light
1	Diamond	2.42	3.52	1.24×10^8 m/s
2	Pliant glass	1.64	2.9–4.5	1.83×10^8 m/s
3	Crown glass	1.52	2.5–2.7	……………………..
4	Simple glass	1.50	2.5	……………………..
5	water	1.33	1.00	……………………..
6	ice	1.31	0.92	……………………..

10.5.2 Relative refractive index

The ratio of speed of light in the first medium and speed of light in the second medium is called relative refractive index. We denote this by ${}_1\mu_2$ or n_{21}.

$$n_{21} = \frac{\text{speed of light in first medium}}{\text{speed of light in second medium}} \qquad \text{....................(1)}$$

$$n_{21} = \frac{v_1}{v_2} \qquad \text{Eq. (2)}$$

Where v_1 is speed of light in the first medium and v_2 is the speed of light in the second medium.

If we divide by c in eq. (2) in denominator and numerator

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

$$= \frac{v_1}{c} \times \frac{c}{v_2}$$

$$= \frac{1}{n_1} \times n_2$$

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

Thus, relative refractive index $(n_{21}) = \dfrac{\text{refractive index of second medium}}{\text{refractive index of first medium}} \; \dfrac{(n_2)}{(n_1)}$

$$n_{21} = \frac{n_2}{n_1} \qquad \text{Eq. (3)}$$

Think

Does refractive index depend on the angle of incidence?

Question 5: If the refractive index of water is 1.33 and refractive index of glass is 1.5 then find ($_wn_g$) refractive index of glass with respect to water?

$$=\frac{n_g}{n_w}=\frac{1.5}{1.33}=1.13$$

And refractive index of water with respect to glass $_gn_w=\frac{n_w}{n_g}=\frac{1.33}{1.5}=0.89$ (approximately)

Remark: We can see above that;

$$\frac{n_g}{n_w}\times\frac{n_w}{n_g}=1$$

$_gn_w \times {}_wn_g = 1$ or $_1n_2 \times {}_2n_1 = 1$

therefore,

$$_1n_2 = \frac{1}{_2n_1}$$

Remember:

- Absolute refractive index of a medium is always greater than one because speed of light in vacuum is greater than speed of light in any other medium.
- Refractive index of air is 1.003 but for simplicity we take it as 1.

10.5.3 Refraction rules

Experiment: To determine relation between angle of incidence and angle of refraction.

Materials required: Drawing board, white chart sheet, drawing pins, pins, rectangular glass slab, pencil, scale, and protractor.

Procedure: Take white chart sheet and fix it on drawing board using drawing pins. Place the rectangular glass slab over the chart sheet in the middle.

Using pencil draw outline of the glass slab and label it as ABCD. Remove the glass slab and draw normal MN on AB. Draw a line such that it makes some angle with the normal MN as in figure 13. Now place 2 pins vertically on the drawn line and mark them as E and F respectively. Put the glass slab again on the drawn outline, look at the images of E and F through the opposite edge and fix the other 2 pins at point say G, H such that all four of them lie in a same line. What do you observe on removing the glass slab? Remove all 4 pins and draw small circle at the position of tip of pins.

Join the positions of tip of pin E and F and produce it to AB using pencil and scale. Let EF meet AB at point O. similarly, do it for points G and H and produce it to edge CD. Let GH meet CD at O'. Now join the points O and O'. Draw normal M'N' at point O'.

You can see that at point O and O' light ray has changed its direction and both points O and O' lie on the surface separating two transparent media.

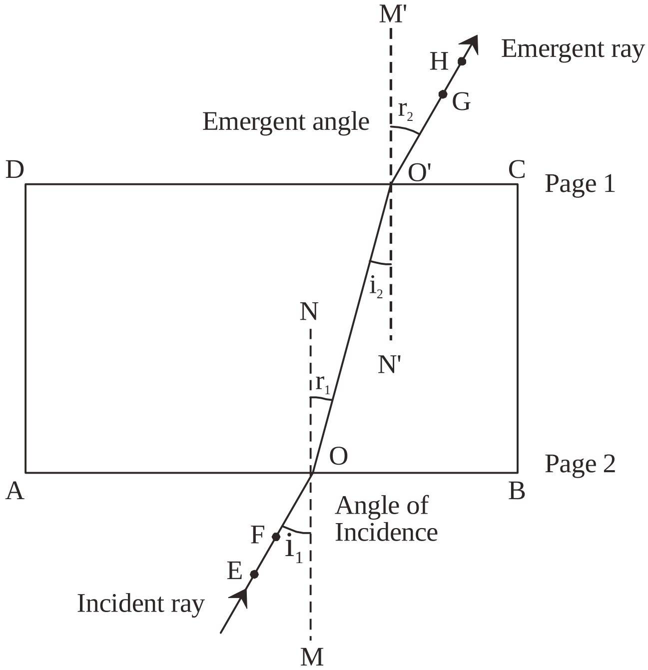


Figure-13: Refraction through the two faces of a rectangular slab

Use the data obtained to fill the given table by changing the angle of incident ray in the above experiment.

Table -2

	Surface 1		**Surface 2**	
S.No.	**Angle of incidence (i_1)**	**Angle of refraction (r_1)**	**Angle of incidence (i_2)**	**Angle of refraction (r_2)**

Compare the angle of incidence and angle of refraction at both refractive surfaces.

By looking at the figure you can easily see that the ray coming out of the slab GH has direction similar to the incident ray EF. The angle of incidence is same as the angle that the ray coming out of slab makes with normal O' for all cases. Which means the extent of bending of light ray at the opposite parallel face of rectangular slab is equal and opposite.

Thus shows that refraction of light follows certain laws, you can read about the laws in the practicals section of this textbook.

10.6 Refraction of light through prism

So far we have studied refraction of light through glass slab, water and through other different medium. In all those activities both refractive surfaces were at same angle. What would happen if both refractive surfaces were placed in such a manner that they are making angle with each other? Here we will study about refraction of light when light is incident on the refractive surface which is making an angle with the other refractive surface.

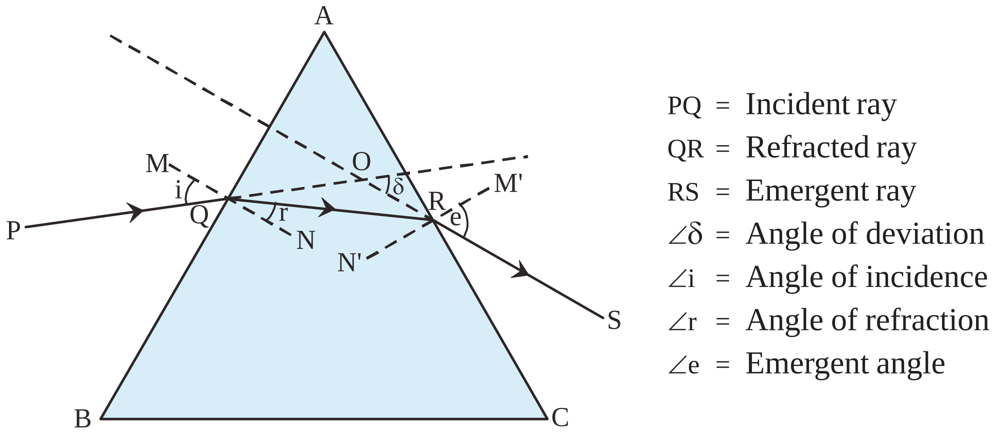


Figure-14:

According to the figure, a light ray PQ is incident on surface AB of a prism and I is the angle of incidence. After refraction from surface AB, the light travels in the QR direction. This ray act as incident ray for surface AC, which after refraction from AC surface comes out of prism and travels in RS direction. If we extend our incident ray PQ in forward direction and ray RS in backward direction they will meet at some point. Call that point as O. Due to refraction of light inside the prism there is some change or deviation in the direction of light. The Angle QOR is known as the angle of deviation.

10.7 Actual and virtual depth

Previously we have done an experiment with a coin in beaker full of water where we have used the term virtual image, now can you tell how that happened?

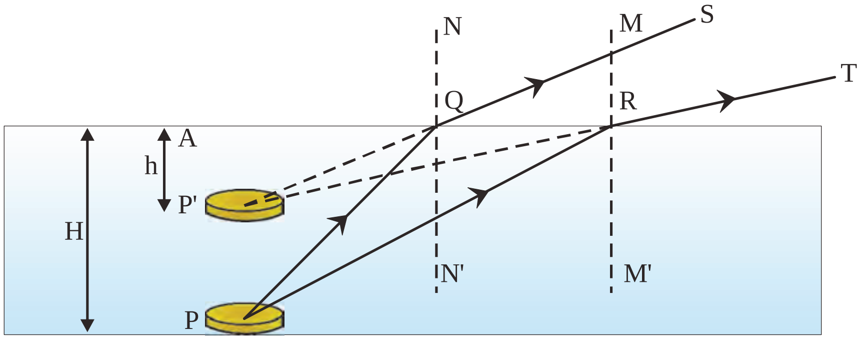


Figure-15

Suppose that a coin is at depth AP =H inside water. At point Q, light rays travel from denser medium (water) to rarer medium (air) and hence are refracted away from normal NN'. It seems that the light ray is coming from P'. Therefore, image of P forms at P'. This is the reason why the virtual depth of coin AP' = h is lower than the actual depth and why the coin seem to be upraised.

$$\text{Refractive Index} = \frac{\text{actual depth}}{\text{virtual depth}} = \frac{H}{h}$$

10.8 Principle of reversibility of Path of light

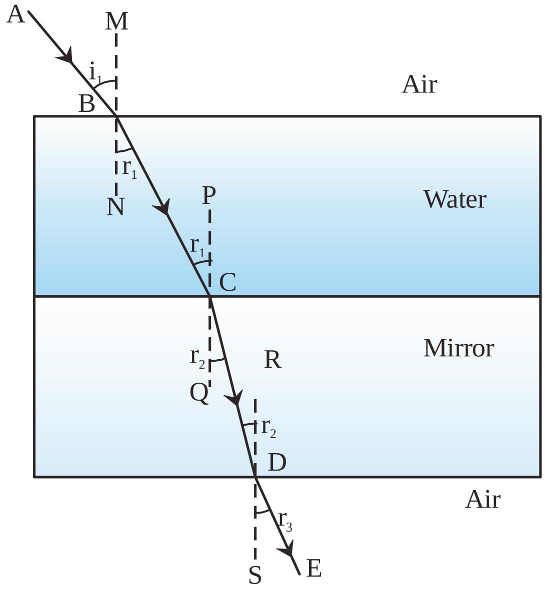


Figure-16

So far, with the help of several activities, we have seen that when light travels from one medium to another it gets refracted in a certain path. Have you ever thought what would be its direction if the direction of ray is changed? To understand the principle of reversibility of light, let us consider a compound plate having water as media and rectangular glass slab with one face coinciding (according to the figure). Let it be held in air medium.

When light ray AB moves from air to water (rarer to denser) at point B refraction occurs, ray AB bend towards the normal MN and follows path BC. At point C when light ray BC enters glass medium from liquid medium again refraction occurs and light ray bend towards the normal PQ. At point D when ray comes out from glass medium again refraction takes place and light ray bends away from normal RS. In this way when light travels from air - liquid - glass - air ABCDE will be the path of light ray. Similarly, if we move from air - glass - liquid - air, according to the laws of refraction EDCBA will be the path along which the light ray will travel. From this, we can conclude that on traveling between different medium, if at a fixed point the direction of ray is reversed then reversibility is seen in the direction of propagation of ray.

10.9 Critical angle and Total internal reflection

Like the last activity, we will take a thick glass slab and use laser light to study refraction of light and other phenomena. When light passes through the glass slab and reaches air, then light ray refracts from dense to light medium. We will first incident the light at an angle of 0° (degree) from the normal in the glass slab. Now, let's think about the following points.

- Can you see the refracted ray?
- Is there any deviation in the path of the light while it passes from glass to air?

Do the above activity for the incident angles 5°, 10°, 15° etc. and observe the angle of refraction.

For a particular value of incident angle, emergent refracted ray will graze through the surface separating both mediums. This angle is known as critical angle of that material.

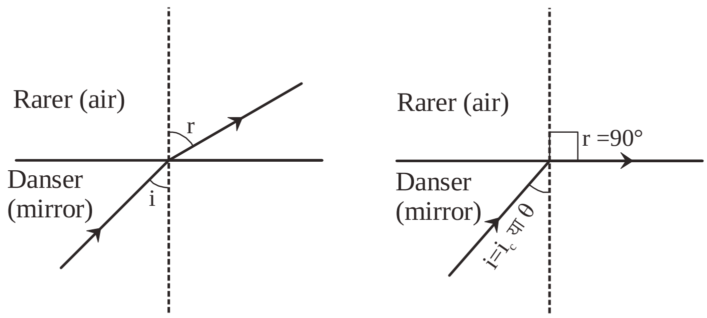


Figure-17

When light passes from dense medium like glass to rarer medium like air, it moves away from the normal. In this situation angle of refraction r is more than angle of incidence i. ($\angle r > \angle i$)

As the angle of incidence "i" is increased, the value of angle of refraction r also increases. At some stage, angle of incidence value will be such that the value of angle of refraction would be $\angle r = 90°$. In this situation, refracted ray will pass touching the surface separating both the mediums. At this situation, the measure of angle of incidence is called as "critical angle". This is represented by I_c or θ_c.

Therefore,critical angle is that value of incident angle in the denser medium for which angle of refraction is 90° in the rarer medium.

10.9.1 Total Internal Reflection

If the incident angle in the denser medium is more than the critical angle then the angle of refraction would be more than 90 degree i.e. light will, instead of passing through the rarer medium (air), pass through the denser medium (glass).This is a situation of reflection and not refraction. Hence, when light passes from denser medium to rarer medium and the incident angle is more than the critical angle then light gets internally reflected in the denser medium. This is known as Total Internal Reflection.

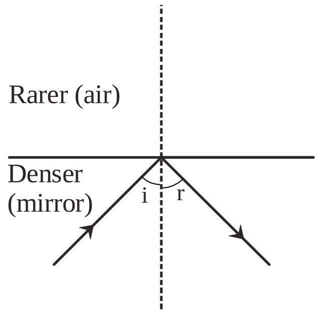


Figure-18

Necessary conditions for total internal reflection:-

1. Light should pass from denser medium to rarer medium.
2. Incident angle should be more than critical angle.

10.9.2 Examples of total internal reflection.

1. An empty test tube (air medium) inclined at some angle is immersed in beaker filled with water, when it is observed from top, the upper part of test tube looks shiny as it has been painted. The reason behind this is that when light ray travelling through water incident on test tube, the rays travels from rarer to denser medium. This is followed by light travelling from the glass wall of test tube towards glass-air boundary, in which some of the rays have angle of incidence greater than critical angle. Therefore, these rays reach eyes after total reflection and hence the upper part of test tube looks as shiny as silver. The shininess disappears as the test tube is filled with water.

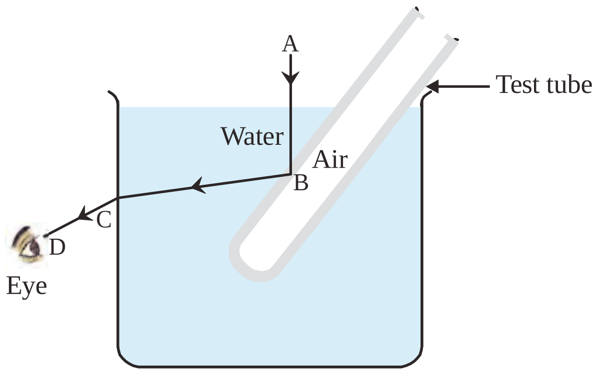


Figure-19

2. Mirage- During hot days in the deserts, people see an inverted reflection of a distant pine tree which make them believe that there is pool of water around the tree. However, when they reach there they find that there is no water. This illusion is known as mirage.

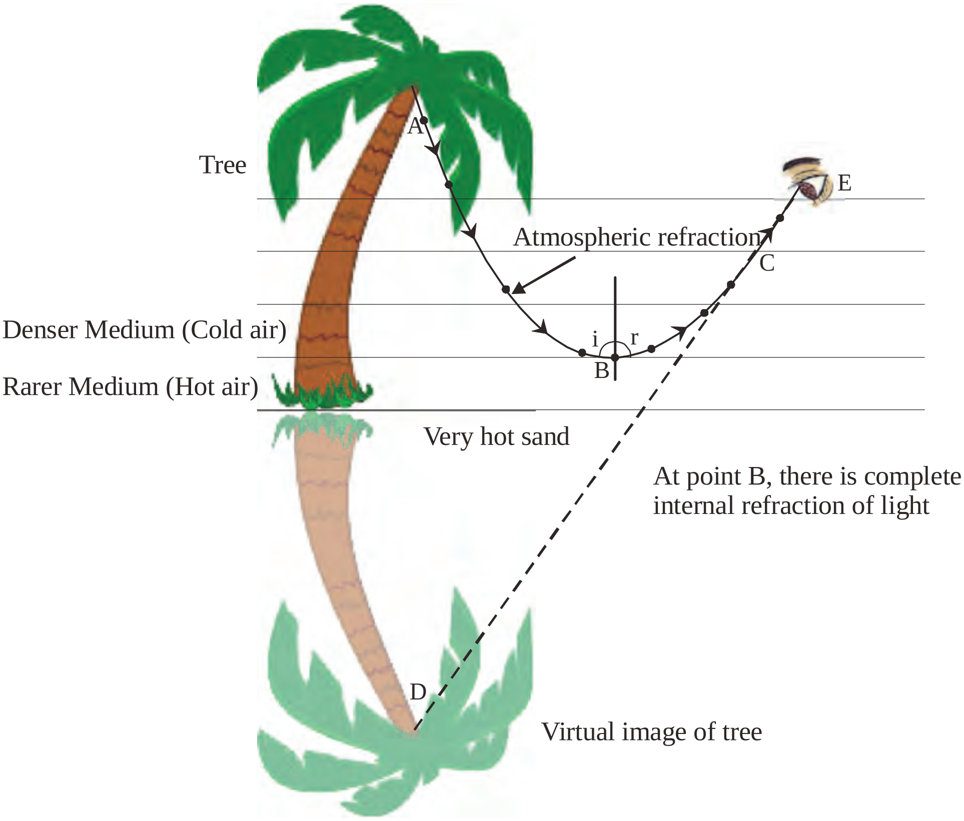


Figure-20

The air near the land surface is hotter and optically rarer while that on a more height is cooler and optically denser.

Light from top parts of a tree travels down towards the land but due to continually changing optical density, it gets refracted. When the angle of incidence becomes more than the critical angle, the light coming from top of the tree gets reflected and starts travelling in the direction away from the land (as shown in the figure). We see this internally reflected light and to us it seems like the light is coming from the direction of land. Hence, it appears as if there is a reflection of the tree on the surface because of a water body, while really there is no water body.

Figure-21

Similarly, Concrete Roads provide an example of Mirage. Discuss with your friends how this can happen?

Key Words:

Reflection, Normal, Incident ray, Reflected ray, Refracted ray, Emergent ray, Angle of Incidence, Angle of Reflection, Angle of Refraction, angle of Deviation, Emergent angle, Real image, Virtual image, Refraction, Refractive index, Prism, Reversibility principle, Critical angle, Total internal reflection, Real depth, Apparent depth.

What we have learnt

- Light ray travels in a straight path.
- When light ray is incident on an opaque object, then the image formation takes place on screen behind the object.
- Angle of incidence is always equal to the angle of reflection.
- Incident ray, reflected ray and normal all lie on same plane.
- Plane mirror always forms virtual, erected image of same size as object.
- By rotating the plane mirror by an angle θ, the reflected ray gets rotated by an angle 2θ.
- To see the full image of person, the height of plane mirror should be at least half the height of person.
- If two plane mirrors are at θ angle, then $\frac{360}{\theta}-1$ images will be formed by them.
- When light travels from one medium to another medium then it gets deviated from its path, it is called Refraction of light
- Speed of light in vacuum is 3×10^{8} m/s .
- When light travels from denser to rarer medium then it bends away from normal.
- When light travels from rarer to denser medium then it bends towards normal.
- The refractive index of a transparent medium is the ratio of speed of light in vacuum to the speed of light in the medium. It is called Absolute refractive index.
- From principle of reversibility ${}_2\mu_1 = \frac{1}{{}_1\mu_2}$.
- First law of refraction says the incident ray, refracted ray and normal to the point of incidence on the plane dividing the two mediums lie in the same plane.
- According to second law of refraction, ${}_1\mu_2 = \frac{\sin i}{\sin r}$, this is known as Snell's law.
- In prism, the angle between the incident ray and emergent ray is called angle of deviation.

Exercise

1. Choose the correct answer–

   (i) If we rotate a plane mirror by 2θ, then the reflected ray will rotate by–

   (a) 2θ (b) 3θ (c) 4θ (d) θ

   (ii) What should be the minimum length of the plane mirror if a person wants to see his full image?

   (a) One fourth of the person's height (b) One third of the person's height

   (c) equal to the person's height (d) One half of the person's height

   (iii) How many images will be formed of an object kept between two mirrors making 45° with eachother?

   (a) 5 (b) 6 (c) 7 (d) 8

   (iv) If an object is placed at a distance of 3 cm from the mirror, then the distance between the image and the object will be–

   (a) 4 cm (b) 6 cm (c) 3 cm (d) 12 cm

2. Fill in the blanks

   (i) Image formed by a plane mirror is erect, virtual and..

   (ii) Second law of refraction is also known as..

   (iii) Light ray falls normally on plane mirror; the angle of reflection will be...................

   (iv) For................................light should travel from denser medium to rarer medium.

3. What are the laws of reflection?

4. What are the laws of refraction?

5. The refractive indices of medium A and B are n_A and n_B respectively. Total internal reflection is possible on going form which medium to which medium given that $n_A > n_B$.

6. What is total internal refraction and what are the necessary conditions for it to take place?

7. Give two examples where refraction is seen in daily life.

8. What do you understand by critical angle?

9. Light travels from air to glass slab having refractive index of 1.50. What will be the speed of light in glass? Speed of light in vacuum is 3×10^8 m/s. (ans- 2×10^8 m/s)

10. Refractive index of diamond is 2.42. Explain this statement.

11. A light ray travelling in the air enters the Ice. Will the light ray move away from the normal or towards the normal? Why?

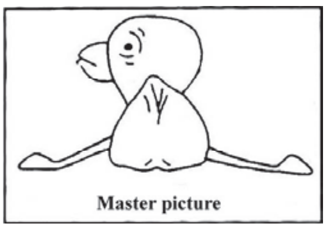
12. If we increase the distance between the mirror the object then what would be the effect on the distance between the image and the object?

13. What is the difference between virtual image and real image?
14. What is the difference between absolute refractive index of a medium and the relative refractive index of two mediums? What is the relation between them?
15. What is the principal of reversibility?
16. State the reasons for following: -
    (i) The position of fish in a pond is not same as it is observed from outside.
    (ii) A Bubble of air shines in water.
    (iii) Mirage is an illusion.
17. Prove that the length of the mirror required to view the complete image of an object is half of the height of the object.
18. What do you mean by refraction of light? How is it different from reflection of light?
19. If the absolute refractive index of glass is 3/2 and that of water is 5/4, then find the ratio of speed of light in water and to that in glass. Ans. (1.2)

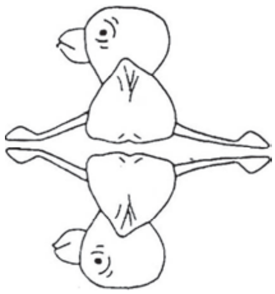
20 A fish seems to be at a depth of 75cm from the surface. What is the actual distance from the surface? (Refractive index of water is 1.33). (Ans - 100 cm)

Ask a mirror

You have been given a master picture and some more pictures. Place a plane mirror around the master picture and see the image formed. The image and master together form a new picture. Use your mirror and master picture to figure out how?



(a)



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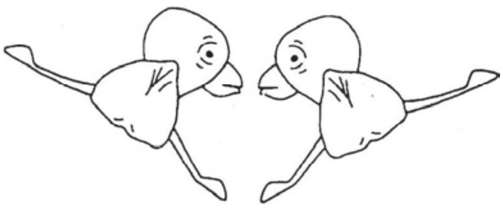

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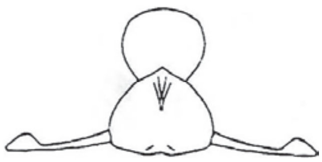

(d)