6. Refraction of light

- Refraction of light
- Refractive index
- Laws of refraction
- Dispersion of light

Can you recall?

1. What is meant by reflection of light?
2. What are the laws of reflection?

We have seen that, generally light travels in a straight line. Because of this, if an opaque object lies in its path, a shadow of the object is formed. We have also seen in previous classes how these shadows change due to the change in relative positions of the source of light and the object. But light can bend under some special circumstances as we will see below

Refraction of light

Try this. **Material:** Glass, 5 rupee coin, Pencil, metallic vessel etc.

Activity 1:

1. Take a transparent glass and fill it with water.
2. Dip some portion of a pencil vertically in water and observe the thickness of the portion of the pencil, in water.
3. Now keep the pencil inclined to water surface and observe its thickness.

In both cases, the portion of the pencil inside water appears to be thicker than the portion above water. In the second case, the pencil appears to be broken near the surface of water. Why does it happen?

Activity 2:

1. keep a 5 rupee coin in a metallic vessel.
2. Slowly go away from the vessel
3. Stop at the place when the coin disappears.
4. Keep looking in the direction of the coin.
5. Ask a friend to slowly fill water in the vessel. You will be able to see the coin once the level of water reaches a certain height. Why does it happen?

In both the above activities the observed effects are created due to the change in the direction of light while coming out of water. **Light changes its direction when going from one transparent medium to another transparent medium. This is called the refraction of light.**

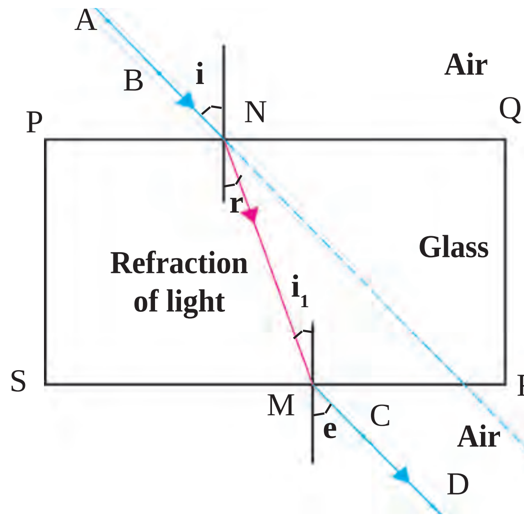
Activity 3:

1. Keep a glass slab on a blank paper and draw its outline PQRS as shown in figure 6.1.
2. Draw an inclined straight line on the side of PQ so that it intersects PQ at N. Pierce two pins vertically at two points A and B along the line.
3. Look at the pins A and B from the opposite side of the slab and pierce pins C and D vertically so that the images of A and B are in line with C and D.
4. Now remove the chip and the pins and draw a straight line going through points C and D so that it intersects SR at M.
5. Join points M and N. Observe the incident ray AN and emergent ray MD.

The first refraction occurs when light ray enters the glass from air at N on the side PQ. The second refraction occurs when light enters air through glass at point M on the side SR. For the first refraction the angle of incidence is i while for the second it is i_1. The angle of refraction at N is r.

Note that i_1 = r. In the second refraction, the angle of refraction is e which is equal to i. On both parallel sides PQ and RS of the glass slab, the change in direction of light ray is equal but in opposite directions.

Thus, the light ray MD emerging from the glass slab is parallel to the incident ray AN on the side PQ of the slab. But the emergent ray is somewhat displaced with respect to the incident ray.



6.1 Refraction of light passing through a glass slab

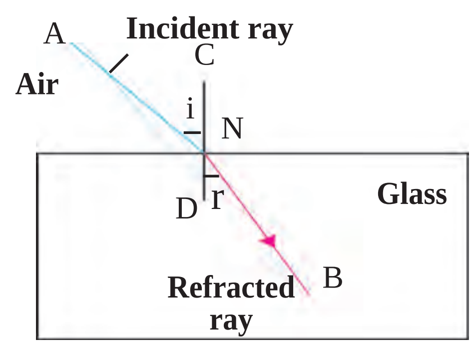
Use your brain power !

1. Will light travel through a glass slab with the same velocity as it travels in air?
2. Will the velocity of light be same in all media?

Laws of refraction

Let us study the light ray entering a glass slab from air as shown in the figure 6.2. Here AN is the incident ray and NB is the refracted ray.

1. Incident ray and refracted ray at the point of incidence N are on the opposite sides of the normal to the surface of the slab at that point i.e. CD, and the three, incident ray, refracted ray and the normal, are in the same plane.
2. For a given pair of media, here air and glass, the ratio of sin i to sin r is a constant. Here, i is the angle of incidence and r is the angle of refraction.



6.2 Light ray entering a glass slab from air

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

n is called the refractive index of the second medium with respect to the first medium. This second law is also called Snell's law. A ray incident along the normal (i = 0) goes forward in the same direction (r = 0).

Refractive index

The change in the direction of a light ray while entering different media is different. It is related to the refractive index of the medium. The value of the refractive index is different for different media and also for light of different colours for the same medium. The refractive indices of some substances with respect to vacuum are given in the table. The refractive index of a medium with respect to vacuum is called its absolute refractive index.

Refractive index depends on the velocity of light in the medium.

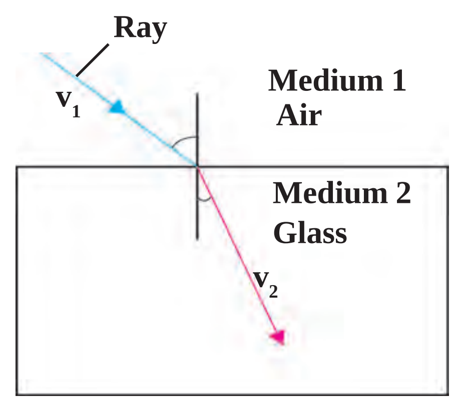
Substance	Refractive index	Substance	Refractive index	Substance	Refractive index
Air	1.0003	Fused Quartz	1.46	Carbon disulphide	1.63
Ice	1.31	Turpentine oil	1.47	Dense flint glass	1.66
Water	1.33	Benzene	1.50	Ruby	1.76
Alcohol	1.36	Crown glass	1.52	Sapphire	1.76
Kerosene	1.39	Rock salt	1.54	Diamond	2.42

Absolute refractive indices of some media

Let the velocity of light in medium 1 be v_1 and in medium 2 be v_2 as shown in figure 6.3. The refractive index of the second medium with respect to the first medium, ${}^1n_2$ is equal to the ratio of the velocity of light in medium 1 to that in medium 2.

$$\text{Refractive index } {}^1n_2 = \frac{\text{Velocity of light in medium 1 } (v_1)}{\text{Velocity of light in medium 2 } (v_2)}$$

Similarly, the refractive index of medium 1 with respect to medium 2 is



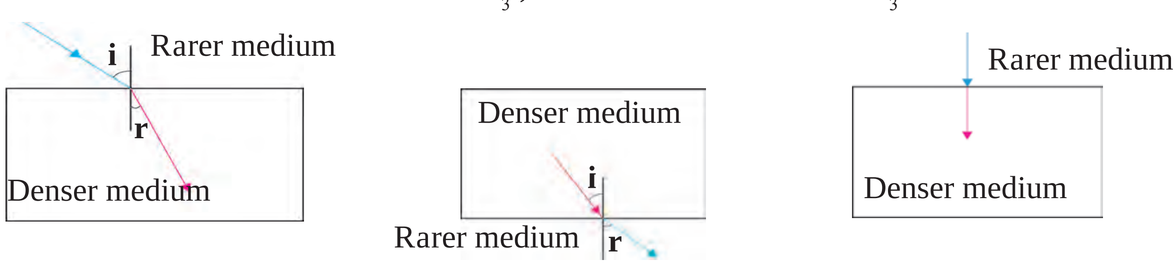
6.3 Light ray going from medium 1 to medium 2

$${}^2n_1 = \frac{v_2}{v_1}$$

If the first medium is vacuum then the refractive index of medium 2 is called absolute refractive index and it is written as n.

Can you tell?

If the refractive index of second medium with respect to first medium is ${}^1n_2$ and that of third medium with respect to second medium is ${}^2n_3$, what and how much is ${}^1n_3$?



6.4 Refraction of light in different media

When a light ray passes from a rarer medium to a denser a medium, it bends towards the normal.

When a light ray passes from a denser medium to a rarer medium, it bends away from the normal.

When a light ray is incident normally at the boundary between two media, it does not change its direction and hence does not get refracted.

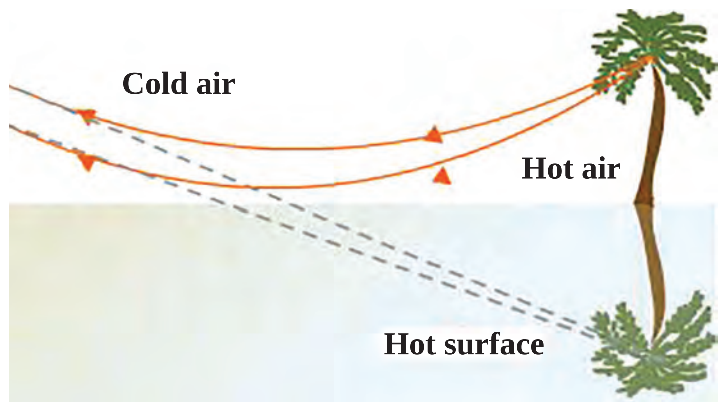
Twinkling of stars

1. Have you seen a mirage which is an illusion of the appearance of water on a hot road or in a desert?
2. Have you seen that objects beyond and above a holi fire appear to be shaking? Why does this happen?

Local atmospheric conditions affect the refraction of light to some extent. In both the examples above, the air near the hot road or desert surface and near the holi flames is hot and hence rarer than the air above it. The refractive index of air keeps increasing as we go to increasing heights. In the first case above, the direction of light rays, coming from a distance, keeps changing according to the laws of refraction.

The light rays coming from a distant object appear to be coming from the image of the object inside the ground as shown in figure 6.5. This is called a mirage.

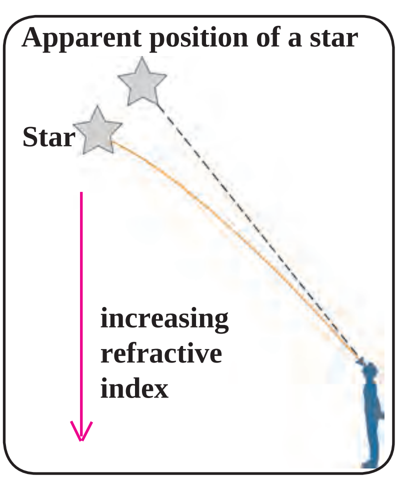
In the second example, the direction of light rays coming from objects beyond the holi fire changes due to changing refractive index above the fire. Thus, the objects appear to be moving.



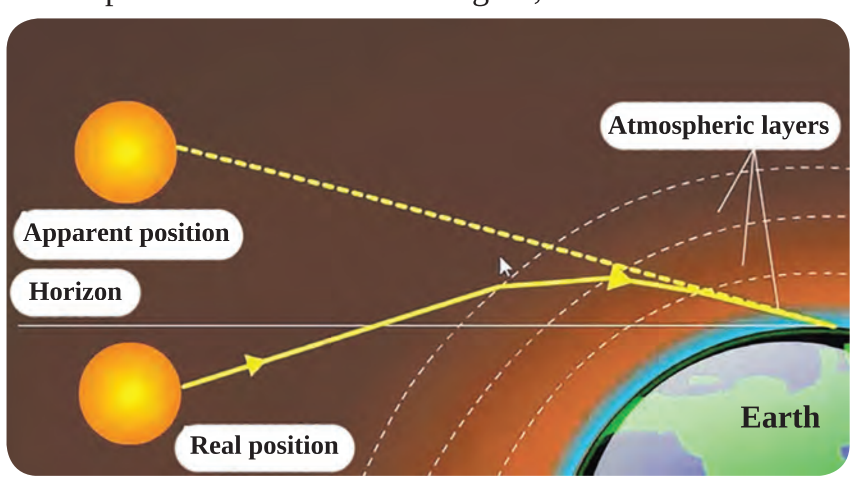
6.5 Mirage

Effect of atmospheric conditions on refraction of light can be seen in the twinkling of the stars.

Stars are self-luminous and can be seen at night in the absence of sunlight. They appear to be point sources because of their being at a very large distance from us. As the desity of air increases with lowering height above the surface of the earth, the refractive index also increases. Star light coming towards us travels from rarer medium to denser medium and constantly bends towards the normal. This makes the star appear to be higher in the sky as compared to its actual position as shown in the figure, 6.6.



6.6 Apparent position of a star



6.7 Effect of atmospheric refraction

The apparent position of the star keeps changing a bit. This is because of the motion of atmospheric air and changing air density and temperature. Because of this, the refractive index of air keeps changing continuously. Because of this change, the position and brightness of the star keep changing continuously and the star appears to be twinkling.

We do not see twinkling of planets. This is because, planets are much closer to us as compared to stars. They, therefore, do not appear as point sources but appear as a collection of point sources. Because of changes in atmospheric refractive index the position as well as the brightness of individual point source change but the average position and total average brightness remains unchanged and planets do not twinkle.

By Sunrise we mean the appearance of the Sun above the horizon. But when the Sun is somewhat below the horizon, its light rays are able to reach us along a curved path due to their refraction through earth's atmosphere as shown in the figure 6.7. Thus, we see the Sun even before it emerges above the horizon. Same thing happens at the time of Sunset and we keep seeing the Sun for a short while even after it goes below the horizon.

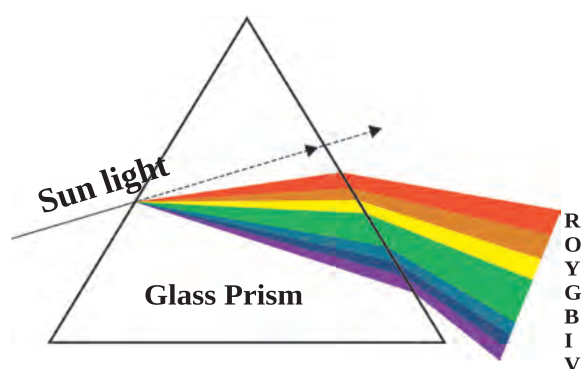
Dispersion of light

Hold the plastic scale in your compass in front of your eyes and see through it while turning it slowly. You will see light rays divided into different colours. These colours appear in the following order: violet, indigo, blue, green, yellow, orange and red. You know that light is electromagnetic radiation. Wavelength is an important property of radiation. The wavelength of radiation to which our eyes are sensitive is between 400 and 700 nm. In this interval, radiation of different wavelengths appears to have different colours mentioned above. The red light has maximum wavelength i.e. close to 700 nm while violet light has the smallest wavelength, close to 400 nm. Remember that 1 nm = 10^{-9} m.

In vacuum, the velocity of light rays of all frequencies is the same. But the velocity of light in a medium depends on the frequency of light and thus different colours travel with different velocity. Therefore, the refractive index of a medium is different for different colours. Thus, even when white light enters a single medium like glass, the angles of refraction are different for different colours. So when the white light coming from the Sun through air, enters any refracting medium, it emerges as a spectrum of seven colours.

The process of separation of light into its component colours while passing through a medium is called the dispersion of light.

Sir Isaac Newton was the first person to use a glass prism to obtain Sun's spectrum. When white light is incident on the prism, different colours bend through different angles. Among the seven colours, red bends the least while violet bends the most. Thus, as shown in figure 6.8, the seven colours emerge along different paths and get separated and we get a spectrum of seven colours.



6.8 Dispersion of light

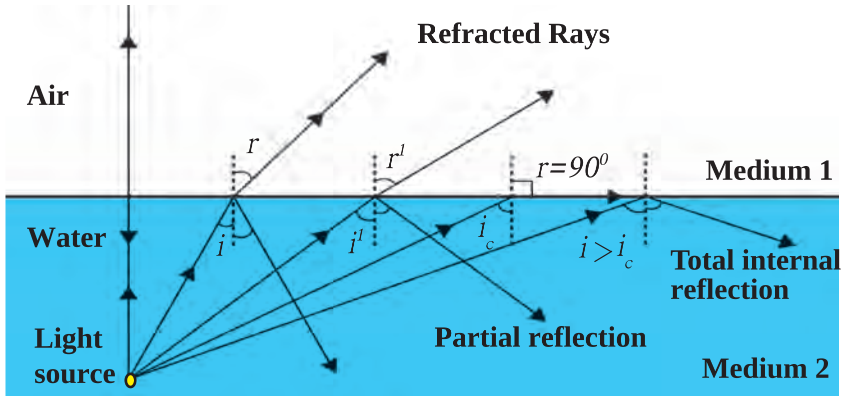
Use your brain power !

1. From incident white light how will you obtain white emergent light by making use of two prisms?
2. You must have seen chandeliers having glass prisms. The light from a tungsten bulb gets dispersed while passing through these prisms and we see coloured spectrum. If we use an LED light instead of a tungsten bulb, will we be able to see the same effect?

Partial and total internal reflection

When light enters a rarer medium from a denser medium, it gets partially reflected i.e. part of the light gets reflected and comes back into the denser medium as per laws of reflection. This is called partial reflection. The rest of the light gets refracted and goes into the rarer medium.

As light is going from denser to rarer medium, it bends away from the normal i.e. the angle of incidence i, is smaller than the angle of refraction r. This is shown on the left side of the figure 6.9. If we increase i, r will also increase according to Snell's law as the refractive index is a constant.



6.9 Partial and total internal reflection

For a particular value of i, the value of r becomes equal to 90°. This value of i is called the critical angle. For angles of incidence larger than the critical angle, the angle of refraction is larger than 90°. Such rays return to the denser medium as shown towards the right in figure 6.9. Thus, all the light gets reflected back into the dense medium. This is called total internal reflection. We can determine the value of the critical angle the as follows.

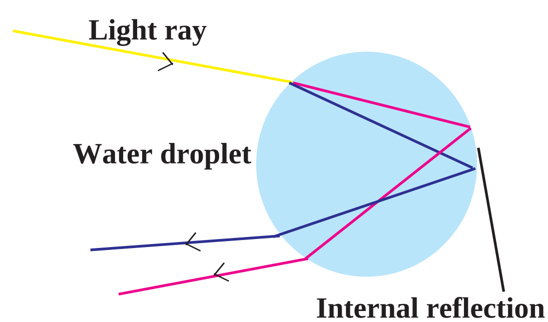
$${}_1n_2 = \frac{\sin i}{\sin r}$$

For total internal reflection, i = critical angle, $r = 90^0$

$${}_1n_2 = \frac{\sin i}{\sin 90^0} = \sin i$$

$(\because \sin 90^0 = 1)$

Rainbow is a beautiful natural phenomenon. It is the combined effect of a number of natural processes. It is the combined effect of dispersion, refraction and total internal reflection of light. It can be seen mainly after a rainfall. Small droplets of water act as small prisms. When light rays from the Sun enter these droplets, it gets refracted and dispersed. Then there is internal reflection as shown in the figure, and after that once again the light gets refracted while coming out of the droplet. All these three processes together produce the rainbow.



6.10 Rainbow production

Books are my friends

1. Why the Sky is Blue - Dr. C.V. Raman talks about science : C. V. Raman and Chandralekha
2. Optics : Principles and Applications : K.K. Sharma
3. Theoretical concepts in Physics : M.S. Longair

Some Fun

Try to see if you can see dispersion of light using plastic jar, mirror and water.

Solved Examples

1. The absolute refractive index of water is 1.36. What is the velocity of light in water? (velocity of light in vacuum 3×10^8 m/s)

Given:

$V_1 = 3\times10^8$ m/s

n = 1.36

$$n = \frac{V_1}{V_2} \qquad 1.36 = \frac{3\times10^8}{V_2}$$

$$V_2 = \frac{3\times10^8}{1.36} = 2.21\times10^8 \text{ m/s}$$

2. Light travels with a velocity 1.5×10^8 m/s in a medium. On entering second medium its velocity becomes 0.75×10^8 m/s. What is the refractive index of the second medium with respect to the first medium?

Given:

$V_1 = 1.5\times10^8$ m/s, $V_2 = 0.75\times10^8$ m/s

$$_2n_1 = ? \qquad _2n_1 = \frac{1.5\times10^8}{0.75\times10^8} = 2$$

Exercise

1. Fill in the blanks and Explain the completed sentences.

a . Refractive index depends on the .... of light.

b. The change in .... of light rays while going from one medium to another is called refraction.

2. Prove the following statements.

a. If the angle of incidence and angle of emergence of a light ray falling on a glass slab are i and e respectively, prove that, i = e.

b. A rainbow is the combined effect of the refraction, dispersion, and total internal reflection of light.

3. Mark the correct answer in the following questions.

A. What is the reason for the twinkling of stars?

i . Explosions occurring in stars from time to time

ii. Absorption of light in the earth's atmosphere

iii. Motion of stars

iv. Changing refractive index of the atmospheric gases

B. We can see the Sun even when it is little below the horizon because of

i. Reflection of light

ii. Refraction of light

iii. Dispersion of light

iv. Absorption of light

C. If the refractive index of glass with respect to air is 3/2, what is the refractive index of air with respect to glass?

a. $\frac{1}{2}$ b. 3

c. $\frac{1}{3}$ d. $\frac{2}{3}$

4. Solve the following examples.

a. If the speed of light in a medium is 1.5×10^8 m/s, what is the absolute refractive index of the medium?

Ans : 2

b. If the absolute refractive indices of glass and water are 3/2 and 4/3 respectively, what is the refractive index of glass with respect to water?

Ans : $\frac{9}{8}$

Project :

Using a laser and soap water, study the refraction of light under the guidance of your teacher.

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