CHAPTER 12

WAVES

Student's learning outcomes (SLOs)

After studying this chapter, students will be able to:

- prove that waves transfer energy without transferring matter.
- describe what is meant by wave motion [as illustrated by vibrations in ropes and springs and by experiments using water waves].
- state the types of waves:
  (i) transverse waves
  (ii) longitudinal waves
- describe the features of a wave [in terms of wave front, wavelength, frequency, time period, crest (peak), trough, compression, rarefaction, amplitude and wave speed].
- define the terms frequency, wavelength and amplitude.
- recall and apply the equation wave speed = frequency × wavelength; $v = f\lambda$
- illustrate that for a transverse wave the direction of vibration is at right angles to the direction of the energy transfer [including giving examples such as electromagnetic radiation, waves on the surface of water, and seismic waves].
- illustrate that for a longitudinal wave, the direction of vibration is parallel to the direction of the energy transfer [including giving examples such as sound waves and seismic P-waves (primary)].
- describe how waves can undergo reflection, refraction and diffraction (using ripple tank).
- describe how wavelength affects diffraction at an edge.
- describe how wavelength and slit size affect diffraction through a slit.
- analyze the phenomenon of tsunamis generated under the surface of water [in terms of underwater earthquakes/volcanic activity generating waves that increase in frequency and amplitude as they encounter increasingly shallow water].

The concept of waves demonstrates the transfer of energy from one place to another without the transfer of the matter. Waves play a vital role in understanding various phenomena of our everyday life. Waves are all around us from small ripples on a quiet lake to the loud sound of thunder in the sky. In this chapter, we will explore various types of waves, their properties, and the principles that govern their behaviour. We will uncover the main concepts such as amplitude, wavelength, frequency, and speed of waves. Through experiments and real life examples, we will also see how waves influence our daily lives and contribute to various fields, including communication, medicine, and technology.

12.1 Waves and Nature of Waves

As waves travel through a medium, they cause the particles within it to vibrate. These vibrations allow energy to be transferred from one particle to the next, as shown in Fig. 12.1. However, the particles themselves do not move along with the wave. They simply oscillate around their original positions. For example, when a twig is dropped into still water, ripples spread across the surface, as shown in Fig. 12.2. These ripples carry energy outward, yet the water and the twig remain mostly in place.

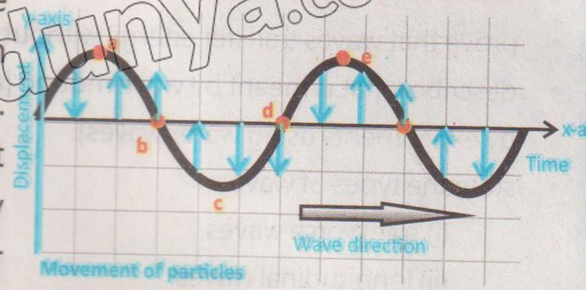


Fig 12.1: Vibration of particles in a wave perpendicular to the wave direction

A similar effect occurs with sound waves. When a guitar string is plucked, it creates vibrations that travel through the air as sound waves (Fig. 12.3). The air particles do not move toward our ears; instead, they vibrate in place to pass the energy forward.

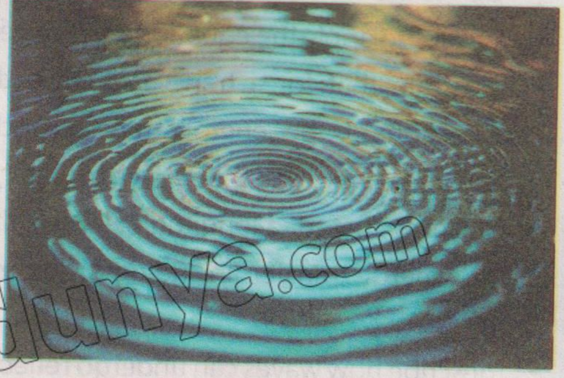


Fig 12.2: Ripples in water showing energy transfer without transfer of matter

Waves can transfer energy from one place to another without transferring matter.

The same principle is illustrated by vibrations in a spring. When one end of a stretched spring is pushed and released, longitudinal waves move through the spring. As shown in

Fig. 12.4, the spring develops regions of compression (where the coils are close together) and rarefaction (where the coils are spread out). These compressions and rarefactions travel along the spring, showing how energy is transmitted without the entire spring moving forward. This experiment visually demonstrates wave motion and how longitudinal waves (such as sound) travel through matter.

Fig 12.3: Vibrations from a guitar string producing sound waves that transfer energy through air to the ear

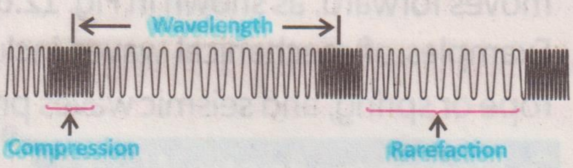


Fig 12.4: Longitudinal wave (Stretched spring)

Water Wave Experiment to Demonstrate Wave Motion

A simple and effective way to understand wave motion is through an experiment using a ripple tank, as shown in Fig. 12.5. In this setup, a shallow tray is filled with water to a uniform depth. A bar, connected to a motor, vibrates up and down gently on the water's surface. This disturbance generates ripples or wave crests that spread outward across the water surface.

Fig. 12.5: Ripple tank

12.2 Types of Waves

There are two main types of waves:

1. Mechanical Waves

Mechanical waves are waves that require a material medium such as air, water, or a solid material to travel. These waves cannot pass through vacuum because they rely on the vibration of particles in the medium to transfer energy. The particles of the medium vibrate

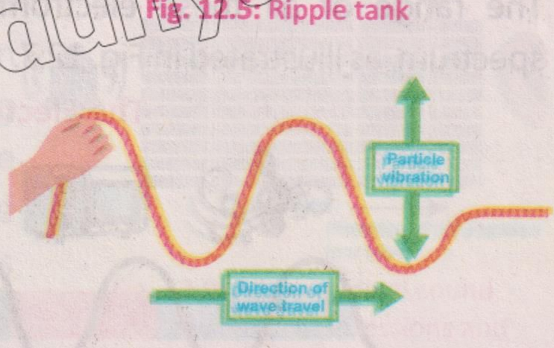


Fig. 12.6: A transverse wave on a rope showing particle vibration perpendicular to the direction of wave travel

and pass the energy along, even though the particles themselves do not move with the wave.

A simple way to observe this is by moving one end of a rope up and down. The wave travels along the rope, but each part of the rope only moves vertically while the wave itself moves forward, as shown in Fig. 12.6.

> **Tidbit**
>
> Waves carry energy across oceans, air, and even empty space without dragging particles along with them.

Examples of mechanical waves include sound waves, water waves, vibrations on a rope or spring, and seismic waves produced by earthquakes.

2. Electromagnetic Waves

Electromagnetic waves are different from mechanical waves because they do not require a material medium to travel. These waves can move through empty space (vacuum), that is why sunlight and other types of radiation from the Sun are able to reach the Earth through space.

> **Do You Know?**
>
> 
>
> **Radiowaves** are electromagnetic waves that travel at the speed of 3,00,000 kilometre per second through air.

Examples of electromagnetic waves include radiowaves, microwaves, infrared rays, visible light, ultraviolet rays, X-rays, and gamma rays. These waves differ in their wavelengths and frequencies, but they all travel at the same speed in vacuum approximately 3,00,000 km per second (3×10^8 m s^{-1}), known as the speed of light.

> **Tidbit**
>
> Infra means below; infrared waves have a lower frequency than red waves. Warm objects radiate light in the infrared region of the spectrum.

The range of all these electromagnetic waves is called the electromagnetic spectrum, as illustrated in Fig. 12.7.

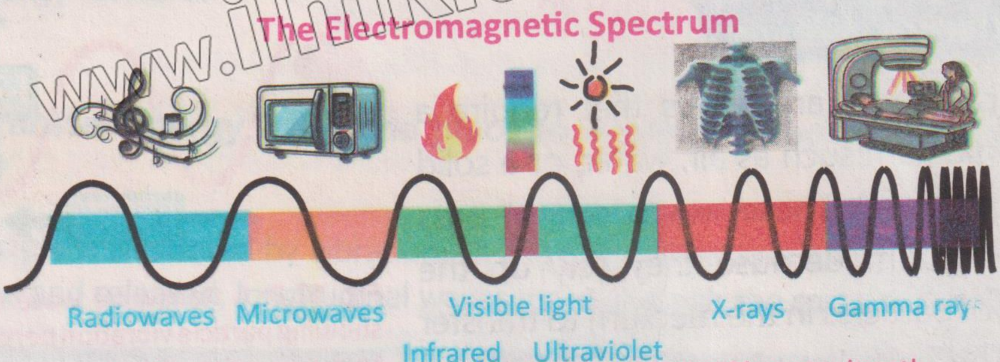


Fig. 12.7: Types of electromagnetic waves arranged by wavelength

Types of Mechanical Waves

Mechanical waves are divided into two main types, depending on how the particles of the medium vibrate in relation to the direction the wave travels. These are:

1. Transverse Waves

2. Longitudinal Waves

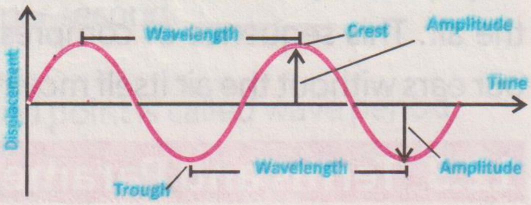


Fig. 12.8: A transverse wave labelled with crest, trough, wavelength, and amplitude

Transverse Waves

In transverse waves, the particles of the medium vibrate at right angles to the direction in which the wave is travelling. This perpendicular vibration causes the energy to transfer through the medium without any significant forward movement of the particles themselves. A simple way to observe a transverse wave is by holding one end of a rope and moving it up and down. While the wave travels horizontally along the rope, the rope segments move vertically. This motion results in the formation of the highest points known as crests and the lowest points called troughs, as shown in Fig. 12.8.

Brain Teaser

When we shake a stretched slinky spring side-to-side and then push it back and forth. What two types of waves did we just create?

An excellent example of a transverse wave is a water wave. As the wave moves forward across the water surface, the water molecules move up and down rather than along with the wave. Another important example is electromagnetic radiation (such as light, radiowaves, and X-rays), where the electric and magnetic fields oscillate perpendicular to the direction of energy propagation.

Longitudinal Waves

In longitudinal waves, the particles of the medium vibrate parallel to the direction in which the wave is travelling. Instead of moving up and down like in transverse waves, where the particles move back and forth along the same path as the energy flow. This creates regions where particles are close together, known as compressions, and regions where particles are spread apart, known as rarefactions (Fig. 12.9).

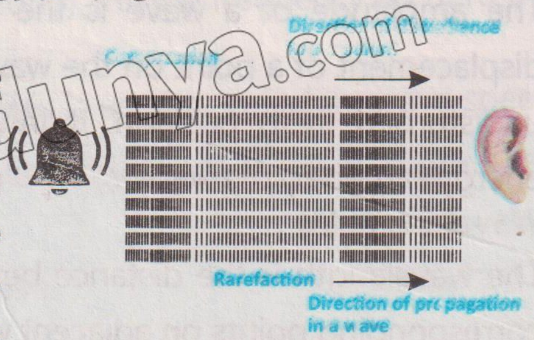


Fig. 12.9: A longitudinal sound wave showing compressions and rarefactions

A common and important example of a longitudinal wave is a sound wave. When a sound is produced, such as when someone claps his hands, the air molecules near the hands are first pushed together, forming a compression. Immediately after, they spread apart into a rarefaction as the wave continues to move forward through the air. This sequence of compressions and rarefactions allows sound to travel to our ears without the air itself moving permanently from the source to the listener.

12.3 Terms and Parameters of Waves

A transverse wave is shown in Fig. 12.8, labelled with crest, trough, wavelength, and amplitude. The definitions of these key terms are given below:

> **Tidbit**
> Frequency tells us how many waves pass a point in one second. That is why FM radio station is called "88.0 MHz". It is sending 88 million wave cycles per second.

Crest

The crest is the region of a transverse wave, above the mean position.
It is the upper part of a wave.

Trough

The trough is the region of a transverse wave, below the mean position.
It is the lower part of a wave.

Compression

A compression is a region in a longitudinal wave where the particles of the medium are close together, resulting in high pressure.

Rarefaction

A rarefaction is a region in a longitudinal wave where the particles are spread apart, resulting in low pressure.

Amplitude

The amplitude of a wave is the maximum displacement of a point on the wave from its undisturbed (rest) position. It indicates the energy carried by the wave.

> **Tidbit**
> The time period tells how long one complete wave takes to pass a point like the rhythm heartbeat of the wave.

Wavelength (λ)

The wavelength is the distance between two corresponding points on adjacent waves (e.g., crest to crest or trough to trough in transverse waves, or compression to compression in longitudinal waves).
Its SI unit is metre (m).

> **Brain Teaser**
> Two waves travel at the same speed, but one has a higher frequency. Which has the shorter wavelength?

Frequency (f)

The frequency of a wave is the number of complete wave cycles that pass a fixed point in one second.

It is measured in hertz (Hz), where; 1 Hz = 1 wave per second

Wave Period (T)

Time required to complete one wave to pass a fixed point is called wave period.

It is the inverse of frequency.

i.e; $T = 1/f$

It is measured in seconds (s).

Wave Front

A wave front is an imaginary surface on which all the points have same phase of vibration (i.e., have the same displacement and direction of motion).

It represents the leading edge of the wave as it travels through a medium.

Wave Speed (v) / Wave Equation

The wave speed is the rate at which the wave propagates through a medium.

As, Speed = Distance travelled / Time taken

Let us consider a wave:

Distance travelled = λ (wavelength)

Time taken = T (time period)

Then $v = S/t$

Since $S = \lambda$ and $t = T$

Substitute into the formula:

Now $v = \lambda / T$ .... (12.1)

$1/T = f$ (where f is frequency)

So $v = f \times \lambda$ .... (12.2)

where v is the wave speed (in metres per second), f is the frequency (in hertz), and λ is the wavelength (in metres).

Equation (12.2) is known as wave equation. This is used to calculate wave speed.

Example: A wave takes 5 seconds to complete 10 cycles. If the wavelength of the wave is 1.2 metres, calculate:

(a) frequency of the wave (b) speed of the wave

Solution:

Given that; Number of cycles = 10

Time t = 5 seconds

Wavelength λ = 1.2 m

To find;
(a) Frequency f =?
(b) Speed of wave v = ?

We know that; f = Number of cycles / Time

$f = 10 / 5 = 2$ Hz

As $v = f \times \lambda$

Substituting the values $v = 2 \times 1.2 = 2.4 \text{ m s}^{-1}$

12.4 Properties of Waves

One of the most fascinating aspects of waves is how they behave when they encounter obstacles or pass from one medium into another. These behaviours include reflection, refraction, and diffraction. Such properties can be observed clearly using a ripple tank, a shallow glass container filled with water, often used in classrooms to study wave motion.

Reflection of Waves

Reflection occurs when waves strike a surface and bounce back into the same medium. This behaviour can be clearly observed using a ripple tank, as shown in Fig. 12.10. In this setup, when straight water waves generated by a vibrating bar move across the tank and strike a barrier, they reflect from the surface (Fig. 12.11).

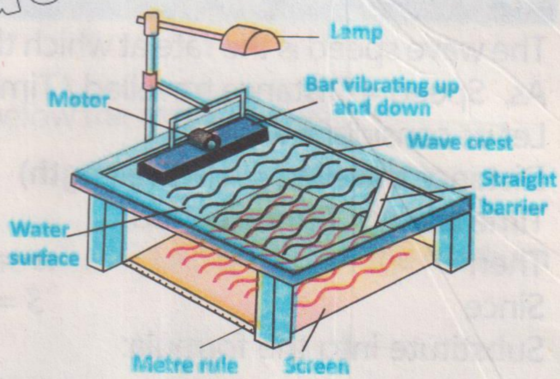


Fig. 12.10: Ripple tank setup showing water waves

The angle at which the waves approach the barrier is called the angle of incidence, and the angle at which they reflect is called the angle of reflection. These two angles are always equal. This is called law of reflection.

Angle of incidence = Angle of reflection

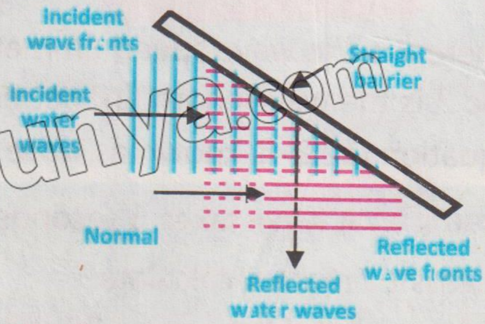


Fig. 12.11: Reflection of water waves

Reflection is the bouncing back of waves into the same medium after striking the surface of another medium.

This property is common to all types of waves, including water waves, sound waves (such as echoes), and light waves (as seen in mirrors).

Refraction of Waves

Refraction occurs when waves pass from one medium into another and change direction due to change in speed.

As the water waves cross into this shallow region, they slow down and bend, demonstrating the refraction of waves. Although the speed and wavelength of the waves change during this process, their frequency remains the same. This bending occurs because waves travel faster in deeper water and slower in shallow water, creating a noticeable change in direction.

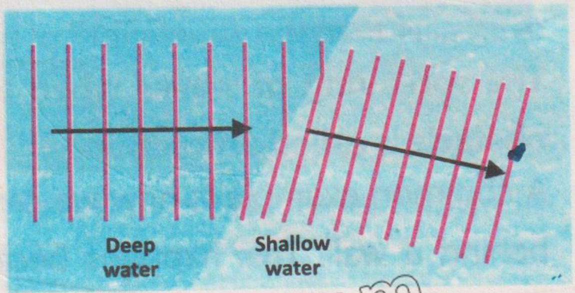


Fig. 12.12: Refraction of waves

This change in wave behaviour is also illustrated in Fig. 12.12, where wave fronts are shown bending as they pass from deep water into shallow water, with a shorter wavelength in the shallow region. The bending clearly shows how the direction and spacing of the waves are affected by the depth of the water.

When a wave passes from one medium into another at an angle, its wavelength and speed change, causing the wave to change direction. This process is called refraction.

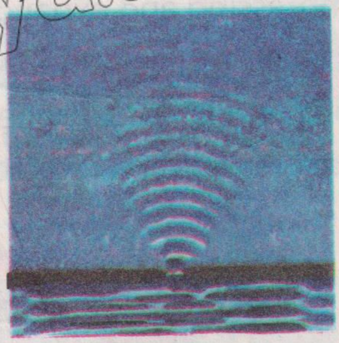
Diffraction of Waves

Diffraction is the bending and spreading of waves as they pass through a narrow slit or move around an obstacle. This behaviour can be easily observed in water waves when they encounter openings of different sizes.

1. When the size of slit is wider than the wavelength, the waves pass mostly straight through with only slight bending at the edges (Fig. 12.13-a).

(a) Size of slit is larger than the wavelength of the water waves

(b) Size of slit is the same as the wavelength of the water waves



(c) Size of slit is smaller than the wavelength of the water waves

Fig. 12.13: Diffraction of water waves

2. If the slit size is nearly equal to the wavelength, the waves spread out more and appear almost circular beyond the slit (Fig. 12.13-b).

3. When the size of slit is smaller than the wavelength, the waves show maximum diffraction, forming strong circular patterns (Fig. 12.13-c).

This shows that the amount of diffraction increases when the size of slit is closer to or smaller than the wavelength of the waves.

The spreading of waves when they pass through a slit or move around an obstacle is called diffraction.

A common example is how we can still hear someone speaking even when he is behind a wall. This happens because sound waves, which have relatively long wavelengths, diffract around corners and obstacles, allowing the sound to reach us even without a direct line of sight.

12.5 Seismic and Tsunami Waves

Seismic and tsunami waves are natural waves produced by disturbances in the Earth's crust and ocean. Understanding them is important for safety and readiness since they have the potential to do a great deal of harm.

Seismic Waves

Seismic waves are those that pass through the Earth and are typically created by earthquakes, volcanic eruptions, or explosions. Seismometers detect these waves, which aid scientists in their investigations of the Earth's insides.

Primary Waves (P-Waves)

These are the fastest seismic waves and the first to be detected during an earthquake. P-waves can travel through solids, liquids, and gases. They move by compressing and expanding the material in the same direction as the wave travels, similar to a slinky toy being pushed and pulled. This compressional movement is shown in Fig. 12.14, where alternating regions of high and low density represent compressions and rarefactions.

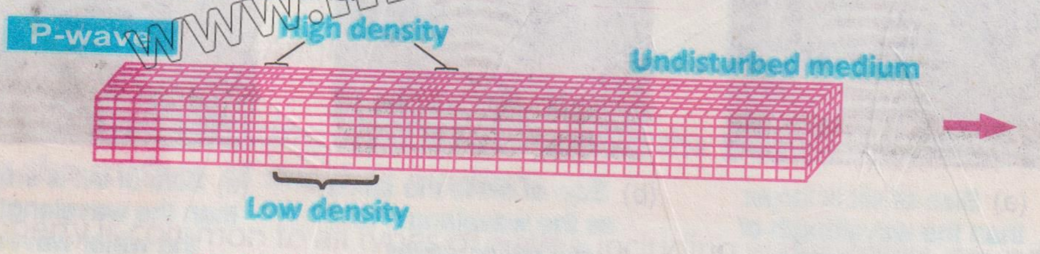


Fig. 12.14: P-wave showing longitudinal motion

Tsunami Waves

Tsunamis are extremely large and powerful ocean waves caused by sudden disturbances under the sea. These disturbances may include underwater earthquakes, volcanic eruptions, or landslides. When such events occur, they can cause a sudden shift in the ocean floor, which pushes a huge volume of water upward. This disturbance creates energy that spreads across the ocean as long, fast-moving waves, as shown in Fig. 12.15.

Fig. 12.15: A large ocean wave formed during a tsunami

Characteristics of Tsunami Waves

In the deep ocean, tsunami waves travel at very high speeds, often reaching up to 800 kilometres per hour. However, in deep water, these waves are often just a few centimetres in height and go unnoticed by ships or people.

As tsunami waves approach shallow coastal areas, their behaviour changes dramatically due to their interaction with the sea floor:

1. **Wave speed decreases:** As the water becomes shallower, the bottom of the wave touches the ocean floor, slowing the wave down.
2. **Wavelength shortens:** The distance between wave crests becomes smaller.
3. **Frequency increases:** More waves arrive at the shore in a shorter period of time.
4. **Amplitude increases:** As the energy gets compressed into a smaller space, the wave height increases significantly.
5. This transformation can result in towering waves, sometimes reaching heights of 30 metres (100 feet) or more, causing severe coastal flooding, destruction of buildings, and loss of life.
6. A tragic real-life example is the 2004

Tidbit

Though often called tidal waves, tsunamis are not caused by tides they are the result of undersea earthquakes; landslides, or volcanic eruptions.

Brain Teaser

If waves do not carry matter, how does a tsunami destroy buildings when it hits the shore?

Do You Know?

Out at sea, a tsunami is only about 1 m high, and could pass a boat without being noticed, as it approaches the shore. Its sudden deceleration from about 250 m s^{-1} to 15 m s^{-1} creates the enormous waves.

Indian Ocean tsunami, caused by a massive undersea earthquake near Sumatra. The earthquake displaced a huge section of the ocean floor, triggering tsunami waves that travelled across thousands of kilometres. These waves struck the coastlines of countries such as Indonesia, Sri Lanka, India, and Thailand, reaching heights of over 15 metres in some areas and causing massive devastation and loss of more than 2,30,000 lives.

EXERCISE

A. Multiple Choice Questions

Tick (✓) the correct answer.

12.1 The direction of vibration in a longitudinal wave is:
(a) at right angles to the wave direction
(b) in circular motion
(c) opposite to the wave direction
(d) in the same direction as the wave travels

12.2 Which part of a transverse wave carry the lowest point?
(a) Crest (b) Compression
(c) Rarefaction (d) Trough

12.3 Which of the following wave type requires a medium to travel?
(a) X-rays (b) Light waves
(c) Radiowaves (d) Sound waves

12.4 The property of a wave which indicates how much energy it carries is:
(a) crest (b) amplitude
(c) wavelength (d) speed

12.5 A wave front is:
(a) the distance between two crests
(b) a region of high pressure in a wave
(c) a line joining points that vibrate in phase
(d) the outer edge of a wave medium

12.6 The wave phenomenon which occurs when waves change direction due to a change in speed is:
(a) diffraction (b) reflection
(c) absorption (d) refraction

12.7 What happens to wave speed and wavelength when a tsunami approaches shallow water?
(a) Speed increases, wavelength increases
(b) Speed decreases, wavelength shortens
(c) Speed remains the same, wavelength shortens
(d) Speed increases, wavelength stays constant

12.8 Which wave behaviour explains how sound is heard around a corner?
(a) Reflection
(b) Refraction
(c) Interference
(d) Diffraction

B. Shorts Answer Questions

12.1 What do waves transfer from one place to another?
12.2 Name any two examples of mechanical waves.
12.3 Which type of wave can travel through vacuum?
12.4 What is the difference between transverse and longitudinal waves?
12.5 What is meant by wavelength?
12.6 Write the definition of frequency.
12.7 What causes a tsunami in the ocean?

C. Constructed Response Questions

12.1 Why sound cannot travel through space, but light can? Explain using the concept of wave types.
12.2 A student shakes one end of a rope and observes waves move along it. What kind of wave is this, and how do the particles move?
12.3 How does the amplitude of a wave relate to the energy it carries? Give an example to support your answer.
12.4 Why do we still hear a person talking even if he is behind a wall? Explain using the concept of diffraction.
12.5 If size of slit, a wave passes through is much smaller than the wavelength, what will happen to the wave after passing through the slit? Explain briefly.

D. Comprehensive Questions

12.1 Explain how waves transfer energy without transferring matter. Give examples from daily life.
12.2 Describe the difference between mechanical and electromagnetic waves with suitable examples.
12.3 What are transverse and longitudinal waves? Explain each with the help of diagrams and examples.
12.4 Discuss the properties of waves; such as reflection, refraction, and diffraction. Support your answer with examples.

12.5 What is diffraction? How do wavelength and slit size affect the diffraction of waves?

E. Numerical Problems

12.1 The wavelength of a wave is 2 metres and its frequency is 5 Hz. What is the speed of the wave? **[Ans: 10 m s^{-1}]**

12.2 A wave travels at a speed of 300 m s^{-1} and has a wavelength of 3 metres. Calculate its frequency. **[Ans: 100 Hz]**

12.3 A sound wave has a frequency of 250 Hz and a speed of 340 m s^{-1}. Find its wavelength. **[Ans: 1.36 m]**

12.4 A wave has a frequency of 50 Hz. How much time does it take to complete one wave? **[Ans: 0.02 s]**

12.5 A wave has a wavelength of 0.5 m and frequency of 200 Hz. Calculate the speed of the wave. **[Ans: 100 m s^{-1}]**

12.6 The time period of a wave is 0.02 seconds. Calculate the frequency of the wave. **[50 Hz]**