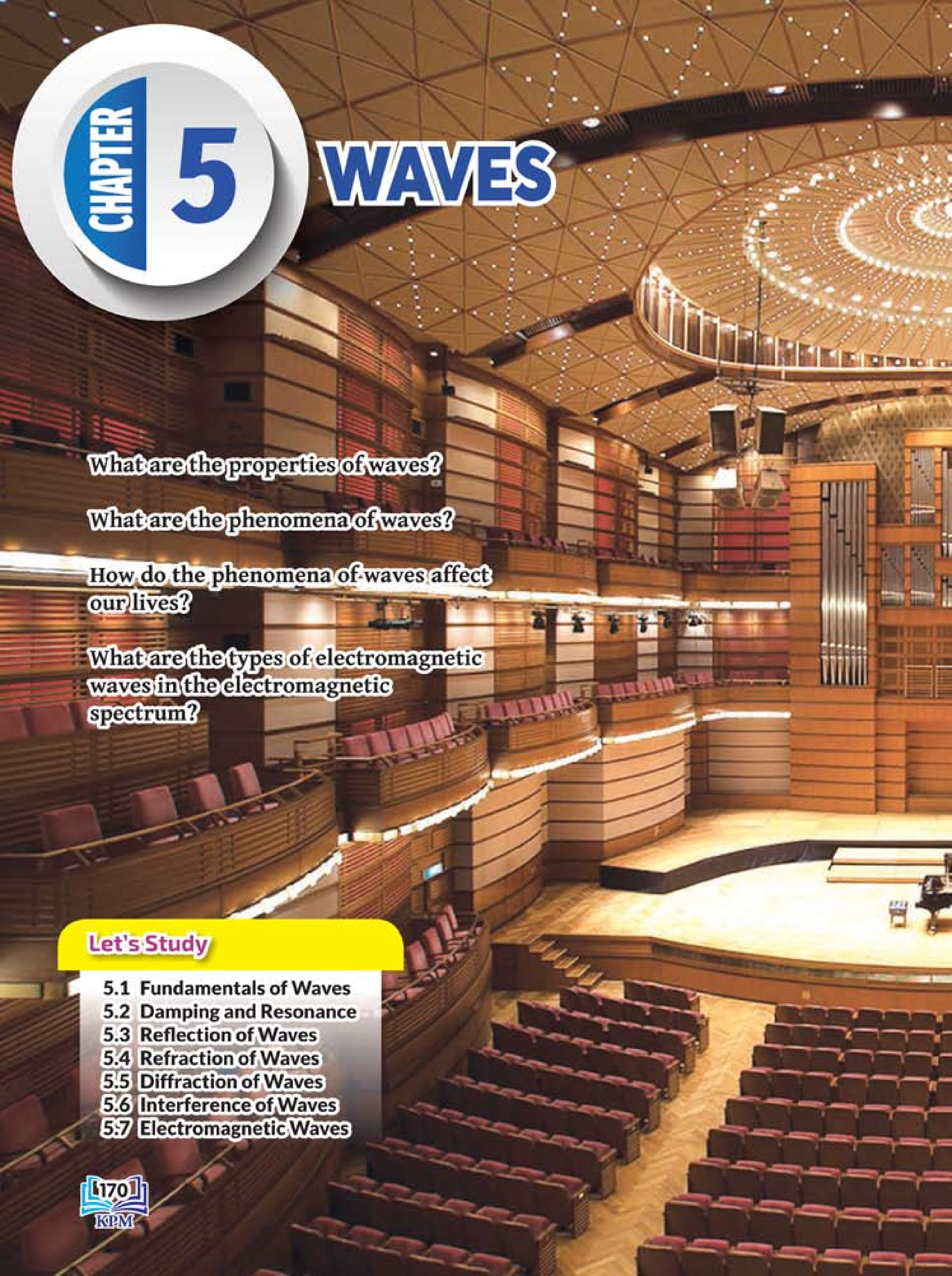
Theme 4

Waves, Light and Optics

Concepts and phenomena of waves, light and optics have many applications in our lives.

The topics in this theme discuss propagation of waves, properties of light and electromagnetic waves. This knowledge is applied in wireless communication, home appliances, medicine, industry and others.



CHAPTER 5 WAVES

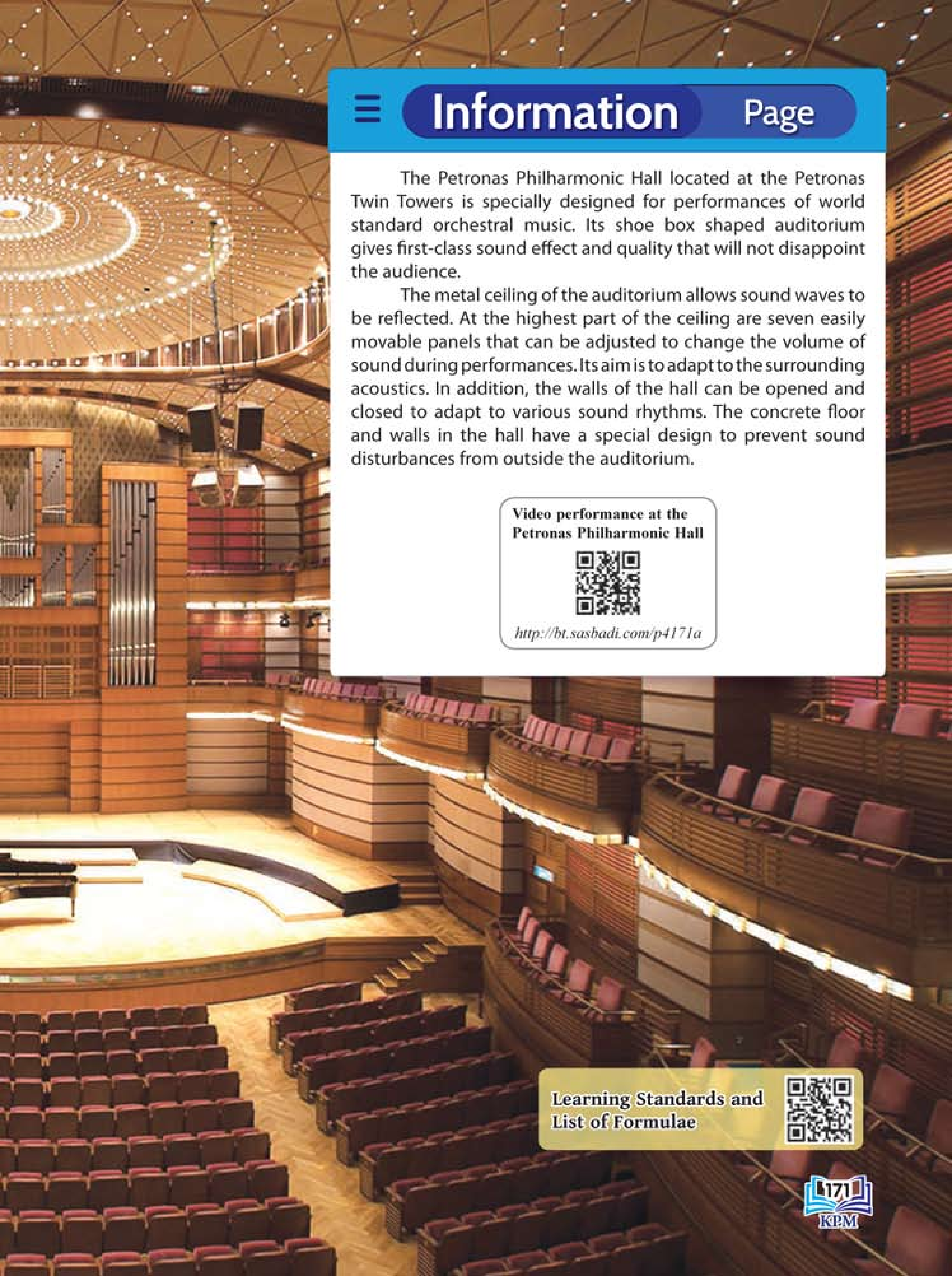
What are the properties of waves?

What are the phenomena of waves?

How do the phenomena of waves affect our lives?

What are the types of electromagnetic waves in the electromagnetic spectrum?

Let's Study



Information Page

The Petronas Philharmonic Hall located at the Petronas Twin Towers is specially designed for performances of world standard orchestral music. Its shoe box shaped auditorium gives first-class sound effect and quality that will not disappoint the audience.

The metal ceiling of the auditorium allows sound waves to be reflected. At the highest part of the ceiling are seven easily movable panels that can be adjusted to change the volume of sound during performances. Its aim is to adapt to the surrounding acoustics. In addition, the walls of the hall can be opened and closed to adapt to various sound rhythms. The concrete floor and walls in the hall have a special design to prevent sound disturbances from outside the auditorium.

Video performance at the Petronas Philharmonic Hall

http://bt.sasbadi.com/p4171a

Learning Standards and List of Formulae

5.1 Fundamentals of Waves

Waves

When you read the word **waves**, what examples of waves do you think of? Photographs 5.1 and 5.2 show two examples of waves. How are waves formed?

***Photograph 5.1** Object falling on the surface of water produces water waves*

***Photograph 5.2** Striking a leather membrane covered drum, kompang produces sound waves*

Activity 5.1

Aim: To study the production of waves by an oscillating system and a vibrating system

Apparatus: Spring, retort stand, iron bob, tray, tuning fork and table tennis ball

Materials: Water, thread and cellophane tape

Instructions:

(A) Oscillation of iron bob at the end of a spring

1. Set up the apparatus as shown in Figure 5.1.
2. Adjust the height of the spring so that the iron bob hangs close to the surface of the water without touching it.
3. Pull the iron bob down untill it touches the water surface and then release it.
4. Observe what happens to the surface of the water.

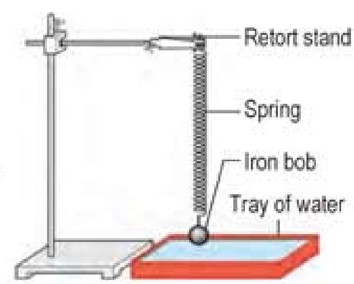


Figure 5.1

(B) Vibration of a tuning fork

1. Attach the tuning fork to the clamp of the retort stand.
2. Tap on the arm of the tuning fork and listen to the sound produced.
3. Use a table tennis ball to touch the arm of the tuning fork as shown in Figure 5.2.
4. Observe the movement of the table tennis ball.

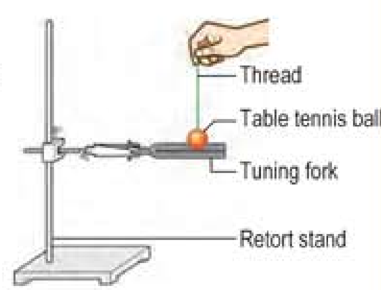


Figure 5.2

Discussion:

1. Describe the movement of the iron bob after it is pulled and released.
2. What is formed on the surface of the water in the tray?
3. Describe the movement of the table tennis ball when it touches the tuning fork which produces sound.
4. Relate the vibration of the table tennis ball to the sound heard.

Waves can be produced by an oscillating or a vibrating system. For example, the oscillation of an iron bob on the water surface produces water waves.

The vibration of a tuning fork in the air produces sound waves. **Oscillation** and **vibration** are repetitive motions about an equilibrium position in a closed path.

DIY

Mexican wave

http://bt.sasbadi.com/p4173

Try to produce the Mexican wave in class with your friends. Discuss the characteristics of the wave you can identify in this movement.

Activity 5.2

Aim: To generate the idea that waves transfer energy without transferring matter

Materials: Slinky spring and ribbon

Instructions:

1. Tie a ribbon to the slinky spring as shown in Figure 5.3.
2. Let two pupils hold each end of the slinky spring.
3. Move end *A* of the slinky spring from side to side while end *B* is fixed.
4. Observe the movement of the waves along the slinky spring and the movement of the ribbon.

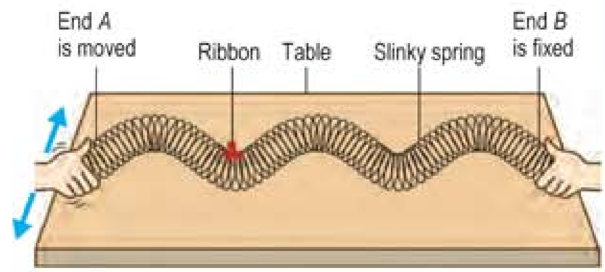


Figure 5.3

Discussion:

1. What is felt by the pupil at end *B* after the slinky spring is moved from side to side?
2. What is the direction of energy transfer along the slinky spring?
3. Describe the movement of the ribbon tied to the slinky spring.

Through Activity 5.2, we can conclude that waves are produced when a medium vibrates at a fixed position. Propagation of the waves transfers energy from one place to another without transferring the matter of the medium.

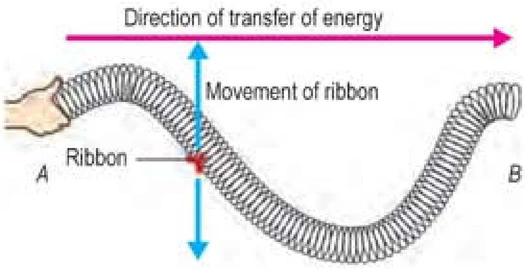


Figure 5.4 Waves transfer energy without transferring matter

Movement of waves from end *A* to end *B* transfers energy from *A* to *B*.

The ribbon only vibrates about in a fixed position. The ribbon does not move in the direction in which the energy is transferred by the waves.

Types of Waves

Figure 5.5 shows the shape of the slinky spring at five consecutive instances after end *A* has been moved as in Activity 5.2. The shape of the slinky spring as waves propagate through it is known as **wave profile**.

Waves can be classified from the aspect of propagation of the wave profile. The wave profile in Figure 5.5 propagates with time along the direction of propagation of the wave. This wave is known as a **progressive wave.**

Photograph 5.3 shows an example of a progressive wave produced by the vibrations on the surface of the water. A wave profile propagates outwards in all directions.

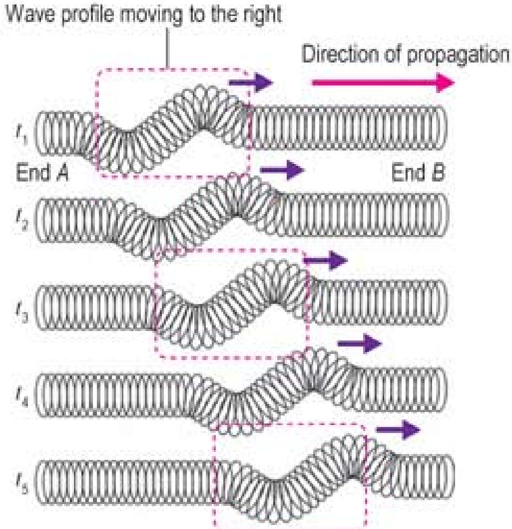
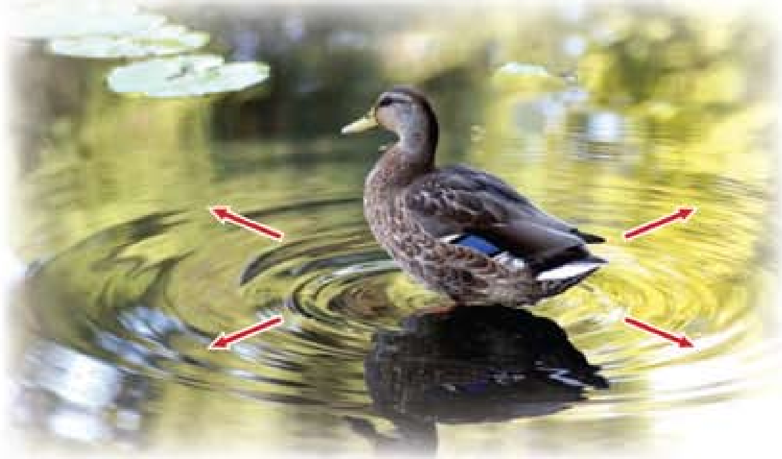


Figure 5.5 Wave profile at five consecutive instances



Photograph 5.3 Progressive waves on the water surface

Video of progressive wave on surface of water

http://bt.sasbadi.com/p4174a

Progressive waves can propagate through a medium as transverse waves or longitudinal waves. Scan the QR code to watch the animation of **transverse waves** and **longitudinal waves**.

Transverse waves and longitudinal waves

http://bt.sasbadi.com/p4174b

Figure 5.6 shows a wave profile at five consecutive instances of a guitar string that is being plucked. Does the wave profile move to the left or right?

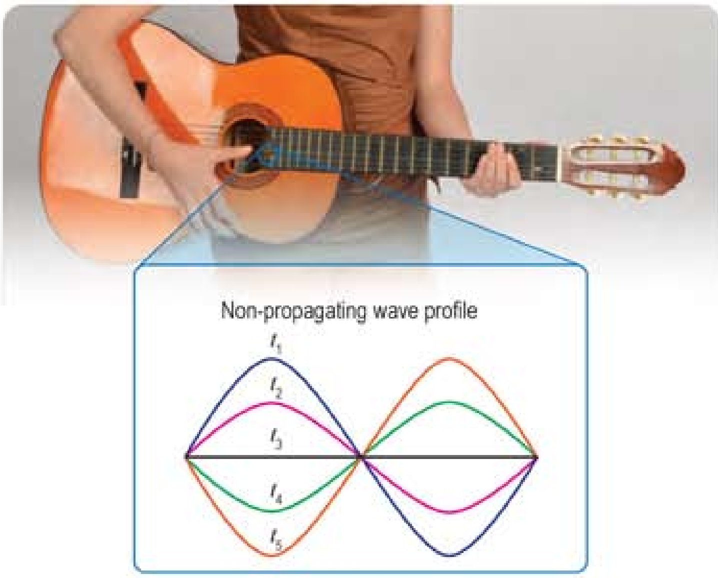


Figure 5.6 *A wave profile at five consecutive instances*

Info File

Stationary wave is produced when two identical progressive waves moving in opposite directions collide with one another.

Wave produced along a guitar string being plucked is an example of a **stationary wave**. A stationary wave is a wave where the profile of the wave does not propagate with time. Scan the QR code given to observe the profile of a stationary wave. Stationary waves are also produced by musical instruments such as ukulele, flute and drum when these instruments are played.

Profile of a stationary wave

http://bt.sasbadi.com/p4175

Waves can also be classified as mechanical waves or electromagnetic waves. Figure 5.7 shows the characteristics of a mechanical wave and an electromagnetic wave.

Mechanical wave

- Requires a medium to transfer energy from one point to another
- Made up of vibrating particles of a medium
- Water waves, sound waves and seismic waves on the surface of the Earth are examples of mechanical waves.

Electromagnetic wave

- Does not require a medium to transfer energy
- Made up of oscillating electric and magnetic fields perpendicular to one another
- Radio waves, light waves and gamma rays are examples of electromagnetic waves.

Figure 5.7 *Characteristics of a mechanical wave and an electromagnetic wave*

5.1.2

Comparison between Transverse Wave and Longitudinal Wave

There are two types of progressive waves, transverse wave and longitudinal wave. What are the similarities and differences between these two waves?

Activity 5.3

Aim: To compare transverse wave and longitudinal wave

Materials: Ribbon and slinky spring

(A) Transverse wave

Instructions:

1. Tie two short ribbons to a slinky spring.
2. Let two pupils hold each end of the slinky spring.
3. Move end *P* left and right repeatedly until a pattern of a wave is formed as shown in Figure 5.8.
4. Observe the propagation of the wave along the slinky spring and the movement of the ribbons.
5. Draw the wave profile formed and mark the direction of propagation of the wave.
6. Mark the direction of the ribbons.

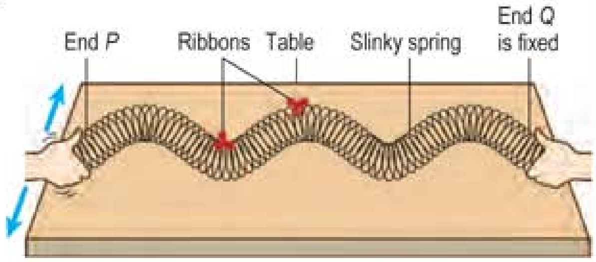


Figure 5.8

Discussion:

Compare the direction of propagation of the wave and the direction of movement of the ribbons.

(B) Longitudinal wave

Instructions:

1. Repeat activity A by moving the end *P* of the slinky spring forward and backward repeatedly until waves are formed as shown in Figure 5.9.
2. Observe the propagation of the waves along the slinky spring and the movement of the ribbons.
3. Sketch the shape of the entire length of the slinky spring and mark the direction of propagation of the waves.
4. Mark the direction of movement of the ribbons.

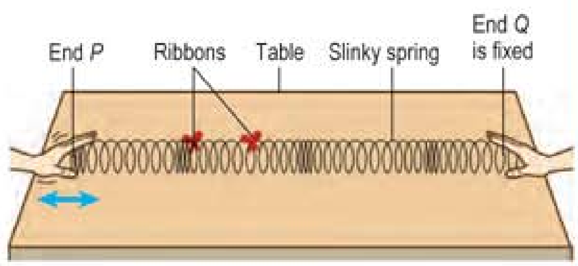


Figure 5.9

Discussion:

Compare the direction of propagation of the wave and the direction of movement of the ribbons.

Transverse wave

- Particles of the medium vibrate in the direction perpendicular to the direction of propagation of the wave.
- Made up of consecutive crests and troughs.

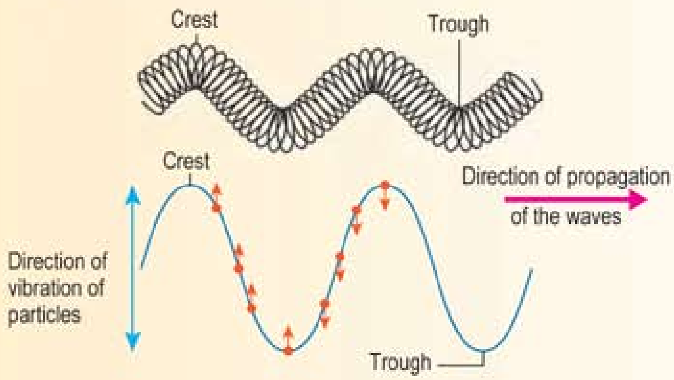


Figure 5.10 *Transverse wave*

- Radio waves, light waves and water waves are examples of transverse waves.

Info File

Earthquakes produce P-waves and S-waves. S-wave is a transverse wave and P-wave is a longitudinal wave. Both waves have different speeds. Analysis of the time difference between the two waves helps to determine the epicentre of earthquakes.

CAREER INFO

A seismologist investigates, predicts and reports earthquakes.

Longitudinal wave

- Particles of the medium vibrate in the direction parallel to the direction of propagation of the wave.
- Made up of consecutive **compressions** (compressed regions) and **rarefactions** (stretched regions).

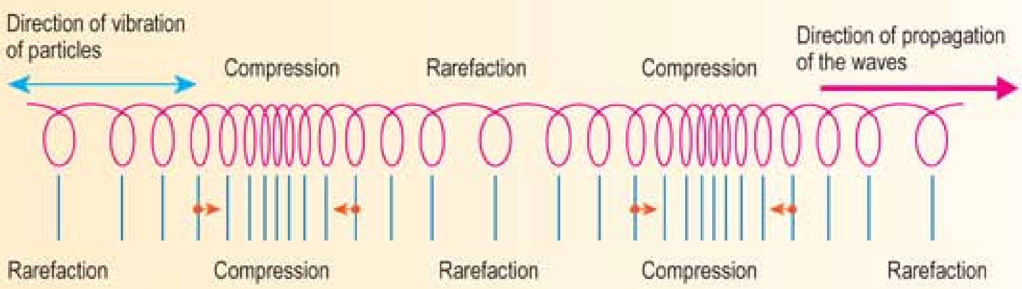
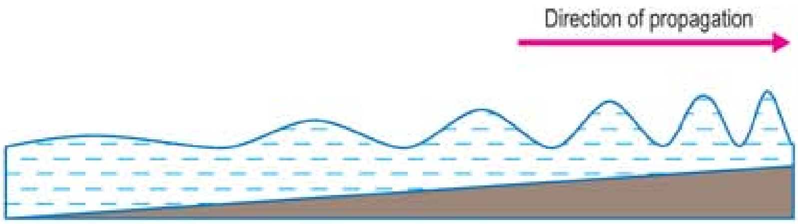


Figure 5.11 *Longitudinal wave*

- Sound wave is an example of longitudinal wave.

Characteristics of Waves

Figure 5.12 shows the profile of a water wave in a pond. What changes can you observe as the wave propagates across the water surface?



Changes in wave profile

http://bt.sasbadi.com/p4178a

Figure 5.12 *Profile of water wave*

To answer this question, you need to know the definition of terms related to waves.

Table 5.1 *Definition of terms related to waves*

Term	Definition
Amplitude, A	Maximum displacement of a particle from its equilibrium position
Period, T	The time taken by a particle to make one complete oscillation or by a source to produce one complete cycle of wave
Frequency, f	Number of complete oscillations made by a particle or number of cycles of wave produced by a source in one second
Wavelength, λ	Distance between two consecutive points in phase
Wave speed, v	Distance travelled per second by a wave profile

Info File

- Equilibrium position is the original position of the particle before a system oscillates.
- For waves of frequency, f: $f = \frac{1}{T}$
- Displacement is the distance of a particle from the equilibrium position.

Carry out Activity 5.4 to explain the definition of terms related to waves.

Activity 5.4

ICS ISS

Aim: To define terms related to waves

Instructions:

1. Work in groups.
2. Scan the QR code and watch the video about waves.
3. Gather information from websites which explain the definition of terms related to waves.
4. Present your findings in the form of an interesting multimedia presentation.

Waves

http://bt.sasbadi.com/p4178b

Figure 5.13 illustrates the amplitude, points in phase and wavelength of a transverse wave. Identify several other distances that are equal to one wavelength.

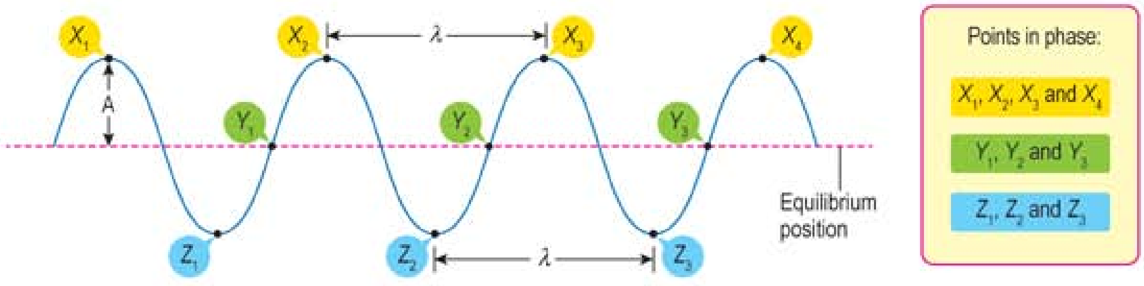


Figure 5.13 *A transverse wave*

Figure 5.14 shows the points in phase and wavelength of a longitudinal wave. Can you define its wavelength in terms of compression or rarefaction?

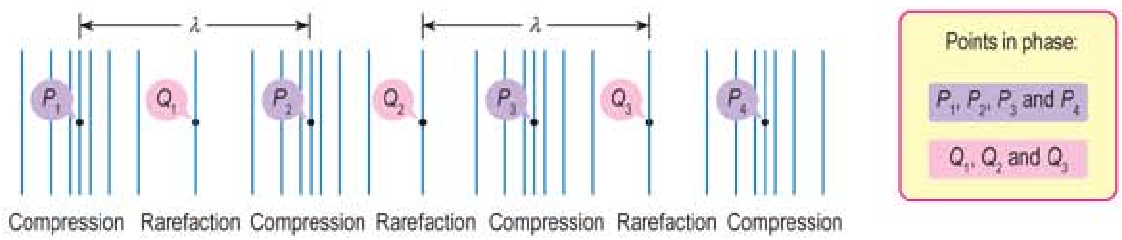


Figure 5.14 *A longitudinal wave*

Figure 5.15 shows the profile of a transverse wave at one instance and after a period, T of the wave. In time, $t = T$, the wave profile propagates through the same distance as the wavelength, λ.

From the equation, speed $= \dfrac{\text{Distance travelled by a wave profile}}{\text{Time}}$

Speed of wave, $v = \dfrac{\lambda}{T}$

$= \left(\dfrac{1}{T}\right)\lambda$

Frequency of wave, $f = \dfrac{1}{T}$

Therefore, speed of wave, $v = f\lambda$

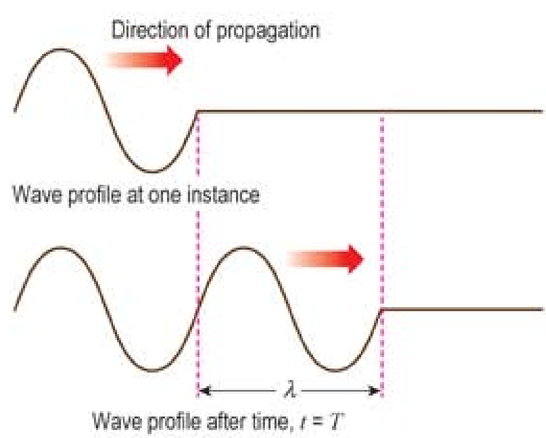


Figure 5.15 *A wave profile*

Sketch and Interpret Wave Graphs

Figure 5.16 shows the profile of a transverse wave at a certain instance.

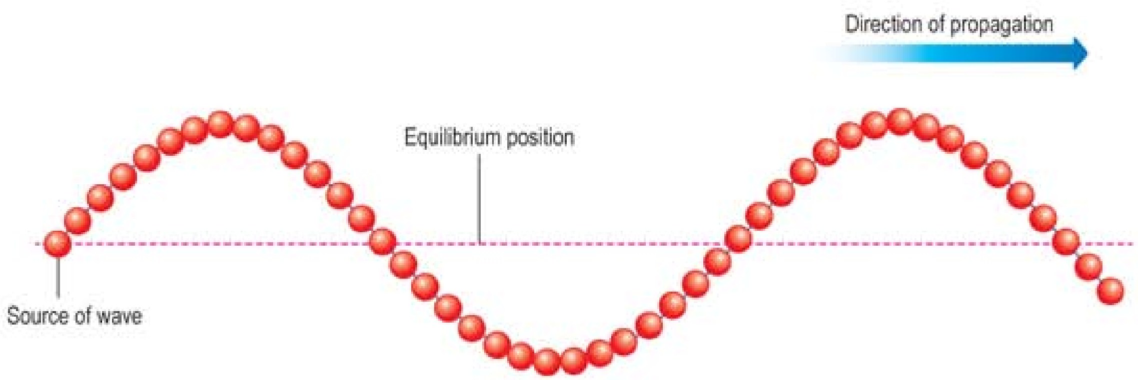


Figure 5.16 *Profile of a transverse wave*

Particles along the wave oscillate up and down about the equilibrium position. Scan the QR code given to observe the change in displacement of the particles. Two types of graphs can be drawn to show the variation of the displacement of wave particles, which are graph of displacement against time and graph of displacement against distance.

Simulation of a wave profile

http://bt.sasbadi.com/p4180a

Activity 5.5

ICS

Aim: To sketch a graph of displacement against time and a graph of displacement against distance

Instructions:

1. Group in pairs.
2. Scan the QR code to observe the method of sketching a graph of displacement against time and a graph of displacement against distance.
3. Sketch a graph of displacement against time for a wave with:
   (a) Amplitude, A = 5 cm
   (b) Period, T = 0.4 s
4. Sketch a graph of displacement against distance for a wave with:
   (a) Amplitude, A = 5 cm
   (b) Wavelength, λ = 4 cm

Video on method of sketching a graph of displacement against time

http://bt.sasbadi.com/p4180b

Video on method of sketching a graph of displacement against distance

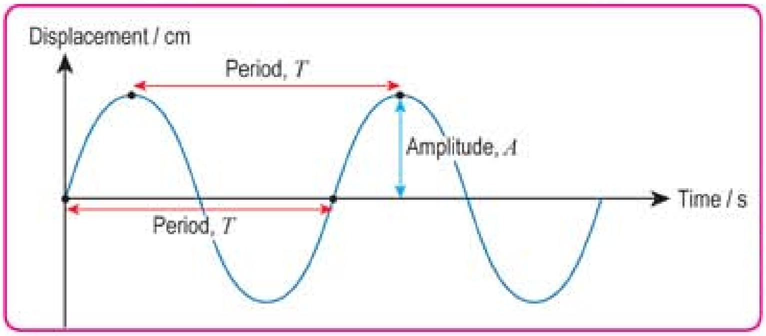
http://bt.sasbadi.com/p4180c

A graph of displacement against time and a graph of displacement against distance respectively give information on the terms related to waves as shown in Figure 5.17.

SMART INFO

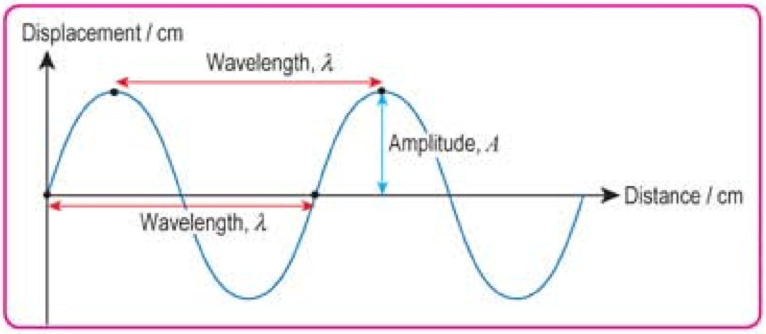
Speed of a wave, $v = f\lambda$ can be calculated from the information obtained from a graph of displacement against time and a graph of displacement against distance.

Graph of displacement against time



Information obtained:
Amplitude, A
Period, T
Frequency, $f = \frac{1}{T}$

Graph of displacement against distance



Information obtained:
Amplitude, A
Wavelength, λ

***Figure 5.17** Information of waves that can be interpreted from the graphs*

Activity 5.6

CPS

Aim: To interpret graph of waves

Instructions:

1. Work in groups.
2. Study the graph of displacement against time and the graph of displacement against distance for a wave propagating along a piece of rope.

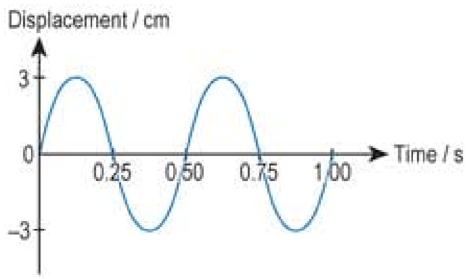


***Figure 5.18** Graph of displacement against time*

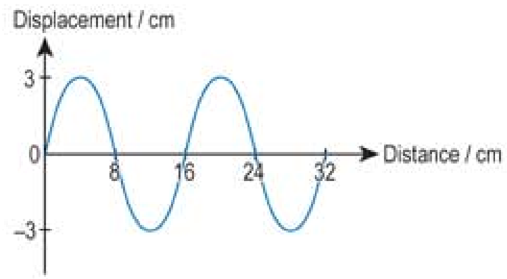


***Figure 5.19** Graph of displacement against distance*

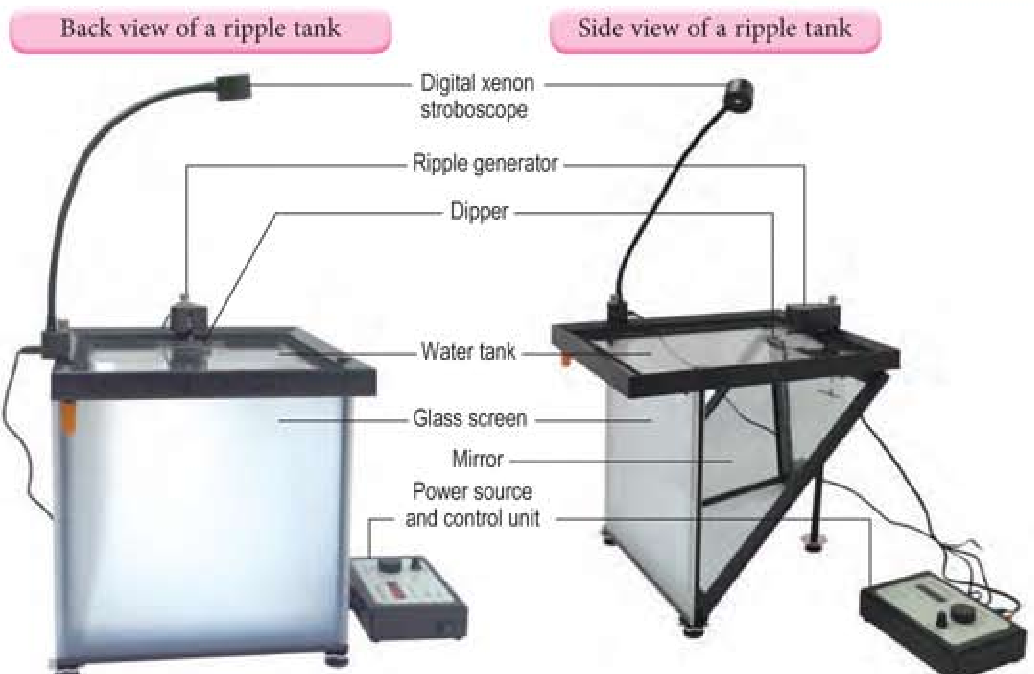
3. Discuss and interpret the following characteristics of waves in both the graphs:
   (a) Amplitude, A
   (b) Period, T
   (c) Frequency, f
   (d) Wavelength, λ
   (e) Wave speed, v

Determining Wavelength, λ, Frequency, f and Wave Speed, v

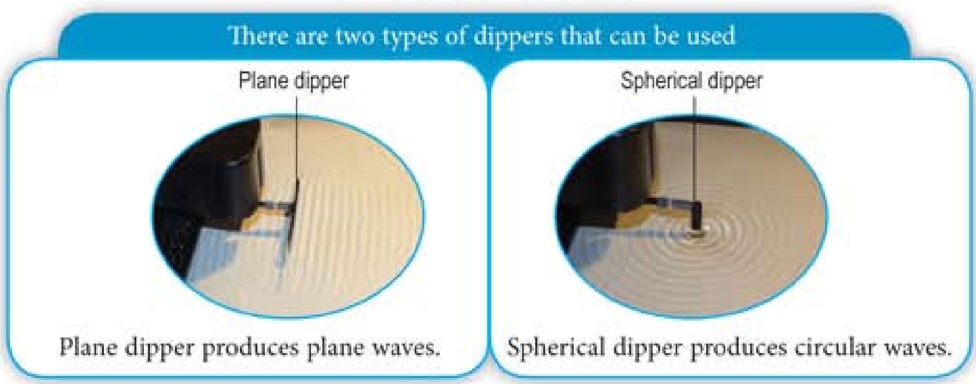
A ripple tank is used in the laboratory to study water waves. It consists of a water tank made from perspex or glass, ripple generator, digital xenon stroboscope, mirror, glass screen and dipper.

Video demonstrating the use of a ripple tank

http://bt.sasbadi.com/p4182



Photograph 5.4 *Ripple tank*



Photograph 5.5 *Types of waves produced by different types of dippers*

Activity 5.7

Aim: To determine the wavelength, frequency and wave speed

Apparatus: Ripple tank and its accessories, digital xenon stroboscope and ruler

Materials: Distilled water

Instructions:

1. Arrange the apparatus as in Photograph 5.6.
2. Switch on the plane dipper and adjust the frequency of the digital xenon stroboscope so that the image on the screen looks stationary.
3. Use a ruler to measure the wavelength of the water wave, that is the distance between two consecutive bright fringes.

Photograph 5.6

Discussion:

1. What is the frequency of the water wave?
2. What is the wavelength of the water wave?
3. What is the wave speed?

Note: If there is no digital xenon stroboscope, handheld stroboscope can be used.

Formative Practice 5.1

1. Figure 5.20 shows a graph of displacement against time for a wave.

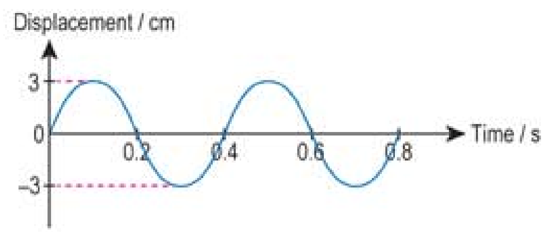


Figure 5.20

   (a) What is meant by amplitude?
   (b) Determine the period of oscillation, T. Then, calculate the frequency of oscillation.

2. Compare and contrast progressive wave and stationary wave.

3. Figure 5.21 shows a slinky spring being moved forward and backward at one of its ends.
   (a) What type of wave is produced by a slinky spring?
   (b) Mark "X" at the rarefaction part of the wave in Figure 5.21.
   (c) What is the wavelength, λ of the wave?

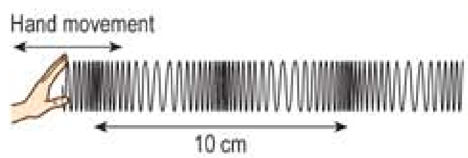


Figure 5.21

5.2 Damping and Resonance

Damping and Resonance for an Oscillating and Vibrating System

An oscillating system that is displaced and then left to oscillate without the action of external forces, will oscillate at its **natural frequency**. What happens to the amplitude of the oscillating system?

Activity 5.8

Aim: To observe the phenomenon of damping on an oscillating system

Apparatus: Simple pendulum made up of a plastic bag filled with granulated sugar tied to a 120 cm long thread, retort stand and G-clamp

Materials: Fine granulated sugar, black paper and sharp pencil

Instructions:

1. Set up the apparatus as shown in Figure 5.22.

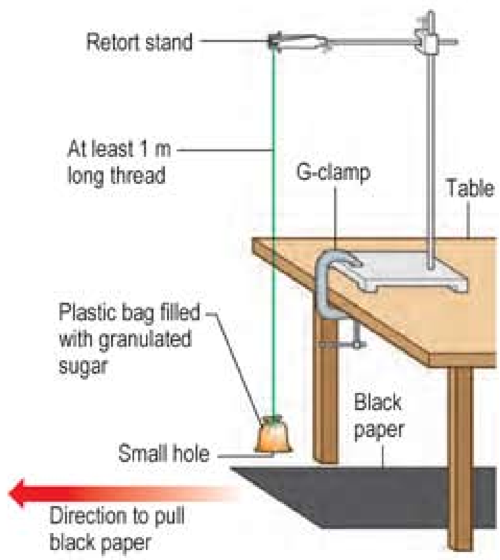


Figure 5.22

2. Use a sharp pencil to prick the bottom of the plastic bag filled with granulated sugar.
3. Displace the plastic bag to the side and release it to oscillate slowly near the floor.
4. Pull the black paper which is under the plastic bag slowly with uniform speed.
5. Observe the pattern formed by the granulated sugar on the black paper.
6. Sketch the pattern formed.

Discussion:

1. What changes happen to the amplitude of oscillation of the plastic bag?
2. Why does the oscillation of the plastic bag stop after some time?

Figure 5.23 shows the graph of displacement against time for the oscillation in Activity 5.8.

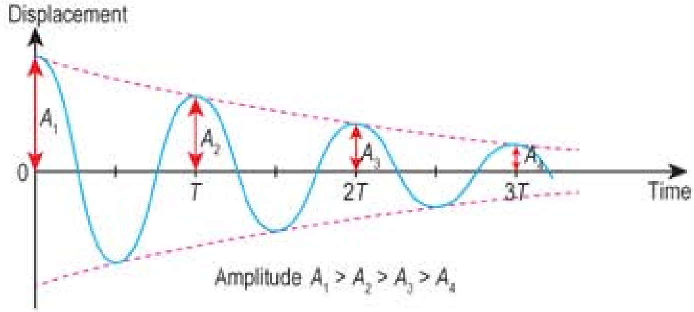


***Figure 5.23** Graph of displacement against time for the oscillation of the simple pendulum*

Observe that the amplitude for the oscillation decreases with time. Figure 5.24 shows the graph of amplitude against time for the oscillation of the simple pendulum.

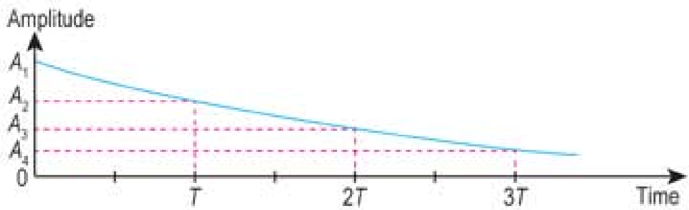


***Figure 5.24** Graph of amplitude against time for the oscillation of the simple pendulum*

Info File

The oscillation of a simple pendulum experiences significant external damping but insignificant internal damping. For the vibration of a spring, both external and internal damping happen significantly.

Info File

Periodic force is a force which acts at specific time intervals. Periodic force does not act continuously.

An oscillation with its amplitude decreasing with time shows that the system experiences a gradual loss of energy. Finally the oscillation stops. This phenomenon is known as damping. Oscillating systems experience loss of energy due to:

External damping	Oscillating system loses energy to overcome friction or air resistance.
Internal damping	Oscillating system loses energy because of the stretching and compression of the vibrating particles in the system.

Damping is the reduction in amplitude in an oscillating system due to loss of energy. During damping, the oscillating frequency remains constant while the oscillating amplitude decreases.

The effect of damping can be overcome by applying periodic external force on the oscillating system. The periodic external force transfers energy into the oscillating system to replace the energy lost. The system is said to be in a forced oscillation.

When a periodic force is applied to an oscillating system at its natural frequency, the oscillating system is said to be at **resonance**.

During resonance:
- System oscillates with its natural frequency.
- System oscillates with maximum amplitude.

Activity 5.9

Aim: To study the production of resonance using Tuning Fork Kit and Barton's pendulum

(A) Tuning Fork Kit

Apparatus: Tuning fork kit is made up of two tuning forks of the same frequency, hammer and tablet installed with sound meter application

Instructions:

1. Set up the apparatus as shown in Figure 5.25.
2. Open the sound meter application on the tablet. Observe and record the reading displayed.
3. Strike tuning fork *P* with a hammer.
4. Move tuning fork *Q* away from tuning fork *P* without touching its prongs.
5. Use the sound meter application to record the level of loudness of sound produced by tuning fork *P* and tuning fork *Q* separately.

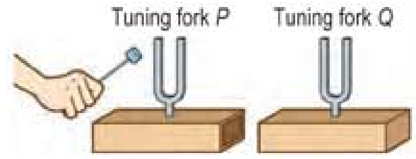


Figure 5.25

Discussion:

1. Is sound detected by the tablet when it is near tuning fork *P* and *Q*?
2. Why does tuning fork *Q* produce sound without being struck? Explain.

(B) Barton's Pendulum

Apparatus: Retort stand, brass bob and G-clamp

Materials: Thread, string, small paper cup and cellophane tape

Instructions:

1. Prepare the apparatus setup as shown in Figure 5.26.
2. Ensure brass bob *X* and paper cup *C* are at the same horizontal level so that pendulums *X* and *C* are of the same length.
3. Displace pendulum *X* and release it.
4. Observe the oscillations of pendulums *A*, *B*, *C* and *D*.
5. Identify the pendulum which oscillates with the largest amplitude.

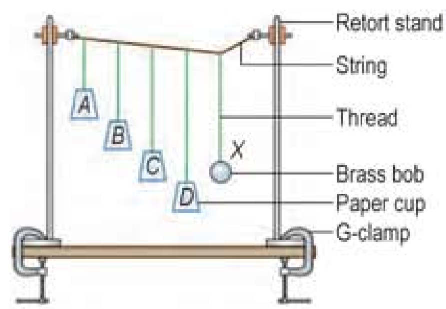


Figure 5.26

Discussion:
1. Which pendulum oscillates with the largest amplitude?
2. Why does that pendulum oscillate with the largest amplitude?

The vibrations of tuning fork *P* have forced tuning fork *Q* to vibrate in resonance with *P*. Energy is transferred from tuning fork *P* to tuning fork *Q*. Tuning fork *Q* vibrates with maximum amplitude and produces sound that can be detected.

The oscillation of brass pendulum *X* transfers energy to pendulums *A*, *B*, *C* and *D* causing all pendulums to oscillate. Resonance happens to pendulum *C* because pendulum *C* has the same natural frequency as pendulum *X*. Pendulum *C* oscillates with the largest amplitude.

Effects of Resonance in Daily Life

Activity 5.10

ISS ICS

Aim: To show a video on effects of resonance in daily life

Instructions:
1. Work in groups.
2. Examples of the effects of resonance in daily life are as follows:

In 1940, the hanging bridge *Tacoma Narrows* in Washington, USA collapsed due to strong winds which caused the bridge to oscillate with large resonance and amplitude.

The *London Millennium Footbridge* was opened in June 2000. This bridge experienced unexpected oscillations when 2 000 pedestrians walked on it.

Resonance is used in the tuning of musical instruments.

3. Search for videos on the effects of resonance given and present your videos.
4. Search for more examples of resonance.

Video on examples of resonance

http://bt.sasbadi.com/p4187

Formative Practice 5.2

1. What is the meaning of damping?
2. Sketch a graph of displacement against time for a system experiencing damping.
3. State three examples of the effects of resonance in our daily lives.
4. How can resonance overcome damping of an oscillating system?

5.2.1 5.2.2

5.3 Reflection of Waves

You have studied that light and sound waves can be reflected. In reality, all waves can be reflected. Photograph 5.7 shows sea waves reflected by an embankment. Scan the QR code to watch the video on the reflection of waves.

Video on reflection of waves

http://bt.sasbadi.com/p4188

Photograph 5.7 *Sea waves reflected by an embankment*

Wavefront

The phenomenon of reflected waves can be studied with the help of a ripple tank and its accessories. Figure 5.27 shows plane waves produced by a ripple tank.

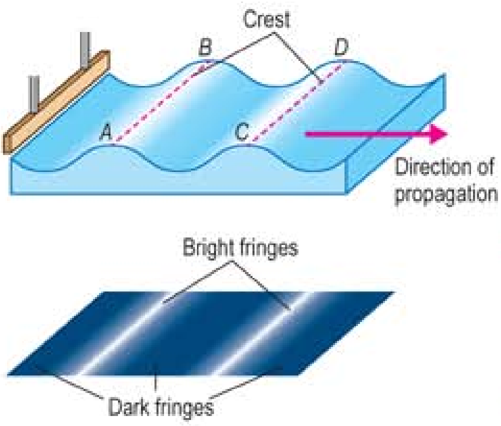


Figure 5.27 *Wavefront*

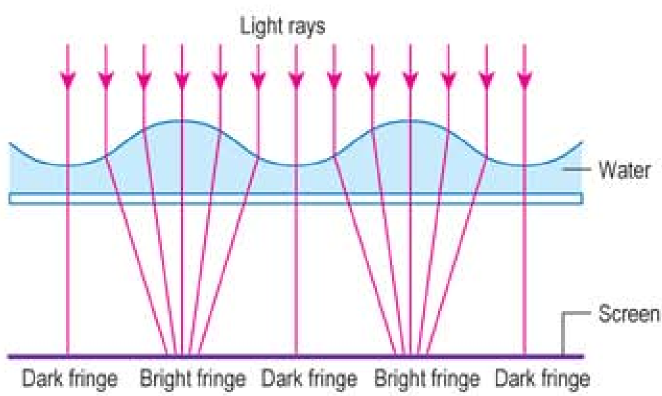
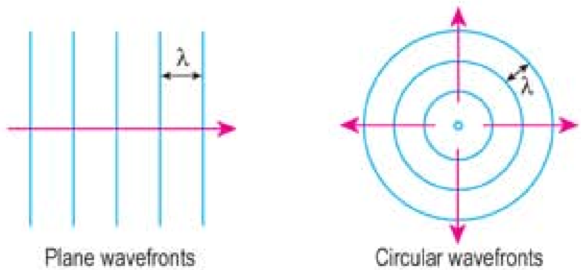


Figure 5.28 *Formation of bright and dark fringes*

All points along line *AB* are in phase as the points are of the same distance from the source of vibration and have the same displacement. Line *AB* which joins the points in phase in a wave is known as **wavefront**. Line *CD* is also a wavefront. When light rays move through water in a ripple tank, alternate bright and dark fringes can be seen on the screen as shown in Figure 5.27. Figure 5.28 shows the formation of bright and dark fringes by light rays.

Figure 5.29 shows the wavefronts for plane waves and circular waves. Study the direction of propagation and wavelength of these waves.



- Direction of propagation of the wave is perpendicular to the wavefront.
- Wavelength, λ is the same as the distance between two consecutive wavefronts.

***Figure 5.29** Plane and circular wavefronts*

What is the effect on the characteristics of waves when a wave is reflected?

Activity 5.11

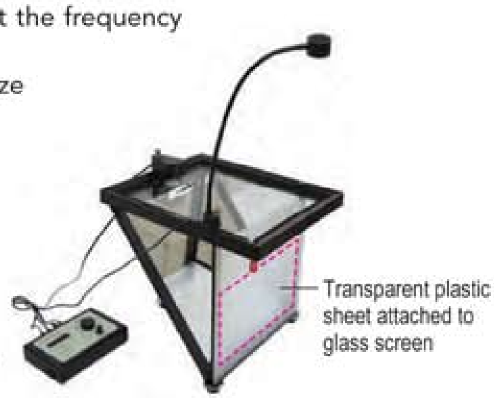
Aim: To study the reflection of waves for plane waves

Apparatus: Ripple tank and its accessories, plane reflector, digital xenon stroboscope, ruler and protractor

Materials: Transparent plastic sheet, marker pen, cellophane tape and distilled water

Instructions:

1. Set up the apparatus as shown in Photograph 5.8.
2. Switch on the wave generator and adjust so that the frequency of vibration is low.
3. Adjust the frequency of the stroboscope to freeze the movement of the waves.
4. Place the plane reflector into the water tank.
5. Use a marker pen to mark on the plastic sheet the position of:
   (a) plane reflector
   (b) three consecutive incident wavefronts
   (c) three consecutive reflected wavefronts
6. Remove the plastic sheet and use a marker pen to draw:
   (a) shape of plane reflector
   (b) three incident wavefronts and reflected wavefronts
   (c) direction of propagation of incident wave and reflected wave
   (d) normal line
7. Determine the following values:
   (a) angle of incidence, i and angle of reflection, r
   (b) incident wavelength and reflected wavelength

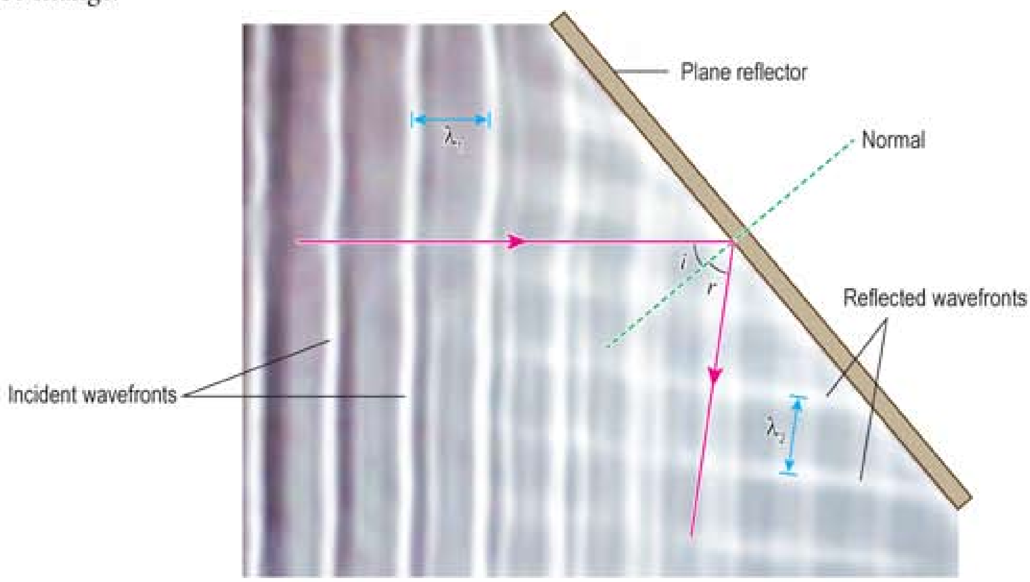


Photograph 5.8

Discussion:

1. Compare angle of incidence and angle of reflection.
2. Compare incident wavelength and reflected wavelength.
3. Can the stroboscope freeze the movement of incident waves and reflected waves at the same time?
4. Based on your answer in question 3, compare the frequency of incident wave and frequency of reflected wave.
5. From your answers in questions 2 and 4, compare the speed of incident wave with reflected wave.

Photograph 5.9 shows reflected plane water waves in a ripple tank. The phenomenon of reflected waves only cause the wave direction to change while other characteristics of the wave do not change.



Photograph 5.9 *Reflection of plane water waves by a plane reflector*

Table 5.2 summarizes the effects of reflection on the characteristics of waves.

Table 5.2 *Effects of reflection on characteristics of waves*

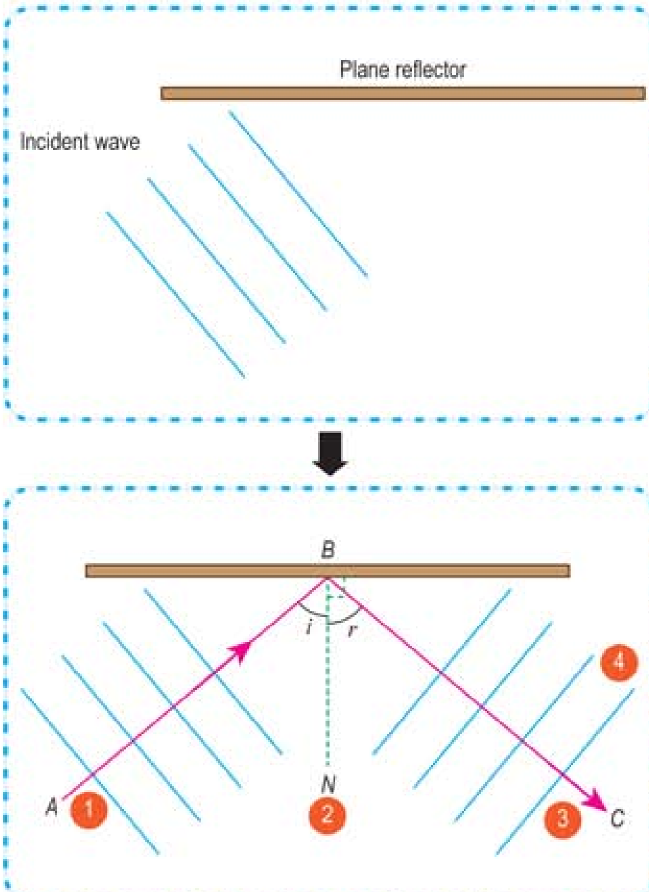
Characteristic of wave	Effect after reflection of wave
Angle of incidence and angle of reflection	Angle of incidence = angle of reflection
Wavelength	No change
Frequency	No change
Wave speed	No change
Direction of propagation	Changes with the condition that the angle of incidence is the same as angle of reflection

Drawing Diagram of Reflection of Water Waves

Figure 5.30 shows the steps to draw a diagram of reflection of water waves.

Video on completing diagram of reflection of wave

http://bt.sasbadi.com/p4191



Step 1 Draw an arrowed line *AB* perpendicular to incident wavefront to represent the direction of propagation of incident wave.

Step 2 Draw the normal *BN* which is perpendicular to the plane reflector.

Step 3 Draw an arrow *BC* with the condition angle *CBN* is the same as angle *ABN* to represent the direction of propagation of reflected wave.

Step 4 Draw lines perpendicular to *BC* to represent reflected wavefronts. The reflected wavelength must be the same as the incident wavelength.

***Figure 5.30** The steps to draw reflection of water waves*

Applications of Reflection of Waves in Daily Life

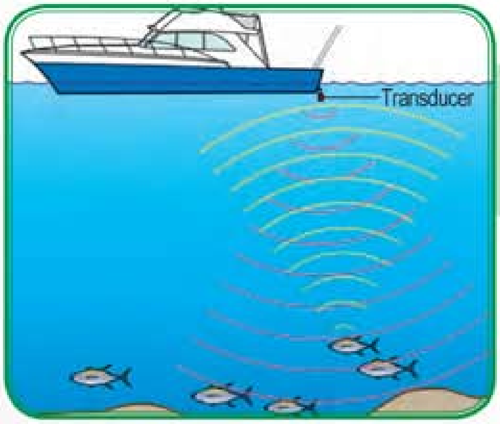
The phenomenon of reflection of waves can be applied in our daily lives. Figure 5.31 shows some examples of the application of reflection of waves.

CAREER INFO

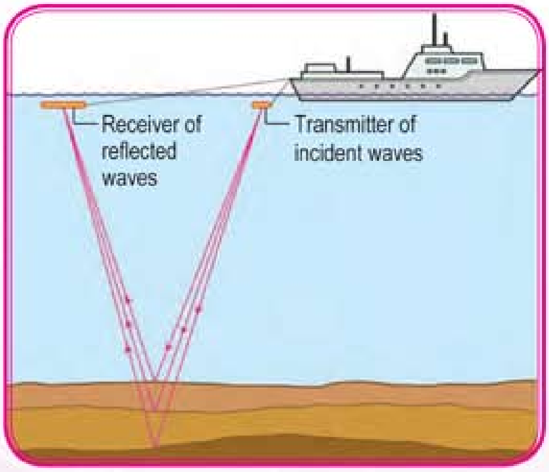
Officers of Science (Physics) in the diagnostic imaging and radiotherapy division in hospitals maintain and callibrate all apparatus that produce electromagnetic and sound waves so that they are safe to use.

Ultrasonic waves are used in the medical field to examine a foetus or other internal organs.

Radio waves from communication satellites are reflected by the parabolic dish and focussed onto the antenna on the feed horn.



Technology of ultrasonic reflection which is known as SONAR helps to detect areas which have a lot of fish. Transducer transmits waves into the water and these waves are reflected by the fish to the transducer.



Patterns of reflected sound waves caused by different rocks enable the location, depth and structure of the seabed which contain sources of natural gas to be identified.

Figure 5.31 Applications of reflected waves in daily life

Solving Problems Involving Reflected Waves

Example 1

Ultrasonic waves of frequency 25 kHz are transmitted from a ship to the seabed to determine the depth of the sea. These waves travel at a speed of 1 500 m s^{-1} in the water. Time between sending the ultrasonic wave and receiving the reflected wave is 120 ms.
Determine
(a) depth of sea, and
(b) ultrasonic wave length.

Solution:

The ultrasonic wave takes 120 ms to travel from the ship to the seabed and back to the ship. Distance travelled by the wave is two times the depth of the sea.

(a)

Step 1
List the given information in symbols.

Speed of the wave, v = 1 500 m s^{-1}
Time interval, t = 120 ms

Step 2
Identify and write down the formula used.

Distance travelled = Speed × time
$2d = vt$

Step 3
Substitute numerical values into the formula and perform the calculations

$$\text{Depth, } d = \frac{vt}{2} = \frac{1\,500(120 \times 10^{-3})}{2} = 90 \text{ m}$$

(b)

$$v = f\lambda$$
$$1\,500 = (25 \times 10^{3})\lambda$$
$$\lambda = \frac{1\,500}{25 \times 10^{3}} = 0.06 \text{ m}$$

Formative Practice 5.3

1. Copy Figure 5.32 and draw the wavefront and the direction of the reflected water waves.

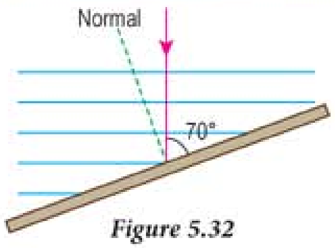


Figure 5.32

2. Figure 5.33 shows the use of ultrasonic waves by a ship to determine the depth of the sea. The interval time between transmission and receiving of echo of the ultrasonic sound is 0.06 seconds. Speed of the ultrasonic wave in the water is 1 500 m s^{-1}. Determine the depth of the sea.

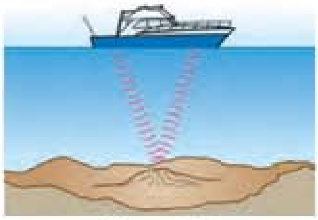


Figure 5.33

5.3.4

5.4 Refraction of Waves

Photograph 5.10 shows the curving wavefront of the sea when approaching the shoreline. The curve of the wavefront is caused by a phenomenon of refraction of waves.

Refraction of waves is the change in direction of propagation of waves caused by **the change in the velocity of waves** when the waves propagate from one medium to another. What is the effect of refraction on the characteristics of waves?

Photograph 5.10 Refraction of sea waves in Imsouane, Morocco
(Source: Image ©2019 CNES/Airbus)

SMART INFO

- Speed of water wave is influenced by depth of water.
- Speed of sound wave is influenced by density of air.
- Speed of light wave is influenced by optical density of medium.

Activity 5.12

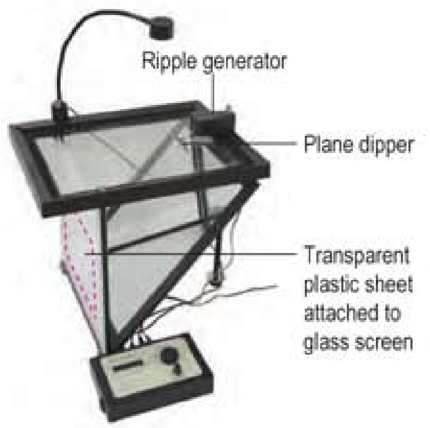
Aim: To study refraction of waves for plane waves

Apparatus: Ripple tank and its accessories, digital xenon stroboscope, plane dipper, ruler, protractor and perspex sheets

Materials: Transparent plastic sheets, marker pen, cellophane tape and distilled water

Instructions:

1. Set up the apparatus as shown in Photograph 5.11.



Photograph 5.11

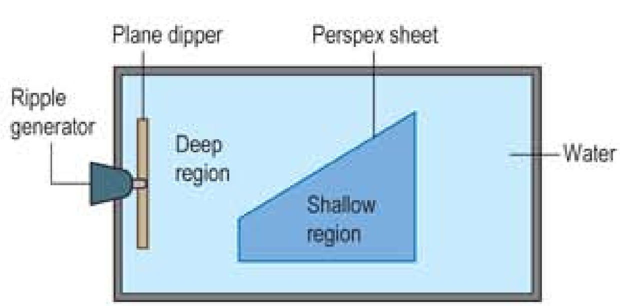


Figure 5.34

5.4.1

2. Switch on the ripple generator and adjust so that plane waves of low frequency are produced.
3. Observe the plane wavefront produced.
4. Place the perspex sheet into the water as shown in Figure 5.34 so that the wave propagates from the deep region to the shallow region of the water.
5. Observe the movement of the wavefront in the deep and shallow regions.
6. Adjust the frequency of the stroboscope to freeze the movement of the wave. Observe the pattern of the waves.
7. Use a marker pen to mark on the plastic sheet the position of:
   (a) boundary between the deep and the shallow regions
   (b) three consecutive incident wavefronts
   (c) three consecutive refracted wavefronts
8. Remove the plastic sheet and use a marker pen to draw:
   (a) boundary between the deep and the shallow regions
   (b) three incident wavefronts and refracted wavefronts
   (c) direction of propagation of incident wave and refracted wave
   (d) normal line
9. Determine the following values:
   (a) angle of incidence, i and angle of refraction, r
   (b) incident wavelength and refracted wavelength
10. Repeat steps 4 to 9 for waves that propagate from the shallow to the deep water region as in Figure 5.35.

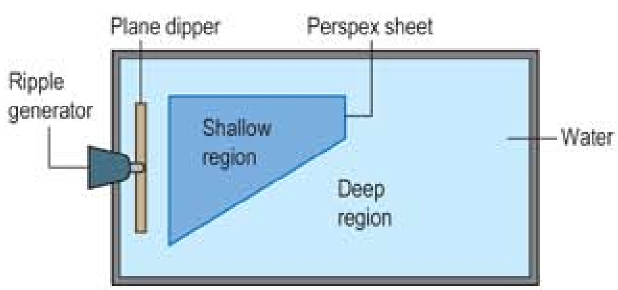


Figure 5.35

Discussion:

1. Compare angle of incidence and angle of refraction for both situations.
2. Compare incident wavelength and refracted wavelength for both situations.
3. Is the stroboscope able to freeze the movements of incident wave and refracted wave at the same time?
4. Based on your answer in question 3, compare the frequency of incident wave and the frequency of refracted wave.
5. From your answer in questions 2 and 4, compare the speed of incident wave and the speed of refracted wave.

From Activity 5.12, you will obtain the refraction of plane water wave. Figure 5.36 shows the refraction of plane water wave.

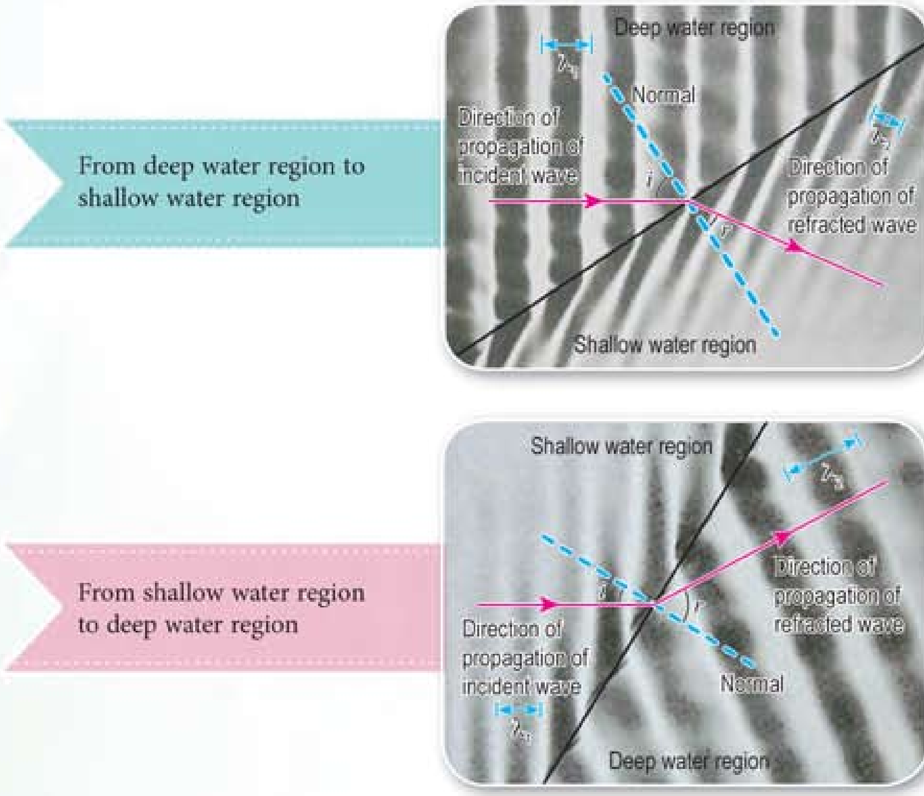


Figure 5.36 *Refraction of plane water waves*

Table 5.3 summarizes the effects of refraction on the characteristics of waves.

Table 5.3 *Effects of refraction on the characteristics of waves*

Characteristic of wave	From deep water region to shallow water region	From shallow water region to deep water region
Angle of incidence and angle of refraction	Angle of incidence > angle of refraction	Angle of incidence < angle of refraction
Wavelength	Decreasing	Increasing
Frequency	No change	No change
Wave speed	Decreasing	Increasing
Direction of propagation	Refracted towards the normal	Refracted away from the normal

Drawing Diagram of Refraction of Plane Water Waves

Figure 5.37(a) shows plane wavefronts in deep water region approaching shallow water region. Figure 5.37(b) which shows wavefronts of refracted waves can be drawn using four steps.

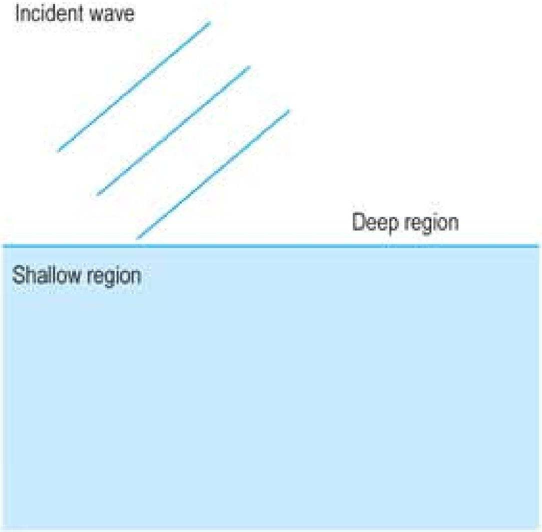


Figure 5.37(a)

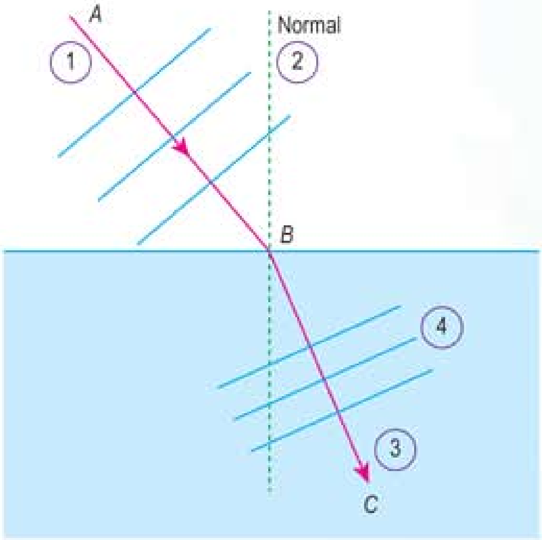


Figure 5.37(b)

The steps to draw refraction of plane water waves are as follows:

Step 1:

Draw an arrowed line *AB* perpendicular to the incident wavefront to represent direction of propagation of the incident wave.

Step 2:

Draw the normal which is perpendicular to the boundary of the deep region and shallow region at *B*.

Step 3:

Draw an arrowed line *BC*, which is nearer the normal than *AB* to represent the direction of propagation of the refracted wave.

If water wave propagates from shallow region to deep region, direction of propagation of the refracted wave is bent away from the normal.

Step 4:

Draw three lines perpendicular to *BC* to represent the refracted wavefronts. The lines have to be closer to one another compared to the incident wavefronts.

5.4.2

Activity 5.13

Aim: To discuss and draw diagrams of refraction of plane water waves that propagate at a specific angle of incidence at two different depths

Instructions:

1. Work in pairs.
2. Scan the QR code to download Figure 5.38 from the website given.

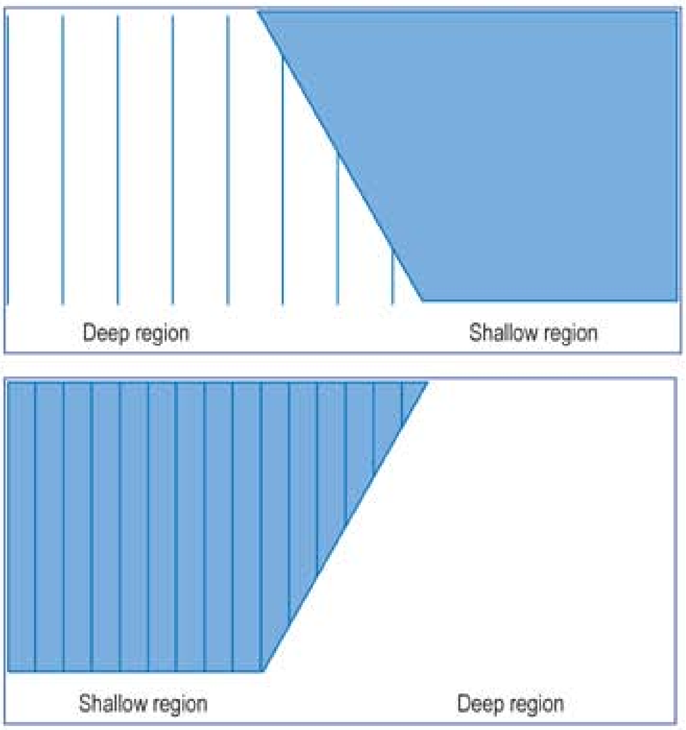


Figure 5.38

Download Figure 5.38

http://bt.sasbadi.com/p4198

3. Discuss and complete the diagrams of refraction of water waves in Figure 5.38.

Phenomena of Refraction of Waves in Daily Life

Activity 5.14

Logical Reasoning | ISS | ICS

Aim: To discuss the natural phenomena of refraction of waves

Instructions:

1. Work in pairs.
2. Search for information on the natural phenomena of refraction of waves.
3. Present your findings in the form of an interesting multimedia presentation.

During the day, air that is closer to the surface of the earth is hotter than the air above. Sound moves faster in hot air than in cold air. As such, sound is refracted away from the ground. Thus, an observer cannot hear sound clearly during the daytime.

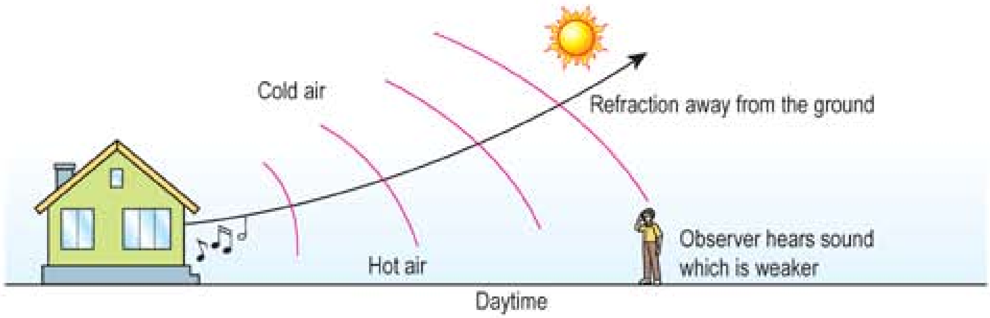


Figure 5.39 *Sound is not heard clearly during the day*

During the night, air that is closer to the surface of the earth is colder. Sound is refracted towards the ground. This causes the observer to hear sound more clearly during the night. Observe Figure 5.40.

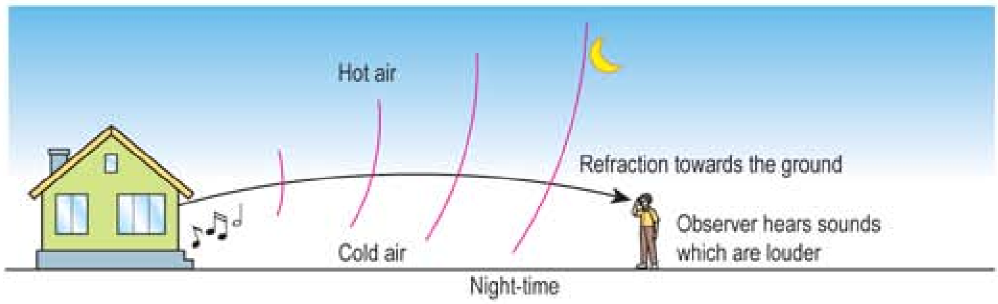


Figure 5.40 *Sound is heard more clearly during the night*

Figure 5.41 shows the phenomenon of refraction of sea waves. The cape is the shallow water region while the bay is the deep water region. Away from the shoreline, the wavefront of the water is almost straight and parallel because water waves move at a uniform speed.

When the wavefront of the water propagates to the cape, the speed of the water waves decreases causing the wavelength to be shorter. Wavefront of water approaching the bay moves at a higher speed and the wavelength is longer. This causes the wavefront to curve and follow the shape of the shoreline.

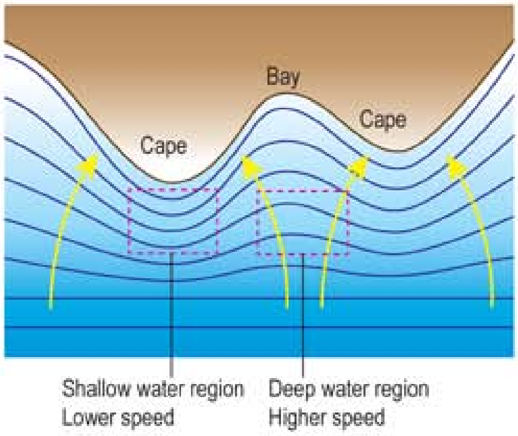


Figure 5.41 *Refraction of sea waves*

Refraction of water waves causes water wave energy to converge towards the cape. Water wave energy diverges from the bay and spread out to a wider region. Thus, the amplitude of waves at bay is smaller than at the cape.

5.4.3

Solving Problems Involving Refraction of Waves

Refraction of waves is caused by the change in speed of waves. For water waves, speed of wave changes when the depth of water changes. This also causes wavelength to change. However, the frequency of waves does not change because wave frequency is determined by the frequency of vibrations at the source of the wave.

Figure 5.42 shows changes in speed and wavelength when water waves propagate from deep region to shallow region.

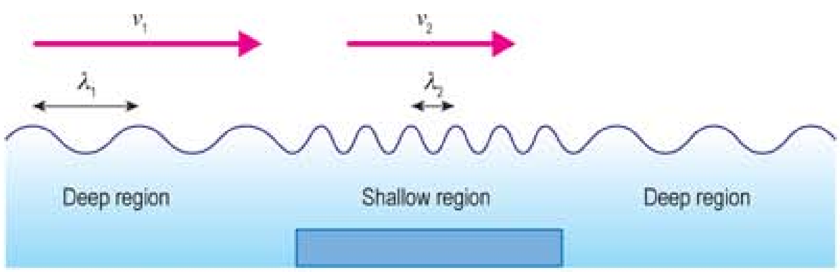


***Figure 5.42** Propagation of water waves from deep region to shallow region*

From formula of speed of wave, $v = f\lambda$,
in deep region: $v_1 = f\lambda_1$ .... (1)
in shallow region: $v_2 = f\lambda_2$ .... (2)
(1) ÷ (2) gives $\frac{v_1}{v_2} = \frac{\lambda_1}{\lambda_2}$,
that is $\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$

Example 1

A plane wave which has a wavelength of 2 cm and speed of 8 cm s^{-1} propagates across a shallow region. When the wave enters the deep region, wave speed becomes 12 cm s^{-1}. Determine the value of the wavelength in the deep region.

Solution:

Step 1
List the given information in symbols.

Shallow region: λ_1 = 2 cm, v_1 = 8 cm s^{-1}
Deep region: v_2 = 12 cm s^{-1}, λ_2 = ?

Step 2
Identify and write down the formula used.

$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$
$$\frac{8}{2} = \frac{12}{\lambda_2}$$

Step 3
Substitute numerical values into the formula and perform the calculations.

$$\lambda_2 = \frac{12 \times 2}{8}$$
$$= 3 \text{ cm}$$

Example 2

Figure 5.43 shows propagation of water wave from region *P* to region *Q* of different depths. Speed of the wave is 18 cm s^{-1} in region *P*. Determine the speed of the wave in region *Q*.

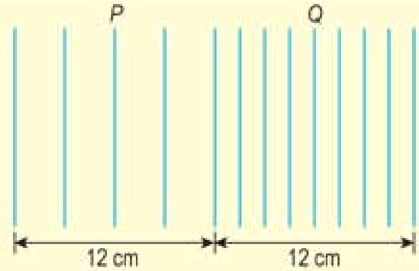


Figure 5.43

Solution:

λ in region *P*, $\lambda_1 = \frac{12}{4}$

$= 3$ cm

λ in region *Q*, $\lambda_2 = \frac{12}{8}$

$= 1.5$ cm

Region *P*: $\lambda_1 = 3$ cm, $v_1 = 18$ cm s^{-1}

Region *Q*: $\lambda_2 = 1.5$ cm, $v_2 = ?$

$$\frac{v_1}{\lambda_1} = \frac{v_2}{\lambda_2}$$

$$\frac{18}{3} = \frac{v_2}{1.5}$$

$$v_2 = \frac{18 \times 1.5}{3}$$

$$= 9 \text{ cm s}^{-1}$$

Formative Practice 5.4

1. What phenomenon of waves happens when sea waves are approaching the beach? Explain your answer with the help of a diagram.

2. Figure 5.44 shows plane water waves of frequency 10.0 Hz propagating from deep region to the boundary of shallow region *PQ*. Speed of the water wave in the deep region is 30 cm s^{-1}.

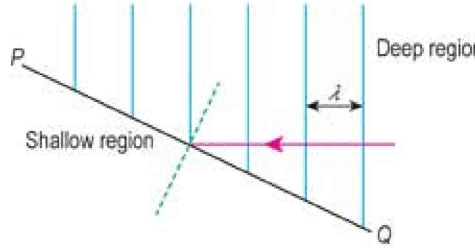


Figure 5.44

   (a) Calculate the wavelength, λ.
   (b) Calculate the speed of the water wave in the shallow region if the wavelength in this region is 1.5 cm.
   (c) Using arrows, draw the direction of propagation of the wave in the shallow region and then sketch the wavefronts of water waves refracted in this region.
   (d) Compare frequency, wavelength and speed in the deep and shallow regions.

5.4.4