Unit 11 SOUND

After studying this unit, students will be able to:

- explain how sound is produced by vibrating sources and that sound waves require a material medium for their propagation.
- describe the longitudinal nature of sound waves (as a series of compressions and rarefactions).
- define the terms pitch, loudness and quality of sound.
- describe the effect of change in amplitude on loudness and the effect of change in frequency on pitch of sound.
- define intensity and state its SI unit.
- describe what is meant by intensity level and give its unit.
- explain that noise is a nuisance.
- describe how reflection of sound may produce echo.
- describe audible frequency range.
- describe the importance of acoustic protection.
- solve problems based on mathematical relations learnt in this unit.

Science, Technology and Society Connections

The students will be able to:

- describe that some sounds are injurious to health.
- describe how knowledge of the properties of sound waves is applied in the design of building with respect to acoustics.
- describe how ultrasound techniques are used in medical and industry.
- explain the use of soft materials to reduce echo sounding in classroom studies, and other public gathering buildings.

We know that vibrations of objects in any medium produce waves. For example, vibrator of ripple tank produces water waves. The medium in this case is liquid, but it can also be a gas or a solid. Now we will discuss another type of waves that we can hear i.e., sound waves.

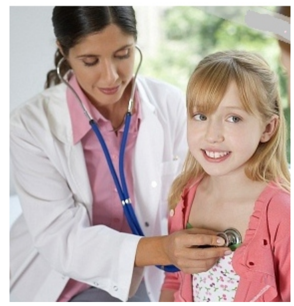
Physics of Sound

All sounds are produced by the vibrations of objects. Sound is a form of energy that travels in the form of waves from one place to another.

11.1 SOUND WAVES

Like other waves, sound is also produced by vibrating bodies. Due to vibrations of bodies the air around them also vibrates and the air vibrations produce sensation of sound in our ear. For example, in a guitar, sound is produced due to the vibrations of its strings (Fig. 11.1). Our voice results from the vibrations of our vocal chords. Human heart beats and vibrations of other organs like lungs also produce sound waves. Doctors use stethoscope to hear this sound.

For your information



Stethoscopes operate on the transmission of sound from the chest-piece, via air-filled hollow tubes, to the listener's ears. The chest-piece usually consists of a plastic disc called diaphragm. If the diaphragm is placed on the patient’s body sounds vibrate the diaphragm, creating acoustic pressure waves which after multiple reflection travel up the tubing to the doctor's ears.

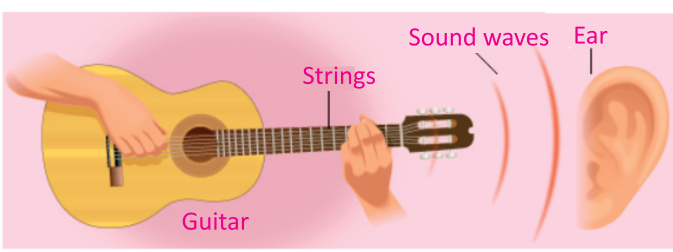


Fig. 11.1: Vibrations of guitar strings produce sound waves

SOUND IS PRODUCED BY A VIBRATING BODY

Activity 11.1: In school laboratories, we use a device called tuning fork to produce a particular sound. If we strike the tuning fork against rubber hammer, the tuning fork will begin to vibrate (Fig. 11.2). We can hear the sound produced by tuning fork by bringing it near our ear. We can also feel the vibrations by slightly touching one of the prongs of the vibrating tuning fork with a plastic ball suspended from a thread (Fig. 11.3). Touch

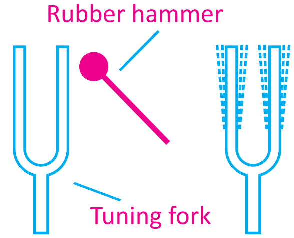


Fig. 11.2: Strike a rubber hammer on a tuning fork

the ball gently with the prong of a vibrating tuning fork. The tuning fork will push the ball because of its vibrations. Now if we dip the vibrating tuning fork into a glass of water, we will see a splash (Fig. 11.4). What does make the water splash?
From this activity, we can conclude that sound is produced by vibrating bodies.

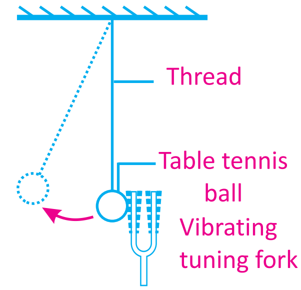


Fig. 11.3: The production of sound waves from a vibrating tuning fork

Sound Requires Material Medium for its Propagation

Activity 11.2: Unlike light waves which are electromagnetic in nature and can also pass through vacuum, sound waves require some material medium for their propagation. This can be proved by bell jar apparatus (Fig. 11.5). The bell jar is placed on the platform of a vacuum pump.

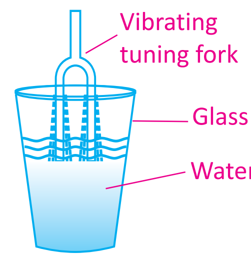


Fig. 11.4

An electric bell is suspended in the bell jar with the help of two wires connected to a power supply. By setting ON the power supply, electric bell will begin to ring. We can hear the sound of the bell. Now start pumping out air from the jar by means of a vacuum pump. The sound of the bell starts becoming more and more feeble and eventually dies out, although bell is still ringing. When we put the air back into the jar, we can hear the sound of the bell again. From this activity, we conclude that sound waves can only travel/propagate in the presence of air (medium).

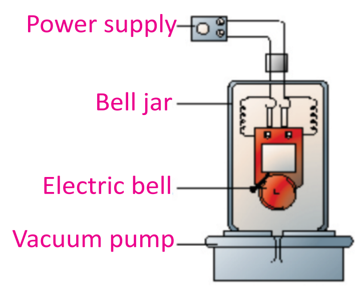


Fig. 11.5: Bell jar apparatus

Longitudinal Nature of Sound Waves

Propagation of sound waves produced by vibrating tuning fork can be understood by a vibrating tuning fork as shown in Fig.11.6. Before the vibration of tuning fork, density of air molecules on the right side is uniform (Fig.11.6-a). When the right prong of tuning fork moves from mean position O to B (Fig.11.6-b), it exerts some pressure on the adjacent layer of air molecules and produces a compression.

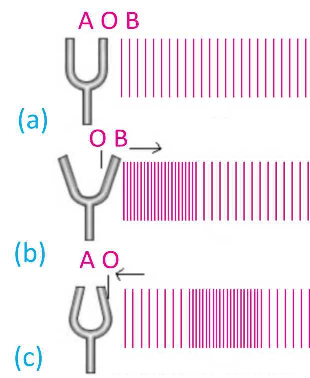


Fig.11.6: Vibrations of tuning fork after striking with a rubber

This compressed air layer in turn compresses the layer next to it and so on. A moment later, the prong begins to move from B towards A (Fig.11.6-c). Now the pressure in the adjacent layer decreases and a rarefaction is produced. This rarefaction is transfered to the air layer next to it and so on. As the tuning fork moves back and forth rapidly, a series of compressions and rarefactions are created in the air. In this way, sound wave propagates through the air.

As in the Fig.11.6, the direction of propagation of sound wave is along the direction of oscillating air molecules. This shows the longitudinal nature of sound waves. Distance between two consecutive compressions or rarefactions is the wavelength of sound wave.

11.2 CHARACTERISTICS OF SOUND

Sounds of different objects can be distinguished on the basis of different characteristics as described below:

Loudness: *Loudness is the characteristic of sound by which loud and faint sounds can be distinguished.*

When we talk to our friends, our voice is low, but when we address a public gathering our voice is loud. Loudness of a sound depends upon a number of factors. Some of them are discussed below:

(a) Amplitude of the vibrating body: The loudness of the sound varies directly with the amplitude of the vibrating body (Fig.11.7). The sound produced by a sitar will be loud if we pluck its wires more violently. Similarly, when we beat a drum forcefully, the amplitude of its membrane increases and we hear a loud sound.

(b) Area of the vibrating body: The loudness of sound also depends upon the area of the vibrating body.

Physics Insight

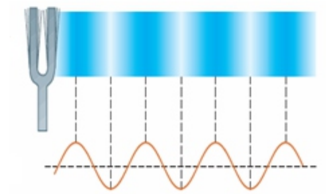


Illustration of longitudinal wave formed by vibrating tuning fork in the air. Compressions are places where air pressure is slightly higher than the surrounding air pressure due to high density of air particles. While rarefactions are the regions correspond to low air pressure due to low density of air particles.

Quick Quiz

Identify which part of these musical instruments vibrates to produce sound:
(a) electric bell (b) loud speaker (c) piano (d) violin (e) flute.

Self Assessment

1. Explain how sound is produced by a school bell.
2. Why are sound waves called mechanical waves?
3.Suppose you and your friend are on the Moon. Will you be able to hear any sound produced by yourfriend?

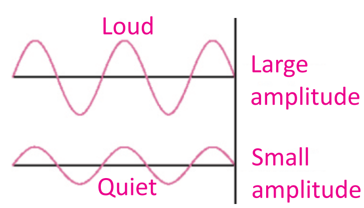


Fig. 11.7: Variation of loudness with amplitude

For example, sound produced by a large drum is louder than that by small one because of its large vibrating area. If we strike a tuning fork on a rubber pad, a feeble sound will be heard. But if the vibrating tuning fork is placed vertically on the surface of a bench, we will hear a louder sound. From this, we can conclude that the loudness increases with the area of the vibrating body and vice versa.

(c) **Distance from the vibrating body:** Loudness of sound also depends upon the distance of the vibrating body from the listener. It is caused by the decrease in amplitude due to increase in distance.
Loudness also depends upon the physical condition of the ears of the listener. A sound appears louder to a person with sensitive ears than to a person with defective ears. However, there is a characteristic of sound which does not depend upon the sensitivity of the ear of the listener and it is called intensity of sound.

Pitch: ***Pitch is the characteristic of sound by which we can distinguish between a shrill and a grave sound.***

It depends upon the frequency. A higher pitch means a higher frequency and vice versa. The frequency of the voice of ladies and children is higher than that of men. Therefore, the voice of ladies and children is shrill and of high pitch. The relationship between frequency and pitch is illustrated in Fig. 11.8.

Quality: ***The characteristic of sound by which we can distinguish between two sounds of same loudness and pitch is called quality.***

While standing outside a room, we can distinguish between the notes of a piano and a flute being played inside the room. This is due to the difference in the quality of these notes.

Figure 11.9 shows the waveform of the sound produced by a tuning fork, flute and clarinet. The loudness and the pitch of

For your information

Thin-walled glass goblets can vibrate when hit by sound waves. This is due to a phenomenon of sound known as resonance. Some singers can produce a loud note of particular frequency such that it vibrates the glass so much that it shatters.

Interesting information

Some people use silent whistle to call dogs whose frequency lies between 20,000 Hz to 25,000 Hz. It is silent for human but not for dogs because the audible frequency range for dogs is much higher.

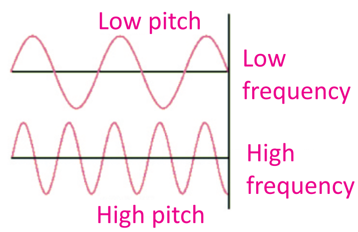


Fig 11.8: Variation of pitch with frequency

For your information

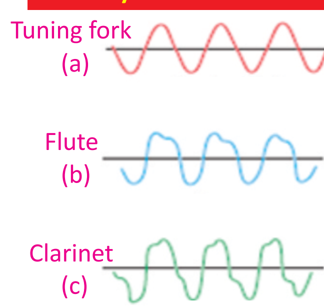


Fig 11.9: Sound waveforms produced by (a) a tuning fork, (b) a flute, and (c) a clarinet, are all at approximately the same frequency. Pressure is plotted vertically, time

these three sounds are the same but their waveforms are different. So their quality is different and they can be distinguished from each other.

Intensity

The sound waves transfer energy from the sounding body to the listener. The intensity of sound depends on the amplitude of sound wave and is defined as:

Sound energy passing per second through a unit area held perpendicular to the direction of propagation of sound waves is called intensity of sound.

Intensity is a physical quantity and can be measured accurately. The unit of intensity of sound is watt per square metre ($W\,m^{-2}$).

Sound Intensity Level

The human ear responds to the intensities ranging from $10^{-12}\,W\,m^{-2}$ to more than $1\,W\,m^{-2}$ (which is loud enough to be painful). Because the range is so wide, intensities are scaled by factors of ten. The barely audible and the faintest intensity of sound i.e., $10^{-12}\,W\,m^{-2}$ is taken as reference intensity, called zero bel (a unit named after Alexander Graham Bell).

The loudness of a sound depends not only on the intensity of sound but also on the physical conditions of the ear. The human ear is more sensitive to some frequencies rather than the others.

The loudness (L) of a sound is directly proportional to the logarithm of intensity i.e.,

$$L \propto \log I$$

$$L = K \log I \qquad .... (11.1)$$

where K is a constant of proportionality.

Let L_o be the loudness of the faintest audible sound of intensity I_o and L be the loudness of an unknown sound of intensity I, then by Eq. (11.1), we can write

$$L_o = K \log I_o \qquad .... (11.2)$$

Subtracting Eq. (11.2) from Eq. (11.1), we get

Quick Quiz

1. Why the voice of women is more shrill than that of men?
2. Which property of sound wave determines its: (a) loudness (b) pitch?
3. What would happen to the loudness of sound with increase in its frequency?

Do you know?

Frequency of tuning fork depends on the mass of its prongs. The greater the mass, the lower the frequency of vibration which means the lower the pitch.

For your information

A sound wave with a frequency of 3500 Hz and an intensity of 80 dB sounds about twice as loud to us as a sound of 125 Hz and 80 dB. It is because our ears are more sensitive to the 3500 Hz sound than to the 125 Hz. Therefore intensity by itself does not mean loudness. Loudness is how our ears detect and our brain perceives the intensity of sound waves.

$$L - L_o = K(\log I - \log I_o) = K \log \frac{I}{I_o}$$

This difference, $(L - L_o)$, between the loudness L of an unknown sound and the loudness L_o is called the intensity level of the unknown sound. Therefore, the intensity level of an unknown sound is given by

$$\text{Intensity level} = K \log \frac{I}{I_o} \quad \text{..........} \quad (11.3)$$

The value of K depends not only on the units of I and I_o but also on the unit of intensity level. If intensity I of any unknown sound is 10 times greater than the intensity I_o of the faintest audible sound i.e., $I = 10I_o$ and the intensity level of such a sound is taken as unit, called bel, the value of K becomes 1. Therefore, using $K = 1$, Eq. (11.3) becomes

$$\text{Intensity level} = \log \frac{I}{I_o} \text{ (bel)} \quad \text{..........} \quad (11.4)$$

bel is a very large unit of intensity level of a sound. Generally, a smaller unit called decibel is used. Decibel is abbreviated as (dB). It must be remembered that 1 bel is equal to 10 dB. If the intensity level is measured in decibels, Eq. (11.4) becomes

$$\text{Intensity level} = 10 \log \frac{I}{I_o} \text{ (dB)} \quad \text{..........} \quad (11.5)$$

Using Eq. (11.5), we can construct a scale for measuring the intensity level of sound. Such scale is known as "decibel scale". The intensity level of different sounds in decibel is given in Table 11.1.

Example 11.1: Calculate the intensity levels of the (a) faintest audible sound (b) rustling of leaves.

Solution: (a) Intensity level of faintest audible sound can be calculated by substituting $I = I_o = 10^{-12}$ Wm^{-2} in Eq. (11.5). Therefore,

$$\text{Intensity level of faintest audible sound} = 10 \log \frac{10^{-12}}{10^{-12}} \text{ dB}$$

$$= 0 \text{ dB}$$

(b) As the intensity of the rustle of leaves is $I = 10^{-11}$ W m^{-2},

Table 11.1

Sources of Sound	Intensity (Wm^{-2})	Intensity level (dB)
Nearby jet airplane	10^{3}	150
Jackhammer/Fast train	10^{1}	130
Siren	10^{0}	120
Lawn mover	10^{-2}	100
Vacuum cleaner	10^{-5}	70
Mosquito buzzing	10^{-8}	40
Whisper	10^{-9}	30
Rustling of leaves	10^{-11}	10
Faintest audible sound i.e., Threshold	10^{-12}	0

For your information

Logarithmic scale	Linear scale
Decibels (dB)	**Amplitude (m)**
0	1
20	10
40	100
60	1,000
80	10,000
100	1000,000
120	1,000,000

The decibel scale is a *logarithmic* measure of the amplitude of sound waves. In a logarithmic scale, equal intervals correspond to multiplying by 10 instead of adding equal amounts.

therefore,

Intensity level due to rustling of leaves = $10 \log 10^{-11}/10^{-12}$ dB

= 10 log10 dB

= 10 dB

11.3 REFLECTION (ECHO) OF SOUND

When we clap or shout near a reflecting surface such as a tall building or a mountain, we hear the same sound again a little later. What causes this? This sound which we hear is called an echo and is a result of reflection of sound from the surface.

When sound is incident on the surface of a medium it bounces back into the first medium. This phenomenon is called echo or reflection of sound.

The sensation of sound persists in our brain for about 0.1 s. To hear a clear echo, the time interval between our sound and the reflected sound must be at least 0.1 s. If we consider speed of sound to be 340 ms^{-1} at a normal temperature in air, we will hear the echo after 0.1 s. The total distance covered by the sound from the point of generation to the reflecting surface and back should be at least $340\ m\ s^{-1} \times 0.1\ s = 34.0\ m$. Thus, for hearing distinct echoes, the minimum distance of the obstacle from the source of sound must be half of this distance, i.e., 17 m. Echoes may be heard more than once due to successive or multiple reflections.

Activity 11.3: Take two identical plastic pipes of suitable length, as shown in Fig. 11.10. (We can make the pipes using chart paper).

- Arrange the pipes on a table near a wall.
- Place a clock near the open end of one of the pipes and try to hear the sound of the clock through the other pipe.
- Adjust the position of the pipes so that you can hear the sound of the clock clearly.
- Now, measure the angles of incidence and reflection and see the relationship between the angles.

Interesting information

A blue whale's 180 dB rumble is the loudest animal sound ever recorded. Whale sounds also appear to be a part of a highly evolved communication system. Some whales are thought to communicate over hundreds and may be thousands of kilometres. This is possible, in part, because sound waves travel five times faster in water than in air. In addition, the temperature characteristics of ocean water — decrease in temperature with depth — create a unique sound phenomenon.

Do you know?

Elephants use low frequency sound waves to communicate with one another. Their large ears enable them to detect these low frequency sound waves, which have relatively long wavelengths. Elephants can effectively communicate in this way, even when they are separated by many kilometres.

- Lift the pipe on the right vertically to a small height and observe what happens.

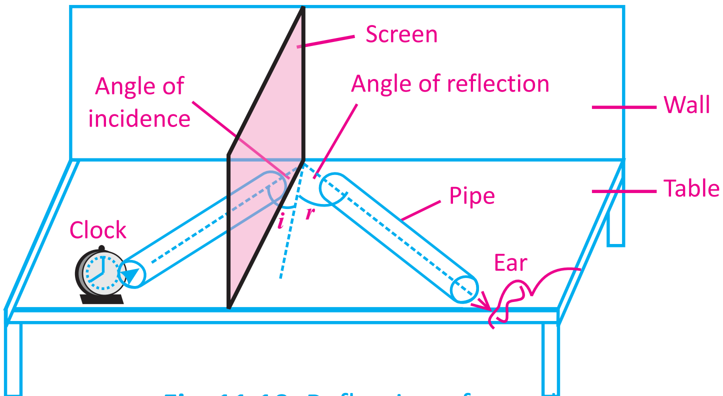
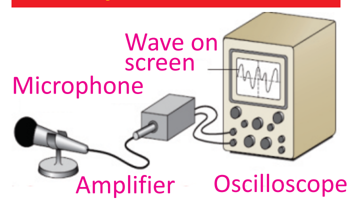


Fig. 11.10: Reflection of sound

For your information



By using an oscilloscope, you can "see" sound waves.

11.4 SPEED OF SOUND

Sound waves can be transmitted by any medium containing particles that can vibrate. They cannot pass through vacuum. However, the nature of the medium will affect the speed of the sound waves. In general, the speed of sound in a liquid is five times that in gases; the speed of sound in solid is about fifteen times that in gases. The speed of sound in air is affected by changes in some physical conditions such as temperature, pressure and humidity etc.

The speed of sound in air is 343 m s^{-1} at one atmosphere of pressure and room temperature (21°C). The speed varies with temperature and humidity. The speed of sound in solids and liquids is faster than in air. Following relation can be used to find the speed of sound:

$$v = f\lambda \quad .... (11.6)$$

where v is the speed, f is the frequency and λ is the wavelength of sound wave.

Table 11.1
Speed of sound in various media

Medium	Speed (m s^{-1})
Gases	
Air(0°C)	331
Air (25°C)	346
Air(100°C)	386
Hydrogen (0°C)	1290
Oxygen (0°C)	317
Helium (0°C)	972
Liquids at 25°C	
Distilled water	1498
Sea water	1531
Solids 25°C	
Wood	2000
Aluminium	6420
Brass	4700
Nickel	6040
Iron	5950
Steel	5960
Flint Glass	3980

Example 11.2: Calculate the frequency of a sound wave of speed 340 m s^{-1} and wavelength 0.5 m.

Solution: Given that; speed of waves $v = 340$ m s^{-1}

Wavelength $\lambda = 0.5$ m
Using the formula $v = f\ \lambda$
Putting the values

$f = 340\ m\ s^{-1}/0.5\ m = 680\ Hz$

Measuring Speed of Sound by Echo Method

Apparatus: Measuring tape, stopwatch, flat wall that can produce a good echo.

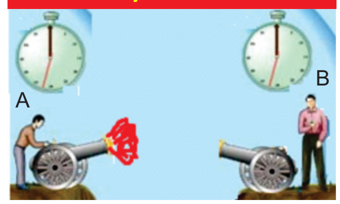
Procedure:

1. Use the tape to measure a distance of 50 metres from the wall.
2. Now clap your hands in front of the wall at a distance of 50 metres and check if you can clearly hear an echo from the wall. Make sure the echo is not coming from any other wall in the area. The time taken by the sound to travel 100 metres is the time difference between the clap and the echo.
3. Now restart the clapping and start the stopwatch at the first clap. Count the number of claps, and stop the clapping and the stopwatch when you hear the echo of the 10th clap (say).
4. Now find the average time for 10 claps. After calculating the time interval *t* between claps and using the formula *S = vt,* we can calculate the speed of the sound.

Example 11.3: Flash of lightning is seen 1.5 seconds earlier than the thunder. How far away is the cloud in which the flash has occurred? (speed of sound = $332\ m\ s^{-1}$).

Solution: Given that, time $t = 1.5$ s, speed of sound $v = 332\ m\ s^{-1}$.
Therefore, distance of the cloud $S = vt = 1.5\ s \times 332\ m\ s^{-1} = 498$ m.

Do you know?



The speed of sound in air was first accurately measured in 1738 by members of the French Academy. Two cannons were set up on two hills approximately 29 km apart. By measuring the time interval between the flash of a cannon and the "boom", the speed of sound was calculated. Two cannons were fired alternatively to minimize errors due to the wind and to delayed reactions in the observers. From their observations, they deduced that sound travels at about $336\ m\ s^{-1}$ at $0^{\circ}C$.

11.5 NOISE POLLUTION

We enjoy the programmes on radio or television by hearing sounds of different qualities. In musical programmes, we hear sound produced by musical instruments such as flute, harmonium, violin, drum etc. Sound of these instruments has pleasant effect on our ears. Such sounds which are pleasant to our ears are called musical sounds. However, some sounds produce unpleasant effects on our ears such as sound of machinery, the slamming of a door, and sounds of traffic in big cities. Sound which has jarring and unpleasant effect on our ears is called noise. Noise corresponds to irregular and sudden vibrations produced by some sounds.

Noise pollution has become a major issue of concern in big cities. Noise is an undesirable sound that is harmful for health of human and other species. Transportation equipment and heavy machinery are the main sources of noise pollution. For example, noise of machinery in industrial areas, loud vehicle horns, hooters and alarms. Noise has negative effects on human health as it can cause conditions such as hearing loss, sleep disturbances, aggression, hypertension, high stress levels. Noise can also cause accidents by interfering with communication and warning signals.

A safe level of noise depends on two factors: the level (volume) of the noise; and the period of exposure to the noise. The level of noise recommended in most countries is usually 85-90 dB over an eight-hour workday. Noise pollution can be reduced to acceptable level by replacing the noisy machinery with environment friendly machinery and equipments, putting sound-reducing barriers, or using hearing protection devices.

Activity 11.4: Develop an action plan to help you address any problem(s) with noise in your workplace considering the following points:

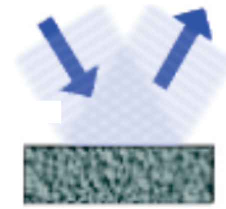
1. Describe the problem(s).
2. What are the sources of the problem(s)?
3. Who are the people being affected?
4. Your suggestions for the solution.

11.6 IMPORTANCE OF ACOUSTICS

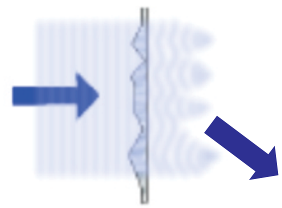
The technique or method used to absorb undesirable sounds by soft and porous surfaces is called acoustic protection.

Reflection of sound is more prominent if the surface is rigid and smooth, and less if the surface is soft and irregular. Soft,

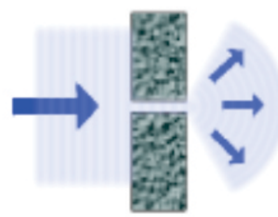
Physics insight



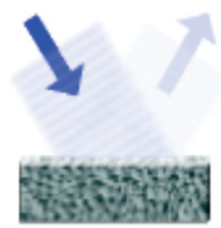
Reflection



Refraction



Diffraction



Absorption

Sound displays all the properties of waves when it interacts with materials and boundaries.

porous materials, such as draperies and rugs absorb large amount of sound energy and thus quiet echoes and softening noises. Thus by using such material in noisy places we can reduce the level of noise pollution. However, if the surface of classrooms or public halls are too absorbent, the sound level may be low for the audience. Sometimes, when sound reflects from the walls, ceiling, and floor of a room, the reflecting surfaces are too reflective and the sound becomes garbled. This is due to multiple reflections called reverberations. In the design of lecture halls, auditorium, or theater halls, a balance must be achieved between reverberation and absorption. It is often advantageous to place reflective surfaces behind the stage to direct sound to the audience.

Generally, the ceilings of lecture halls, conference halls and theatre halls are curved so that sound after reflection may reach all the corners of the hall (Fig 11.11). Sometimes curved sound boards are placed behind the stage so that sound after reflection distributed evenly across the hall (Fig. 11.12).

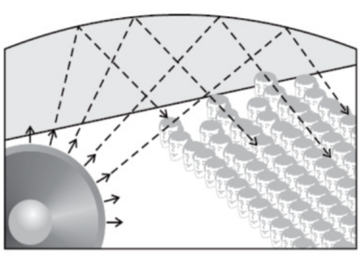


Fig. 11.11: Curved ceiling of a conference hall

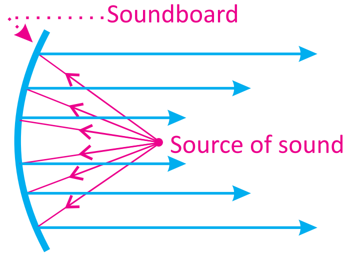
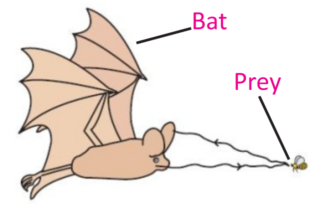


Fig. 11.12: Soundboard used in a big hall

11.7 AUDIBLE FREQUENCY RANGE

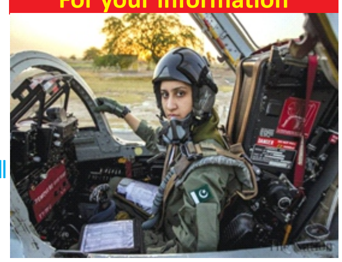
We know that sound is produced by a vibrating body. A normal human ear can hear a sound only if its frequency lies between 20Hz and 20,000 Hz. In other words, a human ear neither hears a sound of frequency less than 20 Hz nor a sound of frequency more than 20,000 Hz. Different people have different range of audibility. It also decreases with age. Young children can hear sounds of 20, 000 Hz but old people cannot hear sounds even above 15, 000 Hz.

For your information



The phrase "blind as a bat" is a false statement. Bats have some vision using light, but when placed in pitch-black rooms crisscrossed with fine wires, they can easily fly around and unerringly locate tiny flying insects for food. We usually assume that vision requires light but both bats and dolphins have the ability to "see" using sound waves. Research in science and technology has developed "eyes" that enable humans also to see using sound waves.

For your information



Pilots wear special headphones that reduce the roar of an airplane engine to a quiet hum.

The range of the frequencies which a human ear can hear is called the audible frequency range.

11.8 ULTRASOUND

Sounds of frequency higher than 20, 000 Hz which are inaudible to normal human ear are called ultrasound or ultrasonics.

Uses of Ultrasound

- Ultrasonic waves carry more energy and higher frequency than audible sound waves. Therefore, according to the wave equation $v = f\lambda$, the wavelength of ultrasonic waves is very small and is very useful for detecting very small objects.
- Ultrasonics are utilized in medical and technical fields.
- In medical field, ultrasonic waves are used to diagnose and treat different ailments. For diagnosis of different diseases, ultrasonic waves are made to enter the human body through transmitters. These waves are reflected differently by different organs, tissues or tumors etc. The reflected waves are then amplified to form an image of the internal organs of the body on the screen (Fig.11.13). Such an image helps in detecting the defects in these organs.
- Powerful ultrasound is now being used to remove blood clots formed in the arteries.
- Ultrasound can also be used to get the pictures of thyroid gland for diagnosis purposes.
- Ultrasound is used to locate underwater depths or is used for locating objects lying deep on the ocean floor, etc. The technique is called *SONAR*, *(sound navigation and ranging)*. The sound waves are sent from a transmitter, and a receiver collects the reflected sound (Fig.11.14). The time-lapse is calculated, knowing the speed of sound in water, the distance of the object from the ocean surface can be estimated.

Tidbits

Bats can hear frequencies up to 120,000 Hz. Other animals cannot hear such high-pitched sounds. Mice can hear frequencies up to 100,000 Hz, dogs up to 35,000 Hz, and cats up to 25,000 Hz. Humans hear sounds only upto about 20,000 Hz, but children can usually hear higher-frequency sounds than adults.

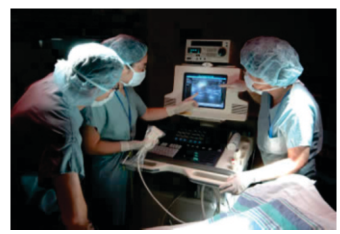


Fig. 11.13: Doctors are taking ultrasound test of a patient with an ultrasound machine

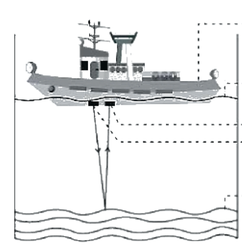


Fig. 11.14: Ultrasonics are used to measure the depth of water by echo method

- SONAR ranging is also used to see the shape and the size of the object.

Cracks appear in the interior of moving parts of high speed heavy machines such as turbines, engines of ships and airplanes due to excessive use. These cracks are not visible from outside but they can be very dangerous. Such cracks can be detected by ultrasonics. A powerful beam of ultrasound is made to pass through these defective parts. While passing, these waves are reflected by the surface of these cracks and flaws. The comparison of the ultrasonic waves reflected from cracks and from the surfaces of these parts can give a clue of the existence of the cracks.

- Germs and bacteria in liquids can also be destroyed by using high intensity ultrasonic waves.

SUMMARY

- Sound is produced by a vibrating body. It travels in the medium from one place to another in the form of compressional waves.
- Loudness is a feature of sound by which a loud and a faint sound can be distinguished. It depends upon the amplitude, surface area and distance from the vibrating body.
- Sound energy flowing per second through unit area held perpendicular to the direction of sound waves is called the intensity of sound. bel is unit of the intensity level of sound, where 1 bel = 10 decibels
- Pitch of the sound is the characteristics of sound by which a shrill sound can be distinguished from a grave one. It depends upon the frequency.
- The characteristics of sound by which two sound waves of same loudness and pitch are distinguished from each other is called the quality of sound.
- The sounds with jarring effect on our ears are called noise and the sounds having pleasant effect on our ears are called musical sounds.
- Noise pollution has become a major issue of concern in some big cities. Any form of sound which disturbs the normal functioning of any natural ecosystem or some human community is the cause of noise pollution.
- Noise pollution can be reduced to acceptable level by replacing the rusty noisy machinery with environment friendly machinery and equipments, putting sound-reducing barriers, or using hearing protection devices.
- The technique or method used to absorb undesirable sound energy by soft and porous surfaces is called acoustic protection. This can be done by using soft, rough and porous materials.

- Human audible frequency range lies between 20 Hz to 20, 000 Hz.
- Sound waves of frequency higher than 20, 000 Hz are called ultrasound while sound waves of frequency lower than 20 Hz are called infrasound.
- Ultrasound is used in many fields of science and technology such as medical, engineering, agriculture. In medical field ultrasound is used to diagnose and treat different ailments. Ultrasound is also used to locate underwater depths or for locating objects lying deep on the ocean floor. The technique is called *SONAR*, an acronym for *sound navigation and ranging*.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the following choices:

i. Which is an example of a longitudinal wave?
   (a) sound wave (b) light wave
   (c) radiowave (d) water wave

ii. How does sound travel from its source to your ear?
   (a) by changes in air pressure (b) by vibrations in wires or strings
   (c) by electromagnetic wave (d) by infrared waves

iii. Which form of energy is sound?
   (a) electrical (b) mechanical
   (c) thermal (d) chemical

iv. Astronauts in space need to communicate with each other by radio links because
   (a) sound waves travel very slowly in space
   (b) sound waves travel very fast in space
   (c) sound waves cannot travel in space
   (d) sound waves have low frequency in space

v. The loudness of a sound is most closely related to its
   (a) frequency (b) period
   (c) wavelength (d) amplitude

vi. For a normal person, audible frequency range for sound wave lies between
   (a) 10 Hz and 10 kHz (b) 20 Hz and 20 kHz
   (c) 25 Hz and 25 kHz (d) 30 Hz and 30 kHz

vii. When the frequency of a sound wave is increased, which of the following will decrease?
   i. wavelength ii. period iii. amplitude
   (a) i only (b) iii only
   (c) i and ii only (d) i and iii only

REVIEW QUESTIONS

11.1. What is the necessary condition for the production of sound?

11.2. What is the effect of the medium on the speed of sound? In which medium sound travels more faster: air, solid or liquid? Justify your answer.

11.3. How can you prove the mechanical nature of sound by a simple experiment?

11.4. What do you understand by the longitudinal wave? Describe the longitudinal nature of sound waves.

11.5. Sound is a form of wave. List at least three reasons to support the idea that sound is a wave.

11.6. We know that waves manifest phenomenon of reflection, refraction and diffraction. Does sound also manifest these characteristics?

11.7. What is the difference between the loudness and intensity of sound? Derive the relationship between the two.

11.8. On what factors does the loudness of sound depend?

11.9. What do you mean by the term intensity level of the sound? Name and define the unit of intensity level of sound.

11.10. What are the units of loudness? Why do we use logarithmic scale to describe the range of the sound intensities we hear?

11.11. What is difference between frequency and pitch? Describe their relationship graphically.

11.12. Describe the effect of change in amplitude on loudness and the effect of change in frequency on pitch of sound.

11.13. If the pitch of sound is increased, what are the changes in the following?

a. the frequency b. the wavelength

c. the wave velocity d. the amplitude of the wave

11.14. If we clap or speak in front of a building while standing at a particular distance, we rehear our sound after sometime. Can you explain how does this happen?

11.15. What is the audible frequency range for human ear? Does this range vary with the age of people? Explain.

11.16. Explain that noise is a nuisance.

11.17. Describe the importance of acoustic protection.

11.18. What are the uses of ultrasound in medicine?

CONCEPTUAL QUESTIONS

11.1. Why two tin cans with a string stretched between them could be better way to communicate than merely shouting through the air?

11.2. We can recognize persons speaking with the same loudness from their voice. How is this possible?

11.3. You can listen to your friend round a corner, but you cannot watch him/her. Why?

11.4. Why must the volume of a stereo in a room with wall-to-wall carpet be tuned higher than in a room with a wooden floor?

11.5. A student says that the two terms *speed* and *frequency* of the wave refer to the same thing. What is your response?

11.6. Two people are listening to the same music at the same distance. They disagree on its loudness. Explain how this could happen.

11.7. Is there any difference between echo and reflection of sound? Explain.

11.8. Will two separate 50 dB sounds together constitute a100 dB sound? Explain.

11.9. Why ultrasound is useful in medical field?

NUMERICAL PROBLEMS

11.1. A normal conversation involves sound intensities of about 3.0×10^{-6} W m^{-2}. What is the decibel level for this intensity? What is the intensity of the sound for 100 dB?

Ans. (64.8 dB, 0.01 W m^{-2})

11.2. If at Anarkali Bazar Lahore, intensity level of sound is 80 dB, what will be the intensity of sound there?

Ans. (10^{-4} W m^{-2})

11.3. At a particular temperature, the speed of sound in air is 330 m s^{-1}. If the wavelength of a note is 5 cm, calculate the frequency of the sound wave. Is this frequency in the audible range of the human ear?

Ans. (6.6×10^{3} Hz, Yes)

11.4. A doctor counts 72 heartbeats in 1 min. Calculate the frequency and period of the heartbeats.

Ans. (1.2 Hz, 0.83 s)

11.5. A marine survey ship sends a sound wave straight to the seabed. It receives an echo 1.5 s later. The speed of sound in seawater is 1500 m s^{-1}. Find the depth of the sea at this position.

Ans. (1125 m)

11.6. A student clapped his hands near a cliff and heard the echo after 5 s. What is the distance of the cliff from the student if the speed of the sound is taken as 346 m s^{-1}?

Ans. (865 m)

11.7. A ship sends out ultrasound that returns from the seabed and is detected after 3.42 s. If the speed of ultrasound through seawater is 1531 m s^{-1}, what is the distance of the seabed from the ship?

Ans. (2618 m)

11.8. The highest frequency sound humans can hear is about 20,000 Hz. What is the wavelength of sound in air at this frequency at a temperature of 20 °C? What is the wavelength of the lowest sounds we can hear of about 20 Hz? Assume the speed of sound in air at 20 °C is 343 m s^{-1}.

Unit 12

GEOMETRICAL OPTICS

After studying this unit. students will be able to:

- describe the terms used in reflection including normal, angle of incidence, angle of reflection and state laws of reflection.
- solve problems of image location by spherical mirrors by using mirror formula.
- define the terminology for the angle of incidence *i* and angle of refraction *r* and describe the passage of light through parallel-sided transparent material.
- solve problems by using the equation sin i /sin $r = n$ (refractive index).
- state the conditions for total internal reflection.
- describe the passage of light through a glass prism.
- describe how total internal reflection is used in light propagation through optical fibres.
- describe how light is refracted through lenses.
- define power of a lens and its unit.
- solve problems of image location by lenses using lens formula.
- define the terms resolving power and magnifying power.
- draw ray diagram of simple microscope and mention its magnifying power.
- draw ray diagram of compound microscope and mention its magnifying power.
- draw ray diagram of a telescope and mention its magnifying power.
- draw ray diagrams to show the formation of images in the normal eye, a short-sighted eye and a long-sighted eye.
- describe the correction of short-sight and long-sight.

Science, Technology and Society Connections

The students will be able to:

- describe the use of spherical mirrors for safe driving, blind turns on hilly roads, dentist mirror.
- describe the use of optical fibres in telecommunications and medical field and state the advantages of their use.
- describe the use of a single lens as a magnifying glass and in a camera, projector and photographic enlarger and draw ray diagrams to show how each forms an image.
- describe the use of lenses/contact lenses for rectifying vision defects of the human eye.
- describe the exploration of the world of micro-organisms by using microscopes and of distant celestial bodies by telescopes.

Light is the main focus of this unit. We shall describe different phenomena of light such as reflection, refraction and total internal reflection. We will learn how images are formed by mirrors and lenses and will discuss working principle of compound microscope and telescope.

12.1 REFLECTION OF LIGHT

Reflection of light is illustrated in Fig. 12.1. When a ray of light from air along the path AO falls on a plane mirror M, it is reflected along the path OB. The ray AO is called incident ray while the ray OB is called reflected ray. The angle between incident ray AO and normal N, i.e., 8 AON is called the angle of incidence represented by ***i***. The angle between the normal and the reflected ray OB, i.e., 8 NOB is called angle of reflection represented by *r*.

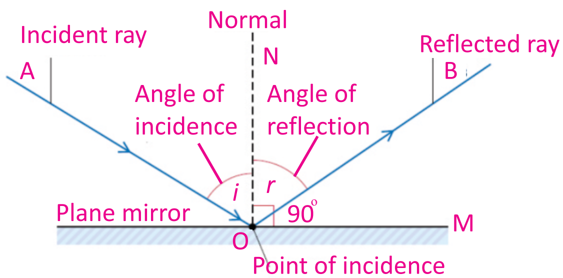


Fig. 12.1: Reflection of light

Now we can define the phenomenon of reflection as:

When light travelling in a certain medium falls on the surface of another medium, a part of it turns back in the same medium.

Laws of Reflection

(i) The incident ray, the normal, and the reflected ray at the point of incidence all lie in the same plane.
(ii) The angle of incidence is equal to the angle of reflection i.e., i = r.

Physics of Light

We see a page of a book because light reflects from each part of the page in all directions, so that some of the light rays from each part of the page enter our eye. Because almost no light is reflected by the printed words, we "see" them as black areas.

For your information

In the early 1700s, there were two ideas about the nature of light: particle nature and wave nature. Newton put forward the idea of corpuscular nature of light. According to him, light consists of tiny, fast-moving particles. Maxwell formulated the wave theory of light. In 1802, Thomas Young proved the wave nature of light experimentally. In 1900, Planck suggested that light consists of small packets of energy called photon. Later on idea of photon was confirmed by experiments. Now we know that light has dual nature; light as well as particle nature.

Types of Reflection

Nature of reflection depends on smoothness of the surface. For example, a smooth surface of silver reflects rays of light in one direction only. The reflection by these smooth surfaces is called ***regular*** reflection (Fig.12.2). Most of the objects in everyday world are not smooth on the microscopic level. The rough surfaces of these objects reflect the rays of light in many directions. Such type of reflection is called ***irregular*** reflection (Fig. 12.3).

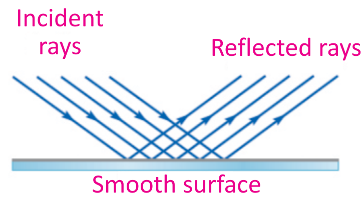


Fig. 12.2: Regular reflection

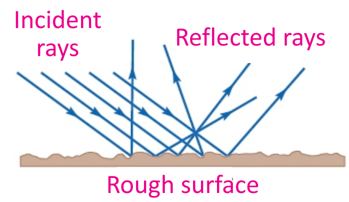
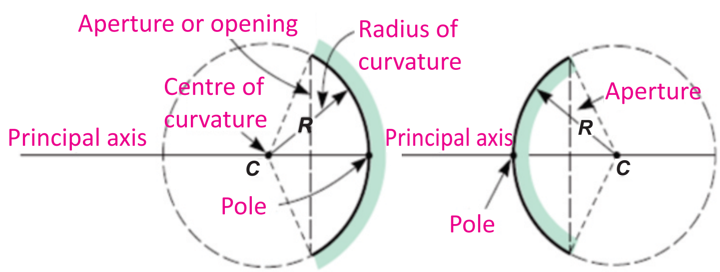


Fig. 12.3: Irregular reflection

12.2 SPHERICAL MIRRORS

A mirror whose polished, reflecting surface is a part of a hollow sphere of glass or plastic is called a spherical mirror. In a spherical mirror, one of the two curved surfaces is coated with a thin layer of silver followed by a coating of red lead oxide paint. Thus, one side of the spherical mirror is opaque and the other side is a highly polished reflecting surface. Depending upon the nature of reflecting surface, there are two types of spherical mirrors as shown in Fig.12.4.



(a) Concave mirror (b) Convex mirror

Fig. 12.4: Types of spherical mirrors

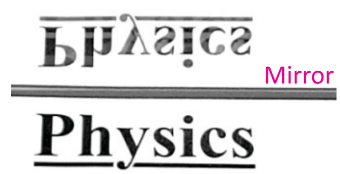
Concave Mirror: A spherical mirror whose inner curved surface is reflecting is called concave mirror. In concave mirror the size of the image depends on the position of the object. Both virtual and real images can be formed by a concave mirror.

Convex Mirror: A spherical mirror whose outer curved surface is reflecting is called convex mirror. In convex mirror the size of the image is always smaller than the object. Only virtual and erect image is formed by a convex mirror.

Pole: It is the midpoint of the curved surface of spherical mirror. It is also called vertex.

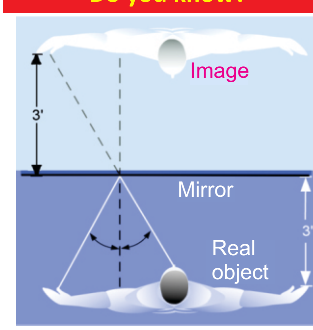
Centre of Curvature (C): A spherical mirror is a part of a

For Your Information



Light rays are reflected in a plane mirror, causing us to see an inverted image.

Do you know?



The image you see in a flat mirror is at the same distance behind the mirror as you are in front of it.

sphere. The centre of this sphere is called centre of curvature.
Radius of Curvature (R): It is the radius of the sphere of which spherical mirror is a part.
Principal Axis: It is the line joining centre of curvature and pole of the spherical mirror.
The Principal focus (*F*): After reflection from a concave mirror, rays of light parallel to the principal axis converge to a point F. This point is called "The Principal Focus" of the mirror (Fig.12.5-a). Hence, Concave mirrors are also called converging mirrors. Since rays actually pass through this point, therefore, it is called real focus.
In the case of a convex mirror, rays parallel to the principal axis after reflection appear to come from a point F situated behind the mirror. In other words rays of light appear to diverge from F. This point is called the principal focus of the convex mirror. Convex mirrors are also called diverging mirrors. The principal focus of a convex mirror is virtual focus because the reflected rays do not actually pass through it but appear to do so (Fig. 12.5-b).
Focal length (f): It is the distance from the pole to the principal focus measured along the principal axis (Fig12.5). The focal length is related to the radius of curvature by $f = R/2$. This means that as the radius of curvature is reduced, so too is the focal length of the reflecting surface.

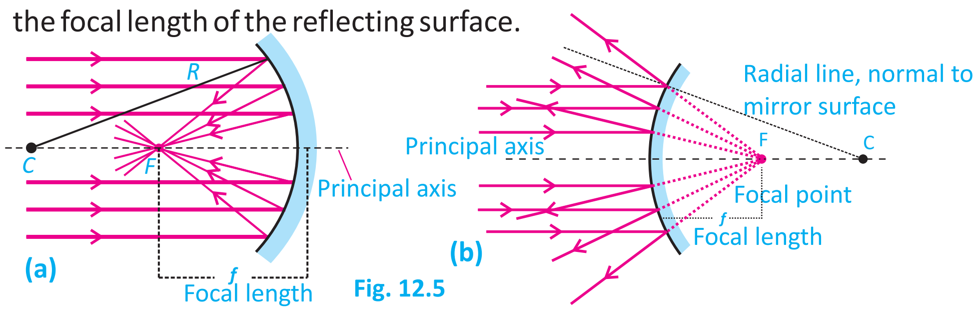


Fig. 12.5

Characteristics of Focus of a Concave and a Convex Mirror

Convex Mirror	Concave Mirror
The Focus lies behind the mirror	The focus is in front of the mirror
The focus is virtual as the rays of light after reflection appear to come from the focus.	The focus is real as the rays of light after reflection converge at the focus.

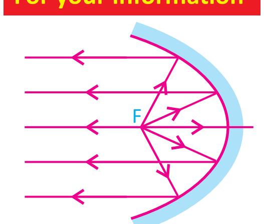
Reflection of Light by Spherical Mirrors

Like plane surfaces, spherical surfaces also reflect light following the two laws of reflection as stated for plane

Can you tell?

In this picture you can see clearly the image of a lion formed inside the pond water. Can you tell which phenomenon of physics is involved here?

For your information



Parabolic mirror used in head lights.

surfaces. Fig.12.6 shows how light is reflected by the spherical surfaces of concave and convex mirrors according to the two laws of reflection.

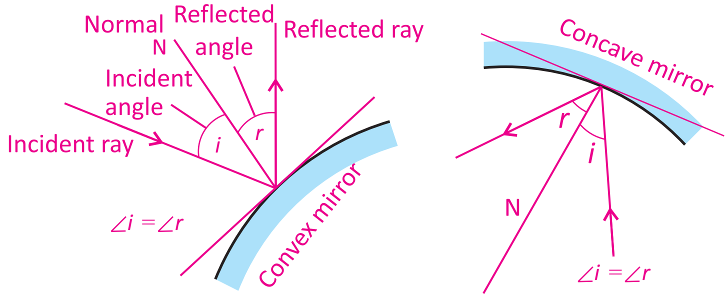


Fig.12.6: Reflection of light by spherical mirrors

Activity12.2: Take a convex mirror or a well polished spoon (using the outside of the spoon, with the convex surface bulging outward), and hold it in one hand. Hold a pencil with its tip in the upright position in the other hand. Try to look at its image in the mirror. Is the image erect or inverted? Is the image smaller or larger in size than the object? Move the pencil away from the mirror. Does the image become smaller or larger? Guess, whether the image will move closer to or farther from the focus?

12.3 IMAGE LOCATION BY SPHERICAL MIRROR FORMULA

How can we tell about the nature of image (whether image is real or imaginary, inverted or erect) formed in a mirror? How can we tell about the size of the image compared with the size of the object? To answer these questions, one method is graphical or ray diagram. But, we can also answer these questions by using a mathematical formula called the mirror formula defined as:

Mirror formula is the relationship between object distance p, image distance q from the mirror and focal length f of the mirror.

Thus we can write mirror formula as:

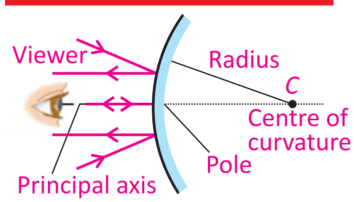
$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \quad .... \quad (12.1)$$

Equation (12.1) is true for both concave and convex mirrors. However, following sign conventions should be

Spoon as mirror

A well polished spoon acts as convex (right) and concave (left) mirrors.

Physics insight



For a convex mirror, focus and centre of curvature lie behind the mirror.

Point to ponder

In large shopping centres, convex mirrors are used for security purposes. Do you know why?

For your information

The focal length of a spherical mirror is one-half of the radius of curvature i.e., $f = R/2$. However, we take the focal length of a convex mirror as negative. It is because the rays appear to come from the focal point behind the mirror. Therefore, for a convex mirror, $f = -R/2$.

followed to apply this equation for solving problems related to mirrors.

Sign Conventions

Quantity	When Positive (+)	When Negative (–)
Object distance p	Real object	Virtual object
Image distance q	Real Image	Virtual image
Focal length f	Concave mirror	Convex mirror

Activity12.3: Take a concave mirror or a well polished spoon (using inside of the spoon with concave surface bulging inward). Hold it in hand towards a distant object, such as the Sun, a building, a tree or a pole. Try to get a sharp, well-focused image of the distant object on the wall or a screen. Measure the distance of the screen from the mirror using a metre scale. Can you find out the rough focal length of the concave mirror? Draw the ray diagram to show the image formation in this situation.

Example 12.1: A convex mirror is used to reflect light from an object placed 66 cm in front of the mirror. The focal length of the mirror is 46 cm. Find the location of the image.

Solution: Given that, p = 66 cm and f = - 46 cm

Using mirror formula,

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$

$$\frac{1}{q} = -\frac{1}{46\text{ cm}} - \frac{1}{66\text{ cm}}$$

$$\frac{1}{q} = -\frac{1}{27\text{ cm}}$$

$$q = -27\text{ cm}$$

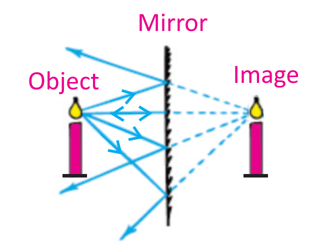
The negative sign indicates that the image is behind the mirror and, therefore, is a virtual image.

Example 12.2: An object is placed 6 cm in front of a concave mirror that has focal length 10 cm. Determine the location of the image.

Physics insight

Note that the word magnification, as used in optics, does not always mean enlargement, because the image could be smaller than the object.

For your information



Ray diagram for the virtual image formation in a plane mirror.

Do you know?

Convex mirrors produce images that are smaller than objects. This increases the view for the observer.

Solution: Given that, $p = 6$ cm and $f = 10$ cm
Using the mirror formula,

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$

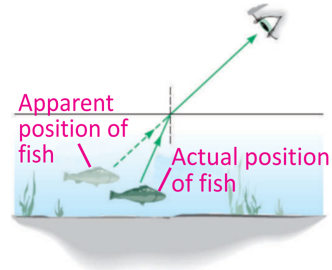
$$\frac{1}{q} = \frac{1}{10\text{ cm}} - \frac{1}{6\text{ cm}}$$

$$\frac{1}{q} = -\frac{1}{15\text{ cm}}$$

$$q = -15\text{ cm}$$

The negative sign indicates that the image is virtual i.e., behind the mirror.

Point to ponder



Why the position of fish inside the water seems to be at less depth than that of its actual position?

12.4 REFRACTION OF LIGHT

If we dip one end of a pencil or some other object into water at an angle to the surface, the submerged part looks bent as shown in Fig.12.7. Its image is displaced because the light coming from the underwater portion of the object changes direction as it leaves the water. This bending of light as it passes from one transparent medium into another is called ***refraction***.

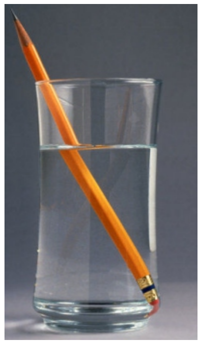


Fig.12.7: Bending of pencil in water due to refraction

Refraction of light can be explained with the help of Fig.12.8. A ray of light IO travelling from air falls on the surface of a glass block.

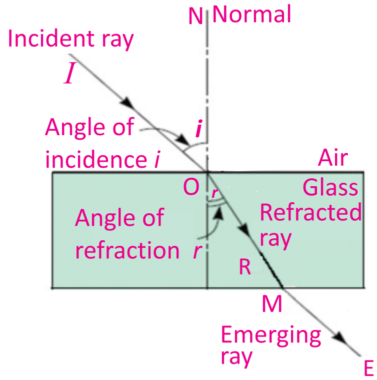
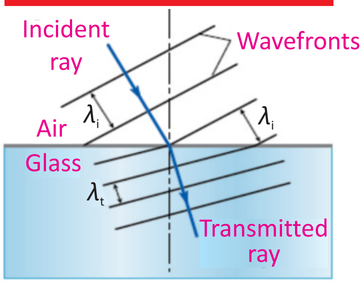


Fig. 12.8: Refraction of light by a glass block

Physics insight



In refraction, the speed of light changes due to change in the wavelength. But, frequency and hence the colour of light does not change.

At the air-glass interface, the ray of light IO changes direction and bends towards the normal and travels along the path OR inside the glass block. The rays IO and OR are called the incident ray and the refracted ray respectively. The angle '*i*' made by the incident ray with the normal is called angle of incidence. The angle '*r*' made by the refracted ray with the normal is called angle of refraction. When refracted ray leaves the glass, it bends away from the normal and travels along a path ME. Thus

The process of bending of light as it passes from air into glass and vice versa is called refraction of light.

LAWS OF REFRACTION

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

(ii) The ratio of the sine of the angle of incidence '*i*' to the sine of the angle of refraction '*r*' is always equal to a constant i.e., $\sin i / \sin r$ = constant = n

where the ratio $\sin i / \sin r$ is known as the refractive index of the second medium with respect to the first medium. So we have

$$\frac{\sin i}{\sin r} = n \quad \text{....... (12.2)}$$

It is called Snell's law.

Speed of light in a medium

Refraction of light is caused by the difference in speed of light in different media. For example, the speed of light in air is approximately 3.0×10^8 m s^{-1} However, when light travels through a medium, such as water or glass, its speed decreases. The speed of light in water is approximately 2.3×10^8 m s^{-1},while in glass, it is approximately 2.0×10^8 m s^{-1}. To describe the change in the speed of light in a medium, we use the term ***index of refraction*** or ***refractive index.***

Refractive Index

The refractive index '*n*' of a medium is the ratio of the speed of light '*c*' in air to the speed '*v*' of light in the medium:

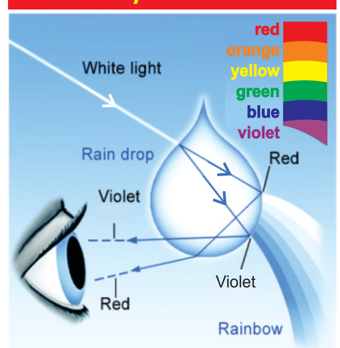
$$\text{Refractive Index} = \frac{\textit{Speed of light in air}}{\textit{Speed of light in medium}}$$

$$\text{or} \quad n = \frac{c}{v} \quad \text{........ (12.3)}$$

For your information

Substance	Index of Refraction (n)
Diamond	2.42
Cubic Zirconia	2.21
Glass (flint)	1.66
Glass(crown)	1.52
Ethyl Alcohol	1.36
Ice	1.31
Water	1.33
Air	1.00

Do you know?



Dispersion of light is due to the variation in refractive index with the colour. Dispersion in drops of water separates the colours of sunlight into a rainbow.

Self Assessment

Whether the bending of light be more or less for a medium with high refractive index?

Example 12.3: A ray of light enters from air into glass. The angle of incidence is 30°. If the refractive index of glass is 1.52, then find the angle of refraction '*r*'.

Solution: Given that, $i = 30°$, $n = 1.52$

Using Snell's law, $\frac{\sin i}{\sin r} = n$

$$1.52 \sin r = \sin 30°$$

or $$\sin r = \sin 30°/1.52$$

$$\sin r = 0.33$$

$$r = \sin^{-1}(0.33)$$

$$r = 19.3°$$

Hence, angle of refraction is 19.3°.

12.5 TOTAL INTERNAL REFLECTION

When a ray of light travelling in denser medium enters into a rarer medium, it bends away from the normal (Fig.12.9-a). If the angle of incidence '*i*' increases, the angle of refraction '*r*' also increases. For a particular value of the angle of incidence, the angle of refraction becomes 90°. The angle of incidence, that causes the refracted ray in the rarer medium to bend through 90° is called critical angle (Fig.12.9-b). When the angle of incidence becomes larger than the critical angle, no refraction occurs. The entire light is reflected back into the denser medium (Fig.12.9-c). This is known as total internal reflection of light.

Example 12.4: Find the value of critical angle for water (refracted angle = 90°). The refractive index of water is 1.33 and that of air is 1.

Solution: When light enters in air from water, Snell's law becomes

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

or $$n \sin i = \sin r$$

$$n \sin i = \sin 90°$$

$$n \sin i = 1$$

But $$n = 1.33$$

Therefore,

$$i = \sin^{-1}[1/1.33]$$

or $$= \sin^{-1}(0.752) = 48.8°$$

$$\text{Critical angle } C = 48.8°$$

Therefore, critical angle of water is 48.8°.

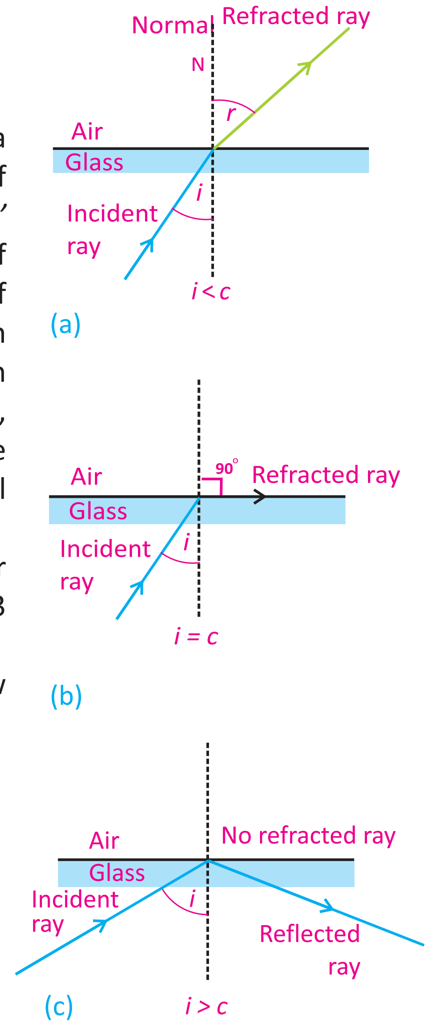


Fig. 12.9: Condition for total internal reflection

12.6 APPLICATIONS OF TOTAL INTERNAL REFLECTION

Totally Internal Reflecting Prism

Many optical instruments use right-angled prisms to reflect a beam of light through 90° or 180° (by total internal reflection) such as cameras, binoculars, periscope and telescope. One of the angles of a right-angled prism is 90°. When a ray of light strikes a face of prism perpendicularly, it enters the prim without deviation and strikes the hypotenuse at an angle of 45°(Fig.12.10). Since the angle of incidence 45°is greater than critical angle of the glass which is 42°, the light is totally reflected by the prism through an angle of 90°. Two such prisms are used in periscope (Fig.12.11). In Fig.12.12, the light is totally reflected by the prism by an angle of 180°. Two such prisms are used in binoculars (Fig.12.13).

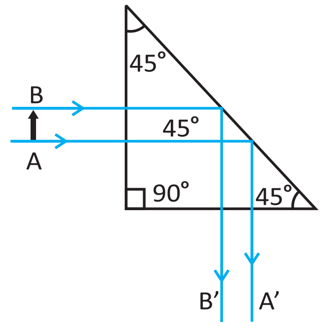


Fig.12.10: Total internal reflection through right angled prism

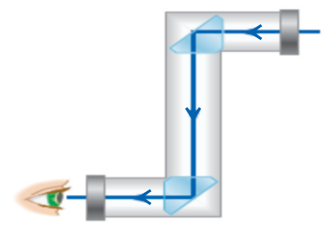


Fig. 12.11: Prism periscope

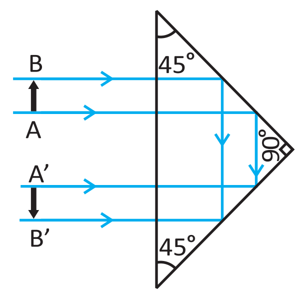


Fig. 12.12

Optical Fibre

Total internal reflection is used in fibre optics which has number of advantages in telecommunication field. Fibre optics consists of hair size threads of glass or plastic through which light can be travelled (Fig. 12.14). The inner part of the fibre optics is called core that carries the light and an outer concentric shell is called cladding. The core is made from glass or plastic of relatively high index of refraction. The cladding is made of glass or plastic, but of relatively low refractive index. Light entering from one end of the core strikes the core-cladding boundary at an angle of incidence greater than critical angle and is reflected back into the core (Fig. 12.14). In this way light travels many kilometres with small loss of energy.

In Pakistan, optical fibre is being used in telephone and advanced telecommunication systems. Now we can listen thousands of phone calls without any disturbance.

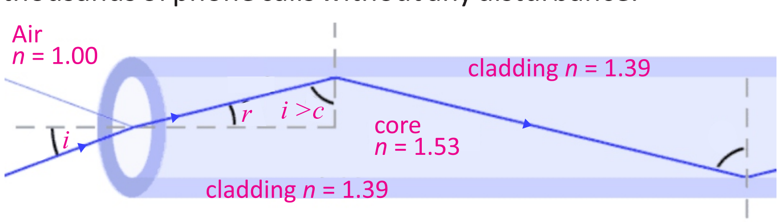


Fig.12.14: Passage of light through optical fibre

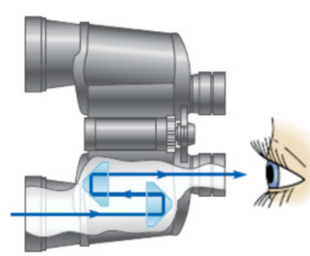


Fig. 12.13: Binoculars

Light Pipe

Light pipe is a bundle of thousands of optical fibres bounded together. They are used to illuminate the inaccessible places by the doctors or engineers. For example, doctors view inside the human body. They can also be used to transmit images from one place to another (Fig. 12.15).

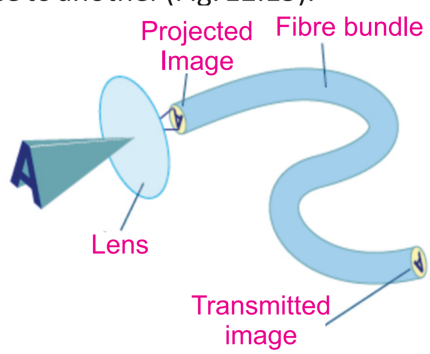


Fig.12.15: A lens and light pipe can be used together to produce a magnified transmitted image of an object

Fig. 12.16: The Doctors are examining a patient with endoscope

Endoscope

An endoscope is a medical instrument used for exploratory diagnostics, and surgical purposes. An endoscope is used to explore the interior organs of the body. Due to its small size, it can be inserted through the mouth and thus eliminates the invasive surgery. The endoscopes used to examine the stomach, bladder and throat are called *Gastroscope*, *C*ystoscope and *B*ronchoscope respectively. An endoscope uses two fibre-optic tubes through a pipe. A medical procedure using any type of endoscope is called endoscopy. The light shines on the organ of patient to be examined by entering through one of the fibre tubes of the endoscope. Then light is transmitted back to the physician's viewing lens through the other fibre tube by total internal reflection (Fig.12.16). Flexible endoscopes have a tiny camera attached to the end. Doctor can see the view recorded by the camera on a computer screen.

12.7 REFRACTION THROUGH PRISM

Prism is a transparent object (made of optical glass) with at least two polished plane faces inclined towards

each other from which light is refracted.
In case of triangular prism (Fig.12.17), the emergent ray is not parallel to the incident ray. It is deviated by the prism from its original path. The incident ray PE makes an angle of incidenace '*i'* at point E and is refracted towards the normal *N* as EF. The refracted ray EF makes an angle '*r'* inside the prism and travels to the other face of the prism. This ray emerges out from prism at point F making an angle 'e'. Hence the emerging ray FS is not parallel to the incident ray PE but is deviated by an angle *D* which is called angle of deviation.

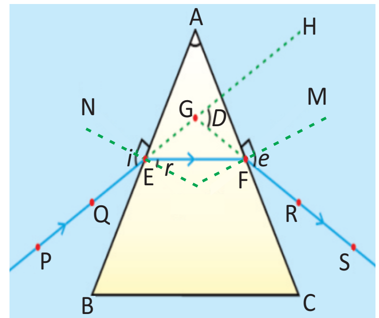


Fig.12.17: Refraction through a triangular glass prism

12.8 LENSES

A lens is any transparent material having two surfaces, of which at least one is curved. Lenses refract light in such a way that an image of the object is formed.
Lenses of many different types are used in optical devices such as cameras, eyeglasses, microscopes, telescopes, and projectors. They also enable millions of people to see clearly and read comfortably.

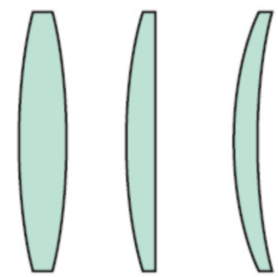


Fig.12.18: Convex lenses

Types of Lenses

There are different types of lenses. The lens which causes incident parallel rays to converge at a point is known as *convex* or *converging* lens. This lens is thick at the centre but thin at the edges (Fig.12.18). Another type of lens causes the parallel rays of light to diverge from a point. This is called concave or diverging lens. This lens is thin at the centre and thick at the edges (Fig.12.19).

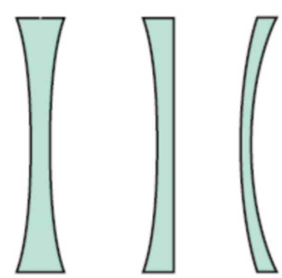


Fig.12.19: Concave lenses

Lens Terminology

Principal Axis: Each of the two surfaces of a spherical lens is a section of a sphere. The line passing through the two centres of curvatures of the lens is called *principal axis (*Fig. 12.20).
Optical Centre, C: A point on the principal axis at the centre of lens is called *optical centre* (Fig. 12.20).

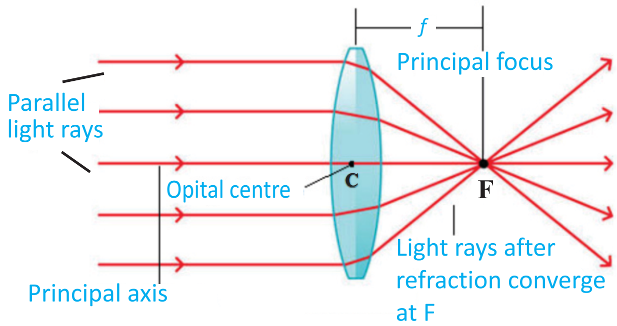


Fig. 12.20: Convex lens

Principal Focus, F: The light rays travelling parallel to the principal axis of a convex lens after refraction meet at a point on the principal axis, called principal *focus* or focal point F. Hence, convex lens is also called converging lens. For a concave lens, the parallel rays appear to come from a point behind the lens called *principal focus* F (Fig. 12.21). Hence concave lens is also called diverging lens.

Focal Length, *f* : This is the distance between the optical centre and the principal focus (Fig. 12.21).

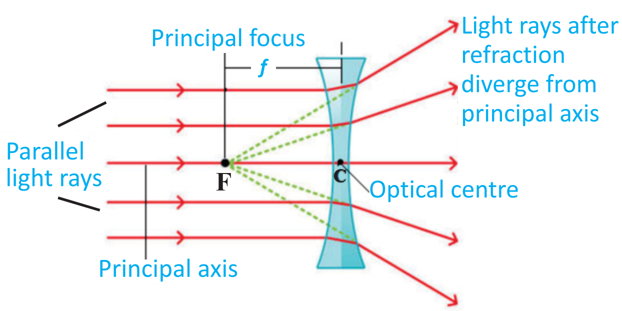
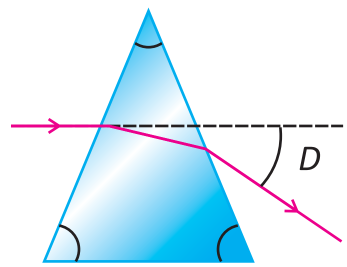


Fig. 12.21: Concave lens

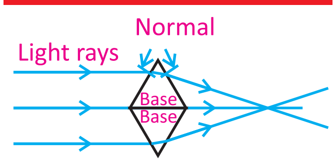
Activity 12.4: Place a convex lens in front of a white screen and adjust its position until a sharp image of a distant object is obtained on the screen. For example, we can do this experiment before an open window to get the image of window on a wall or screen (Fig.12.22). Measure the distance between the lens and the screen. This is the approximate focal length of the lens. Explain. (**Hint:** Make a ray diagram). What is the nature of image?

Refraction through prism



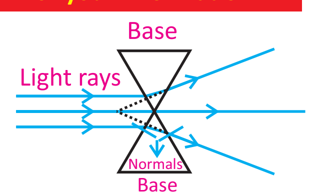
When light passes through prism it deviates from its original path due to refraction.

For your information



System of two prisms resembles a convex lens

For your information



System of two prisms resembles a concave lens

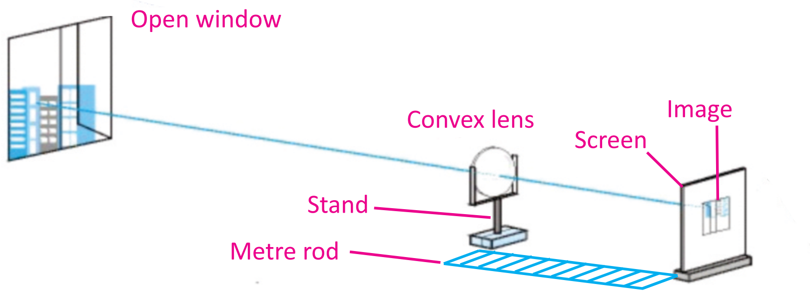


Fig.12.22: Approximate method of finding focal length of a convex lens

Power of a Lens

Power of a lens is defined as the reciprocal of its focal length in metres. Thus

Power of a lens = P = 1 / focal length in metres

The SI unit of power of a lens is "Dioptre", denoted by a symbol D. If f is expressed in metres so that $1\ D = 1\ m^{-1}$. Thus, 1 Dioptre is the power of a lens whose focal length is 1 metre. Because the focal length of a convex lens is positive, therefore, its power is also positive. Whereas the power of a concave lens is negative, for it has negative focal length.

For your information

Dioptres are handy to use because if two thin lenses are placed side by side, the total power is simply the sum of the individual powers. For example, an ophthalmologist places a 2.00 dioptre lens next to 0.35 dioptre lens and immediately knows that the power of the combination is 2.35 dioptres.

12.9 IMAGE FORMATION BY LENSES

In mirrors images are formed through reflection, but lenses form images through refraction. This is explained with the help of ray diagrams as follows:
Image formation in convex lens can be explained with the help of three principal rays shown in Fig.12.23

1. The ray parallel to the principal axis passes through the focal point after refraction by the lens.
2. The ray passing through the optical centre passes straight through the lens and remains undeviated.
3. The ray passing through the focal point becomes

Remember it

When dealing with diverging lenses, you must be careful not to omit the negative sign associated with the focal length and the image position.

parallel to the principal axis after refraction by the lens.

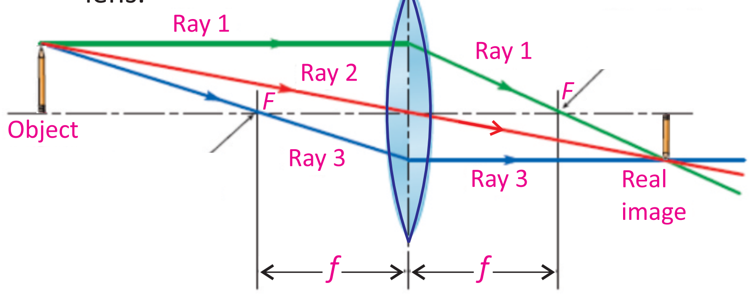


Fig. 12.23: Convex Lens

For your information

You can compare lenses simply by looking at them.

A lens with a long focal length is thin; its surfaces are not very strongly curved.

A lens with a short focal length is fatter; its surfaces are more strongly curved.

The ray diagram for concave lens is shown in Fig.12.24.

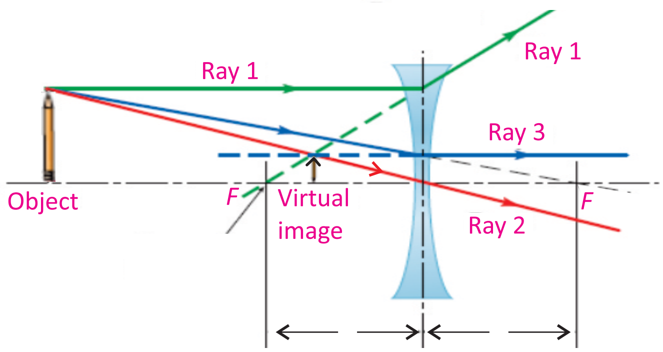
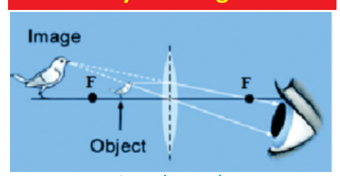


Fig. 12.24: Concave Lens

Physics insight

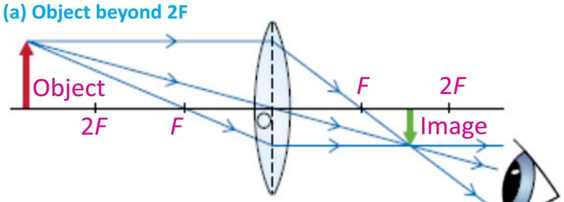


A converging lens becomes a magnifying glass when an object is located inside the lens's focal length.

Image Formation in Convex Lens

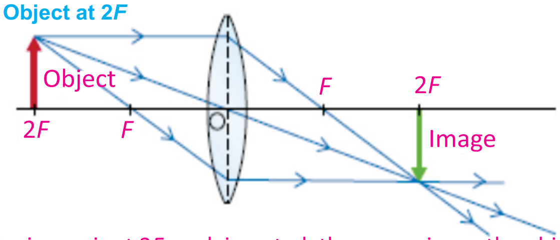
In class VIII, we have learnt image formation by lenses. Let us briefly revise image formation by convex lens (Fig.12.25).

(a) Object beyond 2F



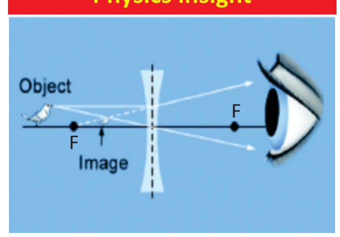
The image is between *F* and 2*F*, real, inverted, smaller than the object.

(b) Object at 2*F*



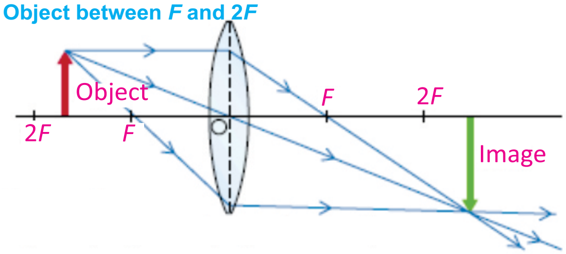
The image is at 2*F*, real, inverted, the same size as the object.

Physics insight



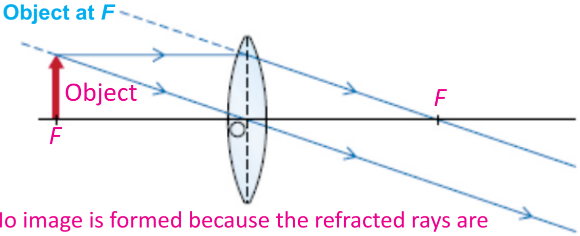
A diverging lens always has the same ray diagram, which forms a smaller image.

(c) Object between *F* and 2*F*



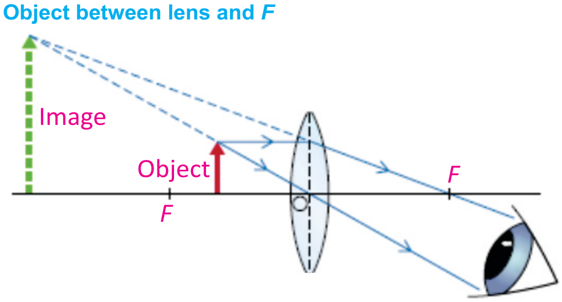
The image is beyond 2*F*, real, inverted, larger than the object.

(d) Object at *F*



No image is formed because the refracted rays are parallel and never meet.

(e) Object between lens and *F*



The image is behind the object, virtual, erect, larger than the object.

Fig. 12.25

12.10 IMAGE LOCATION BY LENS EQUATION

In Fig.12.26, let an object OP is placed in front of a convex lens at a distance *p*. A ray PR parallel to the principal axis after refraction passes through focus *F*. Another ray PC meets the first ray at point P' after passing through the optical centre C. If this process is repeated for the other points of the object, a real and inverted image O'P' is formed at a distance *q* from the lens.

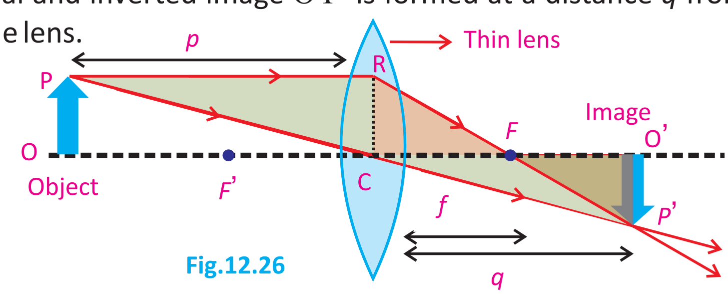


Fig.12.26

Approximations

The thin lens formula assumes the lenses have no thickness. This is a good assumption when objects and images are far away compared with the thickness of a lens.

For your information

The study of light behaviour is called optics. The branch of optics that focuses on the creation of images is called geometrical optics, because it is based on relationships between angles and lines that describe light rays. With a few rules from geometry, we can explain how images are formed by devices like lenses, mirrors, cameras, telescopes, and microscopes. Optics also includes the study of the eye itself because the human eye forms an image with a lens.

What is the size of image formed in a lens for particular distance of object from the lens? What is the nature of image, i.e., whether image is real or imaginary, erect or inverted? Lens formula is a tool that we use to answer all such questions. We define lens formula as,

The relation between the object and image distance from the lens in terms of the focal length of the lens is called lens formula.

$$\frac{1}{f} = \frac{1}{p} + \frac{1}{q} \qquad \text{.........} \quad (12.4)$$

Equation (12.4) is valid for both concave and convex lenses. However, following sign conventions should be followed while using this equation to solve problems related to lenses.

Sign Conventions for Lenses

Focal length:

- f is positive for a converging lens
- f is negative for a diverging lens.

Object Distance:

- p is positive, if the object is towards the left side of the lens. It is called a real object.
- p is negative, if the object is on the right side of the lens. It is called virtual object.

Image Distance:

- q is positive for a real image made on the right side of the lens by real object.
- q is negative for a virtual image made on the left side on the lens by real object.

Example 12.5: A person 1.7 m tall is standing 2.5 m in front of a camera. The camera uses a convex lens whose focal length is 0.05 m. Find the image distance (the distance between the lens and the film) and determine whether the image is real or virtual.

Uses of lenses

Solution: To find the image distance q, we use the thin lens equation with $p = 2.5$ m and $f = 0.05$ m.

$$\frac{1}{q} = \frac{1}{f} - \frac{1}{p}$$

$$\frac{1}{q} = \frac{1}{0.05\text{ m}} - \frac{1}{2.5\text{ m}}$$

$$\frac{1}{q} = 19.6\text{ m}^{-1}$$

or $q = 0.05$ m

Since the image distance is positive, so a real image is formed on the film at the focal point of the lens.

Example 12.6: A concave lens has focal length of 15 cm. At what distance should the object from the lens be placed so that it forms an image at 10 cm from the lens? Also find the magnification of the lens.

Solution: A concave lens always forms a virtual, erect image on the same side of the object. Given that, $q = -10$ cm

$f = -15$ cm, $p = ?$

Using the lens formula: $$\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$$

$$\frac{1}{p} = -\frac{1}{q} + \frac{1}{f}$$

$$= -\frac{1}{(-10\text{ cm})} + \frac{1}{(-15\text{ cm})}$$

$$= \frac{1}{10\text{ cm}} - \frac{1}{15\text{ cm}}$$

$$\frac{1}{p} = \frac{3\text{ cm} - 2\text{ cm}}{30\text{ cm}^2}$$

$$\frac{1}{p} = \frac{1}{30\text{ cm}}$$

$$p = 30\text{ cm}$$

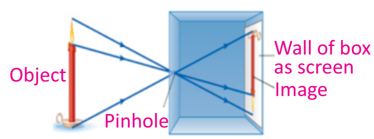
Thus, the object distance is 30 cm, on the left side from the concave lens.

Magnification of the lens is $m = \frac{q}{p} = \frac{-10\text{ cm}}{30\text{ cm}} = \frac{1}{3}$

(Ignore nagetive sign)

The image is reduced to one-third in size than the object.

A camera without lens!



Even simpler than a camera with one lens is a pinhole camera. To make a pinhole camera, a tiny pinhole is made in one side of a box. An inverted, real image is formed on the opposite side of the box.

12.11 APPLICATIONS OF LENSES

Now we discuss applications of lenses in some optical devices such as camera, slide projector and photograph enlarger.

1. CAMERA

A simple camera consists of a light-proof box with a converging lens in front and a light sensitive plate or film at the back. The lens focuses images to be photographed onto the film. In simple lens camera, the distance between lens and film is fixed which is equal to the focal length of the lens. In camera, object is placed beyond 2*F*. A real, inverted and diminished image is formed in this way as shown in Fig.12.27.

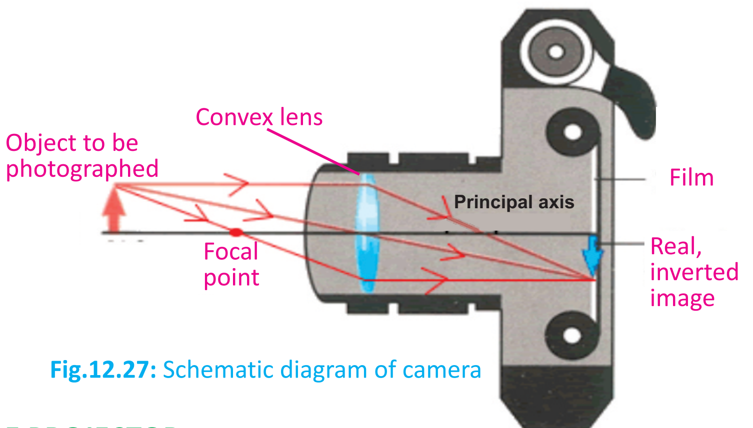


Fig.12.27: Schematic diagram of camera

2. SLIDE PROJECTOR

Fig.12.28 shows how a slide or movie projector works. The light source is placed at the centre of curvature of a converging or concave mirror. The concave mirror is used to reflect light back in fairly parallel rays. The condenser is made up of 2 converging lenses that refract the light so all parts of the slide are illuminated with parallel rays.

Self Assessment

Where a pen is placed in front of a convex lens if the image is equal to the size of the pen? What will be the power of the lens in dioptres?

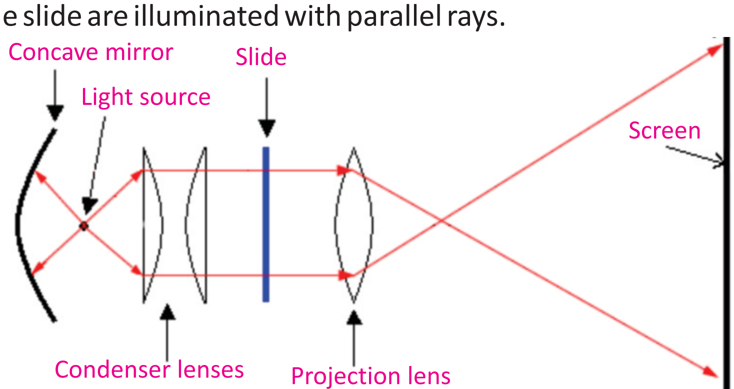


Fig.12.28: Diagram of slide projector

The projection or converging lens provides a real, large and inverted image. It must be real to be projected on a screen. The slide (object) must be placed between F and 2F of projection lens so as to produce a real, large, and inverted image. Because the image is inverted, the slide must be placed upside down and laterally inverted so we can see the image properly.

3. PHOTOGRAPH ENLARGER

In the case of photograph enlarger object is placed at distance of more than *F* but less than 2*F*. In this way, we get a real, inverted and enlarged image as shown in Fig. 12.29. The working principle of photograph enlarger is basically the same as that of a slide projector. It uses a convex lens to produce a real, magnified and inverted image of the film on photographic paper.

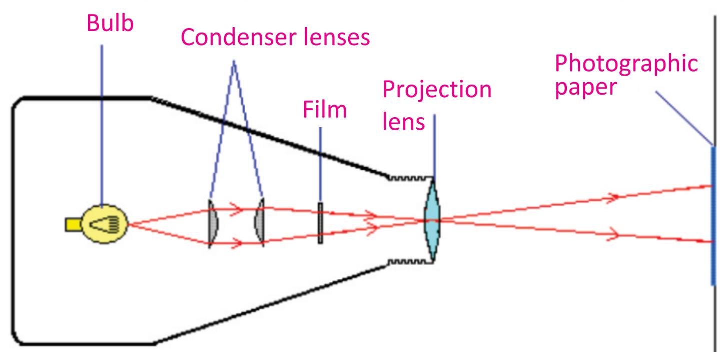


Fig.12.29: Diagram of photograph enlarger

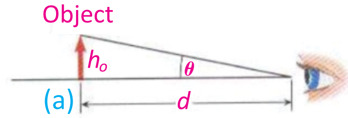


Fig.12.30

12.12 SIMPLE MICROSCOPE

A magnifying glass is a convex lens which is used to produce magnified images of small objects. Hence, it is also called simple microscope. The object is placed nearer to the lens than the principal focus such that an upright, virtual and magnified image is seen clearly at 25cm from the normal eye.

Magnifying Power

Let θ be the angle subtended at the eye by a small object when it is placed at near point of the eye(Fig.12.30-a).

If the object is now moved nearer to the eye(Fig.12.30-b), the angle on the eye will increase and becomes θ', but the eye will not be able to see it clearly. In order to see the object clearly,

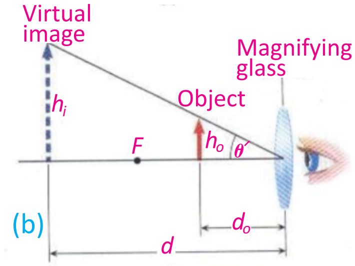


Fig.12.30: Image formation in magnifying glass

we put a convex lens between the object and the eye, so that the lens makes a large virtual image of the object at near point of the eye. In this way, the object appears magnified. The magnifying power in this case will be:

$$M = \frac{\theta'}{\theta}$$

It can be shown that the magnifying power is given by the relation:

$$M = \frac{\theta'}{\theta} = 1 + \frac{d}{f}$$

where f is the focal length of lens and d is near point of eye. It is clear from this relation that a lens of shorter focal length will have greater magnifying power.

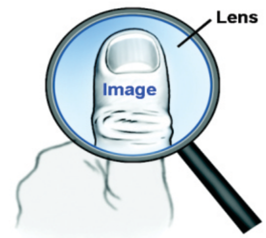
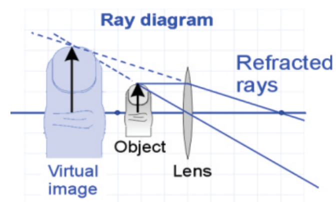


Image in a magnifying glass



Magnifying glass is a lens that forms a virtual image that is larger than object and appears behind the lens.

Resolving Power

The resolving power of an instrument is its ability to distinguish between two closely placed objects or point sources.

In order to see objects that are close together, we use an instrument of high resolving power. For example, we use high resolving power microscope to see tiny organisms and telescope to view distant stars.

12.13 COMPOUND MICROSCOPE

Compound microscope has two converging lenses, the objective and the eyepiece and is used to investigate structure of small objects (Fig.12.31). Following are some features of compound microscope:

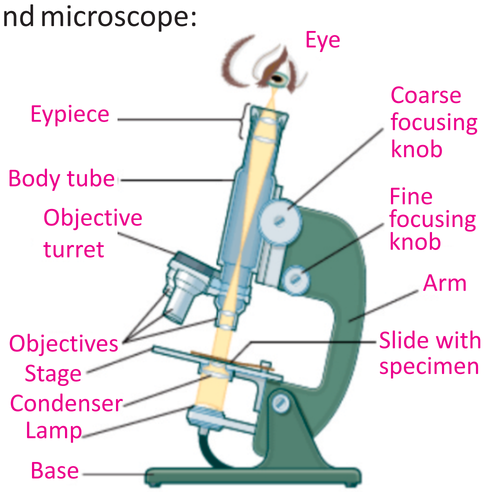


Fig.12.31: Compound microscope

- It gives greater magnification than a single lens.
- The objective lens has a short focal length, f_o< 1 cm.
- The eyepiece has a focal length, f_e of a few cm.

Magnification of the Compound Microscope

Magnification can be determined through the ray diagram as shown in Fig. 12.32. Objective forms a small image I_1 inside the focal point of eyepiece. This image acts as an object for the eyepiece and the final larger image I_2 is formed outside the focal point of the objective.

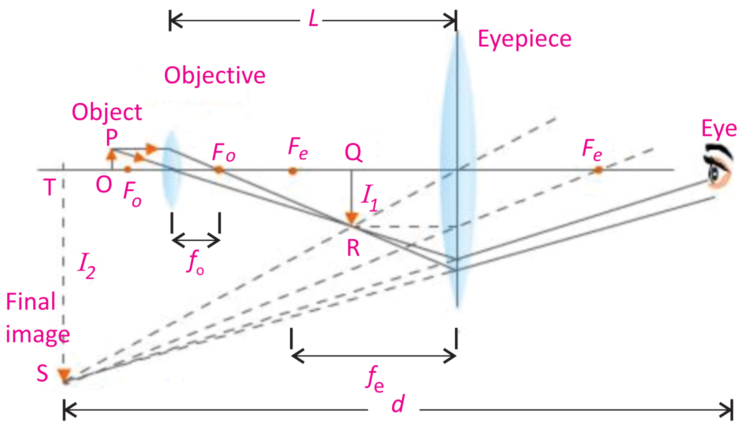


Fig. 12.32: Ray diagram for compound microscope

Compound microscops

Objective lens has smaller focal length, than the eyepiece.
Distance between the objective lens and the eyepiece is greater than f_0+f_e. It is used to see very small objects.

The magnification of a compound microscope is given by

$$M = \frac{L}{f_o}\left(1 + \frac{d}{f_e}\right)$$

where L is the length of a compound microscope which is equal to the distance between objective and eye piece, d is distance of final image from eye, f_o and f_e are the focal lengths of objective and eye piece respectively.

Astronomical telescope

Objective lens has larger focal length than the eyepiece.
Distance between the objective lens and the eyepiece is equal to f_0+f_e.
It is used to see distant astronomical objects.

Uses of Compound Microscope

A compound microscope is used to study bacteria and other micro objects. It is also used for research in several fields of sciences like, Microbiology, Botany, Geology, and Genetics.

12.14 TELESCOPE

Telescope is an optical instrument which is used to observe distant objects using lenses or mirrors. A telescope that uses two converging lenses is called *refracting telescope* (Fig.12.33). In refracting telescope, an objective lens forms a real image of the distant object, while an eyepiece forms a virtual image that is viewed by the eye.

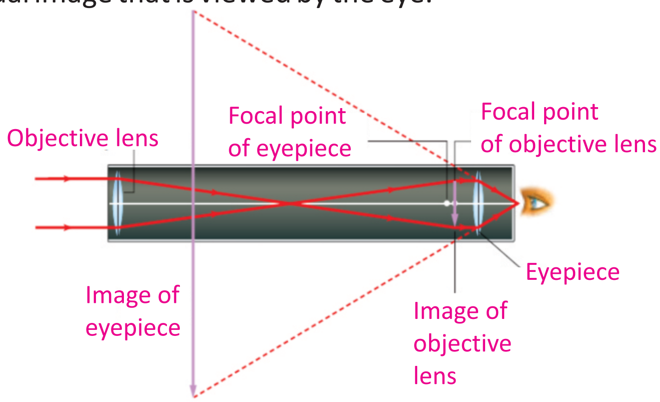


Fig. 12.33: An astronomical refracting telescope creates a virtual image that is inverted compared to the object.

WORKING OF REFRACTING TELESCOPE

The ray diagram of refracting telescope is shown in Fig.12.34. When parallel rays from a point on a distant object pass through objective lens, a real image I_1 is formed at the focus F_o of the objective lens. This image acts as an object for the eyepiece. A large virtual image I_2 of I_1 is formed by the eyepiece at a large distance from the objective lens. This virtual image makes an angle θ at the eyepiece.

Magnification of Telescope

Magnification of a refracting telescope can be determined through the ray diagram of Fig. 12.34 and is given by $M = \frac{f}{f_e}$

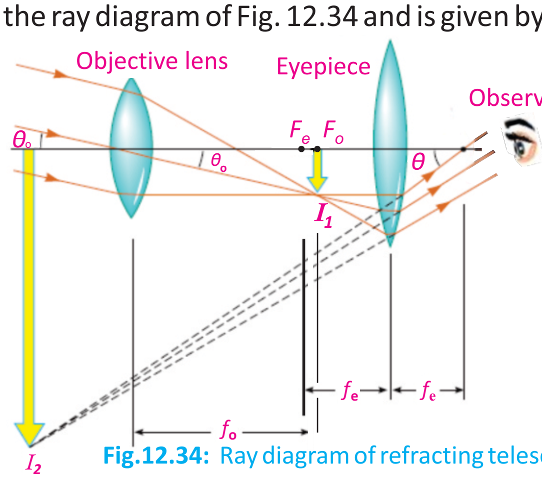


Fig.12.34: Ray diagram of refracting telescope

For your information

Terrestrial telescope is similar to refracting telescope except with an extra lens between objective and eyepiece.

For your information

The magnification of a combination of lenses is equal to the product of the magnifications of each lens.

For your information

A telescope cannot make stars look bigger, because they are too far away. But there is something important the telescope can do – it makes stars look brighter. Dim stars look bright, and stars that are too faint to see come into view. Without a telescope, we can see up to 3000 individual stars in the night sky; a small telescope can increase this by a factor of at least 10. So a telescope is better than the naked eye for seeing dim stars. The reason is that the telescope gathers more light than the eye.

12.15 THE HUMAN EYE

The image formation in human eye is shown in Fig.12.35. Human eye acts like a camera. In place of the film, the retina records the picture. The eye has a refracting system containing a converging lens. The lens forms an image on the retina which is a light sensitive layer at the back of the eye. In the camera, the distance of lens from film is adjusted for proper focus but in the eye, the lens changes focal length. Light enters the eye through a transparent membrane called the cornea. The iris is the coloured portion of the eye and controls the amount of light reaching the retina. It has an opening at its centre called the *pupil.* The iris controls the size of the pupil. In bright light, iris contracts the size of the pupil while in dim light pupil is enlarged. The lens of the eye is flexible and accommodates objects over a wide range of distances.

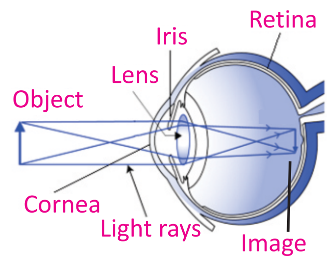


Fig.12.35: Image formation in human eye

Accommodation

The camera focuses the image of an object at a given distance from it by moving the lens towards or away from the film. The eye has different adjusting mechanism for focusing the image of an object onto the retina. Its ciliary muscles control the curvature and thus the focal length of the lens, and allow objects at various distances to be seen.

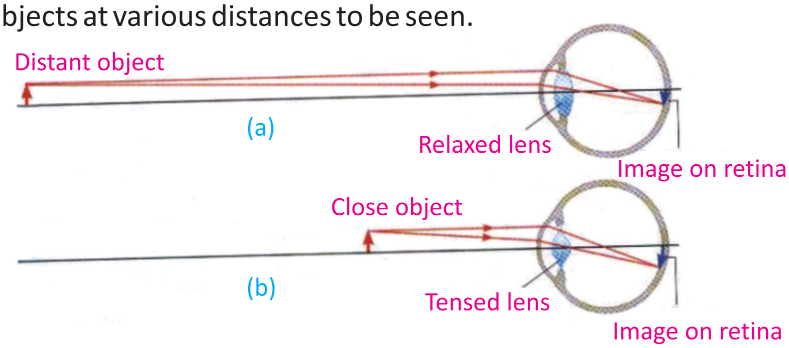
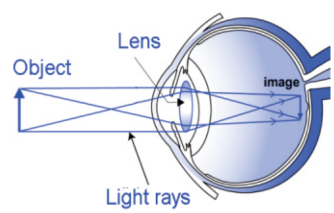


Fig.12.36: Human eye accommodation

If an object is far away from the eye, the deviation of light through the lens must be less. To do this, the ciliary muscles relax and decrease the curvature of the lens, thereby, increasing the focal length. The rays are thus focused onto the retina producing a sharp image of the distant object (Fig.12.36-a).

For your information

The eye



We see because the eye forms images on the retina at the back of the eyeball.

Quick Quiz

How the size of the pupil of our eye will change:

(a) in dim light?
(b) in bright light?

If an object is close to the eye, the ciliary muscles increase curvature of the lens, thereby, shortening the focal length. The divergent rays from the nearer object are thus bent more so as to come to a focus on the retina (Fig.12.36-b).

The variation of focal length of eye lens to form a sharp image on retina is called accommodation.

It is large in young people while it goes on decreasing with age. Defects in accommodation may be corrected by using different type of lenses in eyeglasses. In the following sections, we will describe defect of vision and their remedies.

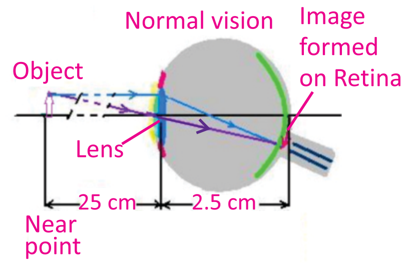


Fig.12.37: Image formation in human eye when object is placed at near point.

Near Point and Far Point

When we hold a book too close, the print is blurred because the lens cannot adjust enough to bring the book into focus.

The near point of the eye is the minimum distance of an object from the eye at which it produces a sharp image on the retina.

This distance is also called the least distance of distinct vision (Fig.12.37). An object closer to the eye than the near point appears blurred. For people in their early twenties with normal vision, the near point is located about 25 cm from the eye. It increases to about 50 cm at the age 40 years and to roughly 500 cm at the of age 60 years.

The far point of the eye is the maximum distance of a distant object from the eye on which the fully relaxed eye can focus.

A person with normal eyesight can see objects very far away, such as the planets and stars, and thus has a far point located at infinity. Majority of people not have "normal eyes" in this sense!

Do you know?

Contact lenses produce the same results as eyeglasses do. These small, thin lenses are placed directly on the corneas. A thin layer of tears between the cornea and lens keeps the lens in place. Most of the refraction occurs at the air-lens surface, where the difference in indices of refraction is greatest.

12.16 DEFECTS OF VISION

The inability of the eye to see the image of objects clearly is called defect of vision.

The defects of vision arise when the eye lens is unable to accommodate effectively. The images formed are therefore blurred.

Nearsightedness (myopia)

Some people cannot see distant objects clearly without the aid of spectacles. This defect of vision is known as short sight or nearsightedness and it may be due to the eyeball being too long. Light rays from a distant object are focused in front of the retina and a blurred image is produced (Fig.12.38-a).

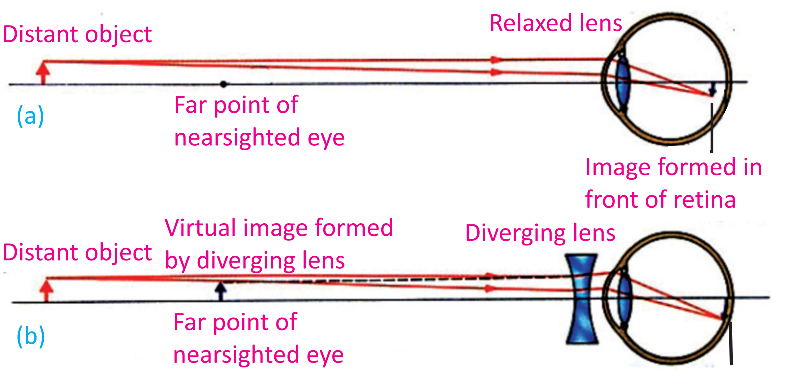


Fig. 12.38: Correction of near sightedness

The nearsighted eye can be corrected with glass or contact lenses that use diverging lenses. Light rays from the distant objects are now diverged by this lens before entering the eye. To the observer, these light rays appear to come from far point and are therefore focused on the retina, thus forming a sharp image (Fig.12.38-b).

Farsightedness (hypermetropia)

The disability of the eye to form distinct images of nearby objects on its retina is known as farsightedness.

When a farsighted eye tries to focus on a book held closer than the near point, it shortens its focal length as much as it can. However, even at its shortest, the focal length is longer than it should be. Therefore, the light rays from the book would form a blurred image behind the retina (Fig.12.39-a).

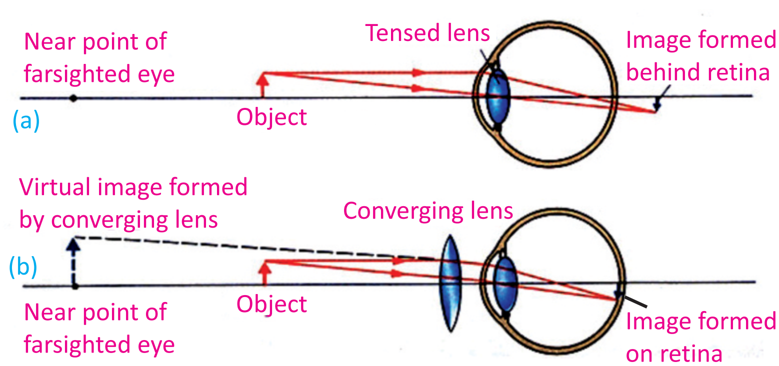


Fig. 12.39: Correction of farsightedness

Interesting information

Some animals like fish has the ability to move their eye lenses forward or backward and hence, are able to see clearly objects around them.

For your information

A thin film can be placed on the lenses of eyeglasses to keep them from reflecting wavelengths of light that are highly visible to the human eye. This prevents the glare of reflected light.

This defect can be corrected with the aid of a suitable converging lens. The lens refracts the light rays and they converge to form an image on the retina. To an observer, these rays appear to come from near point to form a sharp virtual image on the retina (Fig.12.39-b).

SUMMARY

- When light travelling in a certain medium falls on the surface of another medium, a part of it turns back in the same medium. This is called reflection of light. There are two laws of reflection:
  i. The incident ray, the reflected ray, and the normal all lie in the same plane.
  ii. The angle of incidence is equal to the angle of reflection (i.e., $i = r$).
- Like plane surfaces, spherical surfaces also reflect light satisfying the two laws of reflection.
- In mirrors, image formation takes place through reflection of light while in lenses image is formed through refraction of light.
- The equation relating the distance of the object p from the mirror/lens, distance of the image q and the focal length f of the mirror/lens is called mirror/lens formula, given by $\frac{1}{f} = \frac{1}{p} + \frac{1}{q}$
- Magnification of a spherical mirror or thin lens is defined as "the ratio of the image height to the object height," i.e., Magnification $m = \frac{\text{Image height}}{\text{Object height}} = \frac{h_i}{h_o}$
- Power of a lens is defined as "the reciprocal of its focal length in metres". Thus Power of a lens = P = 1 / focal length in metres. The SI unit of power of a lens is "Dioptre", denoted by a symbol D. If f is expressed in metres so that 1 D = 1 m^{-1}. Thus, 1 Dioptre is the power of a lens whose focal length is 1 metre.
- The refractive index '*n*' of a material is the ratio of the speed of light '*c*' in air to the speed of light '*v*' in the material, thus

$$n = \frac{\textit{Speed of light in air}}{\textit{Speed of light in medium}} = \frac{c}{v}$$

- The bending of light from its straight path as it passes from one medium into another is called *refraction*.
- Refraction of light takes place under two laws called laws of refraction. These are stated as:
  i. The incident ray, the refracted ray, and the normal at the point of incidence all lie in the same plane.

ii. *The ratio of the sine of the angle of incidence 'i' to the sine of the angle of refraction 'r' is always equal to a constant i.e.,* $\frac{\sin i}{\sin r}$ *= constant.*

where the ratio $\frac{\sin i}{\sin r}$ is equal to the refractive index of the second medium with respect to the first medium.

$$\text{i.e.,}\quad \frac{\sin i}{\sin r} = n$$

This is also called Snell's law.

- The angle of incidence for which the angle of refraction becomes 90° is called critical angle. When the angle of incidence becomes larger than the critical angle, no refraction occurs. The entire light is reflected back into the denser medium. This is known as total internal reflection of light.
- A simple microscope, also known as a magnifying glass, is a convex lens which is used to produce magnified images of small objects.
- A compound microscope is used to investigate structure of small objects and has two converging lens, the objective and the eyepiece.
- Telescope is an optical instrument which is used to observe distant objects using lenses or mirrors. A telescope that uses two converging lenses is called refracting telescope. A telescope in which the objective lens is replaced by a concave mirror is called *reflecting power telescope*.
- The magnifying power is defined as "the ratio of the angle subtended by the image as seen through the optical device to that subtended by the object at the unaided eye".
- The resolving power of an instrument is its ability to distinguish between two closely placed objects.
- The ability of the eye to change the focal length of its lens so as to form a clear image of an object on its retina is called its power of accommodation.
- The disability of the eye to form distinct images of distant objects on its retina is known as nearsightedness**.** The nearsighted eye can be corrected with glass or contact lenses that use *diverging* lenses. Light rays from the distant objects will diverge by this lens before entering the eye.
- The disability of the eye to form distinct images of nearby objects on its retina is known as *farsightedness.* This defects can be corrected with the aid of a suitable converging lens. The lens refracts the light rays more towards the principal axis before they enter the eye.

MULTIPLE CHOICE QUESTIONS

Choose the correct answer from the given choices:

i. Which of the following quantity is not changed during refraction of light?
   (a) its direction (b) its speed
   (c) its frequency (d) its wavelength

ii. A converging mirror with a radius of 20 cm creates a real image 30 cm from the mirror. What is the object distance?
   (a) -5.0 cm (b) -7.5 cm
   (c) -15 cm (d) -20 cm

iii. An object is placed at the centre of curvature of a concave mirror. The image produced by the mirror is located
   (a) out beyond the centre of curvature.
   (b) at the centre of curvature.
   (c) between the centre of curvature and the focal point
   (d) at the focal point

iv. An object is 14 cm in front of a convex mirror. The image is 5.8 cm behind the mirror. What is the focal length of the mirror?
   (a) -4.1 cm (b) -8.2 cm
   (c) -9.9 cm (d) -20 cm

v. The index of refraction depends on
   (a) the focal length (b) the speed of light
   (c) the image distance (d) the object distance

vi. Which type of image is formed by a concave lens on a screen?
   (a) inverted and real (b) inverted and virtual
   (c) upright and real (d) upright and virtual

vii. Which type of image is produced by the converging lens of human eye if it views a distant object?
   (a) real, erect, same size (b) real, inverted, diminished
   (c) virtual, erect, diminished (d) virtual, inverted, magnified

viii. Image formed by a camera is
   (a) real, inverted, and diminished
   (b) virtual, upright and diminished
   (c) virtual, upright and magnified
   (d) real, inverted and magnified

ix. If a ray of light in glass is incident on an air surface at an angle greater than the critical angle, the ray will
   (a) refract only

(b) reflect only
(c) partially refract and partially reflect
(d) diffract only

x. The critical angle for a beam of light passing from water into air is 48.8 degrees. This means that all light rays with an angle of incidence greater than this angle will be
(a) absorbed
(b) totally reflected
(c) partially reflected and partially transmitted
(d) totally transmitted

REVIEW QUESTIONS

12.1. What do you understand by reflection of light? Draw a diagram to illustrate reflection at a plane surface.

12.2. Describe the following terms used in reflection:
(i) normal (ii) angle of incidence (iii) angle of reflection

12.3. State laws of reflection. Describe how they can be verified graphically.

12.4. Define refraction of light. Describe the passage of light through parallel-sided transparent material.

12.5. Define the following terms used in refraction:
(i) angle of incidence (ii) angle of refraction

12.6. What is meant by refractive index of a material? How would you determine the refractive index of a rectangular glass slab?

12.7. State the laws of refraction of light and show how they may be verified using rectangular glass slab and pins.

12.8. What is meant by the term total internal reflection?

12.9. State the conditions for total internal reflection.

12.10. What is critical angle? Derive a relationship between the critical angle and the refractive index of a substance.

12.11. What are optical fibres? Describe how total internal reflection is used in light propagating through optical fibres.

12.12. Define the following terms applied to a lens:
(i) principal axis (ii) optical centre (iii) focal length

12.13. What is meant by the principal focus of a (a) convex lens (b) concave lens? Illustrate your answer with ray diagrams.

12.14. Describe how light is refracted through convex lens.

12.15. With the help of a ray diagram, how you can show the use of thin converging lens as a magnifying glass.

12.16. A coin is placed at a focal point of a converging lens. Is an image formed? What is its nature?

12.17. What are the differences between real and virtual images?

12.18. How does a converging lens form a virtual image of a real object? How does a diverging lens can form a real image of a real object?

12.19. Define power of a lens and its units.

12.20. Describe the passage of light through a glass prism and measure the angle of deviation.

12.21. Define the terms resolving power and magnifying power.

12.22. Draw the ray diagrams of
(i) simple microscope (ii) compound microscope (iii) refracting telescope

12.23. Mention the magnifying powers of the following optical instruments:
(i) simple microscope (ii) compound microscope (iii) refracting telescope

12.24. Draw ray diagrams to show the formation of images in the normal human eye.

12.25. What is meant by the terms nearsightedness and farsightedness? How can these defects be corrected?

CONCEPTUAL QUESTIONS

12.1. A man raises his left hand in a plane mirror, the image facing him is raising his right hand. Explain why.

12.2. In your own words, explain why light waves are refracted at a boundary between two materials.

12.3. Explain why a fish under water appears to be at a different depth below the surface than it actually is. Does it appear deeper or shallower?

12.4. Why or why not concave mirrors are suitable for makeup?

12.5. Why is the driver's side mirror in many cars convex rather than plane or concave?

12.6. When an optician's testing room is small, he uses a mirror to help him test the eyesight of his patients. Explain why.

12.7. How does the thickness of a lens affect its focal length?

12.8. Under what conditions will a converging lens form a virtual image?

12.9. Under what conditions will a converging lens form a real image that is the same size as the object?

12.10. Why do we use refracting telescope with large objective lens of large focal length?

NUMERICAL PROBLEMS

12.1. An object 10.0 cm in front of a convex mirror forms an image 5.0 cm behind the mirror. What is the focal length of the mirror? **Ans. (-**

10 cm)

12.2. An object 30 cm tall is located 10.5 cm from a concave mirror with focal length 16 cm. (a) Where is the image located? (b) How high is it?

Ans. [(a) 30.54 cm (b) 87.26 cm]

12.3. An object and its image in a concave mirror are of the same height, yet inverted, when the object is 20 cm from the mirror. What is the focal length of the mirror?

Ans. (10 cm)

12.4. Find the focal length of a mirror that forms an image 5.66 cm behind the mirror of an object placed at 34.4 cm in front of the mirror. Is the mirror concave or convex?

Ans. (-6.77 cm, Convex mirror)

12.5. An image of a statue appears to be 11.5 cm behind a concave mirror with focal length 13.5 cm. Find the distance from the statue to the mirror. **Ans. (77.62 cm)**

12.6. An image is produced by a concave mirror of focal length 8.7 cm. The object is 13.2 cm tall and at a distance 19.3 cm from the mirror. (a) Find the location and height of the image. (b) Find the height of the image produced by the mirror if the object is twice as far from the mirror.

Ans. [(a) 15.84 cm, 10.83 cm (b) 5.42 cm]

12.7. Nabeela uses a concave mirror when applying makeup. The mirror has a radius of curvature of 38 cm. (a) What is the focal length of the mirror? (b) Nabeela is located 50 cm from the mirror. Where will her image appear? (c) Will the image be upright or inverted? **Ans. [(a) 19 cm, (b) 30.64 cm, (c) upright]**

12.8. An object 4 cm high is placed at a distance of 12 cm from a convex lens of focal length 8 cm. Calculate the position and size of the image. Also state the nature of the image.

Ans. (24 cm, 8 cm, image is real, inverted and magnified)

12.9. An object 10 cm high is placed at a distance of 20 cm from a concave lens of focal length 15 cm. Calculate the position and size of the image. Also, state the nature of the image. **Ans. (-8.57 cm, 4.28 cm, image is virtual, erect and diminished)**

12.10. A convex lens of focal length 6 cm is to be used to form a virtual image three times the size of the object. Where must the lens be placed? **Ans. (4 cm)**

12.11. A ray of light from air is incident on a liquid surface at an angle of incidence 35°. Calculate the angle of refraction if the refractive index of the liquid is 1.25. Also calculate the critical angle between the liquid air inter-face. **Ans. (27.31°, 53.13°)**

12.12. The power of a convex lens is 5 D. At what distance the object should be placed from the lens so that its real and 2 times larger image is formed. **Ans. (30 cm)**