Physics

Waves and their applications

04

You have seen the ripples formed when you drop a pebble onto a still water surface. The disturbance caused by the pebble spreads over the water surface in the form of circles centered around the point where the pebble hit the water surface as shown in Figure 4.1.

Figure 4.1 – Formation of ripples on a water surface.

If you hold a rope horizontally as shown in Figure 4.2, and then shake the rope up and down, you will observe ripples forming in the rope. Here too the disturbance caused by the hand travels along the rope.

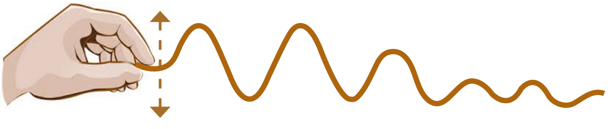


Figure 4.2 – Formation of ripples on a horizontal string

Such a disturbance propagating through a medium or space is known as a **wave**.

If you place an object like a plastic ball on the water surface and then disturb the water surface, how would the plastic ball move?

You will observe that the plastic ball moves up and down perpendicular to the water surface. In order for the ball to move up and down, energy must be transmitted to the ball. Here, energy was transmitted to the ball through the water waves.

An important property of waves is that they carry energy from one point to another. This energy transmission takes place in a manner that does not transmit the substance of the medium between the points concerned.

As an example, when a water wave travels on a water surface, although the water particles at each point move up and down, the water particles do not travel along with the water wave.

• Wave Motion

In the two examples given above, the waves propagate through a certain medium. The medium in the case of water waves is water. The medium in the case of waves propagating along the rope is the material of the rope. The motion of the particles in each medium transmits energy in the form of waves through the medium even though the particles themselves do not travel along with the wave. Apart from the two media mentioned above, waves propagate through many other media.

We hear various sounds through sound waves propagating through air. Sound propagates not only through air but also through liquids and solids.

In addition to waves that travel through various media, there are waves traveling without a material medium. Light is an example for a wave that travels without a medium. Although there are regions between the sun and the earth without any material medium, the earth receives light and heat from the sun. Light and heat from the sun arrive at the earth as electromagnetic waves and a material medium is not required for the propagation of electromagnetic waves.

Radio waves too are a form of electromagnetic waves. Radio programs transmitted by a radio transmission station reach the radio set in your home through air. However, air is not required for radio transmissions.

4.1 Mechanical Waves

Wave motion can be studied using a slinky. A slinky is a coil formed with a steel wire. Figure 4.3 shows a slinky.

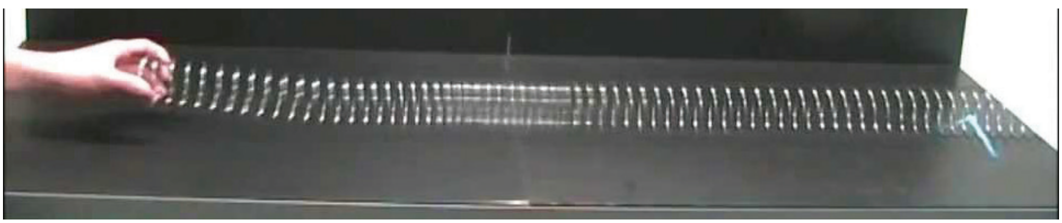


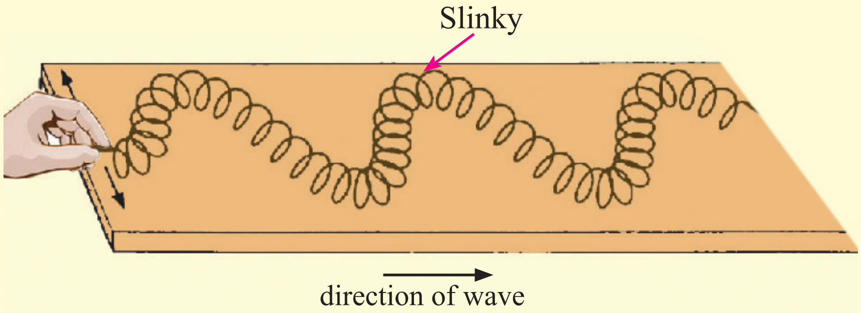
Figure 4.3 - Figure of a slinky

Let us do activity 4.1. to investigate wave motion.

Activity 4.1

Apparatus: A slinky

- Place a slinky on a table as shown in Figure 4.4
- Hold one end of the slinky and shake it to left and right on the plane of the table.



4.4 - Demonstration of the formation of waves using a slinky

You will see a wave propagating through the slinky as shown in the figure.

The wave propagating along this slinky is an example for a wave that needs a medium for propagation. Waves that need a material medium for propagation are known as **mechanical waves.** Waves formed on water surfaces, sound waves that travel in air, and waves formed on a guitar string when the string is plucked are some examples for mechanical waves.

For the propagation of mechanical waves, the participation of the particles in the medium is essential. Based on the direction of motion of the particles of the medium and the direction of propagation of the wave, mechanical waves can be divided into two categories.

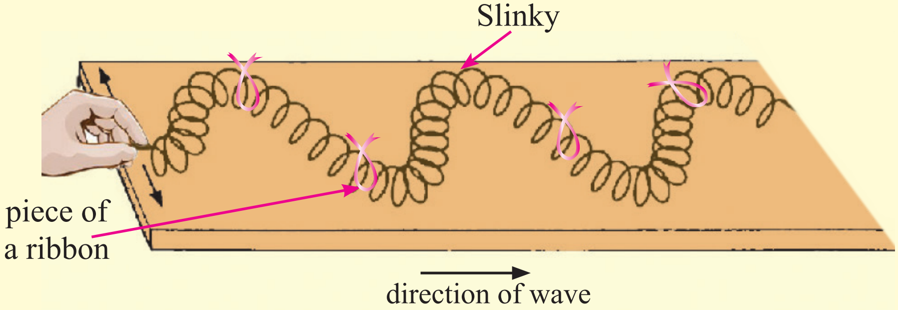
1. Transverse waves
2. Longitudinal waves

4.1.1 Transverse Waves

Activity 4.2

Apparatus: A slinky, a few pieces of ribbon.

- Tie pieces of ribbon at several places on the slinky.
- Place the slinky on the table as in activity 4.1 and shake it to left and right on the plane of the table.
- Observe how each piece of ribbon moves.



4.5 - Demonstration of the formation of transverse waves using a slinky

In this case, the wave propagates from the end held by the hand towards the fixed end. You will observe that the wave is travelling in a direction perpendicular to the direction the ribbons are moving. Such **waves that propagate in a direction perpendicular to the direction the particles of the medium move are called transverse waves.** Therefore, this wave is a transverse wave.

In the water waves generated by disturbing a still water surface by dropping an object such as a pebble, water particles of the medium move up and down within a certain range while the wave travels in a direction perpendicular to that.

We mentioned before that when we disturb a water surface after placing a floating object such as a plastic or rubber ball on the surface, the floating object moves up and down. From the up and down motion of the floating object we can understand that the force exerted on the object by the water particles is vertical. That means the water particles move up and down while the waves spread in a direction perpendicular to this. Therefore, the waves that travel on the water surface are transverse waves.

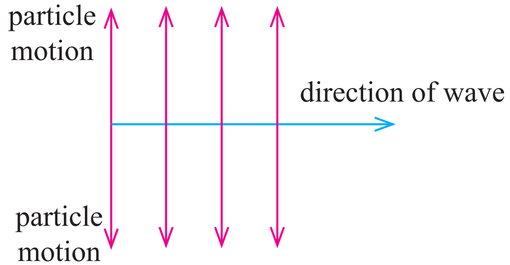


Figure 4.6 Direction of motion of the particles of the medium

As shown in Figure 4.6, in a transverse wave, the particles of the medium move in a direction perpendicular to the direction of the wave. Figure 4.7 shows how the cross section of a water wave appears at a given instance. The arrow heads indicate the direction that the water particles are moving at that instance.

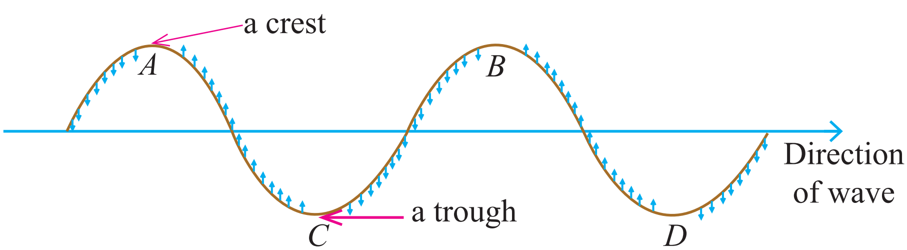


Figure 4.7 – Cross section of a water wave

The particles at points *A* and *B* have traveled the maximum distance in the upward direction. Such points in a wave are known as **crests**. The particles at *C* and *D* have traveled the maximum distance in the downward direction. Such points of a wave are known as **troughs**.

As shown in Figure 4.8, the waves formed by shaking one end of a string up and down whose other end is tied to a post also belong to the category of transverse waves.

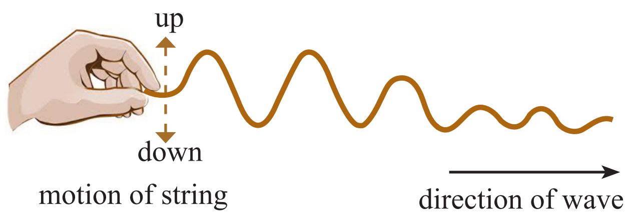


Figure 4.8 - Formation of transverse waves in a string

4.1.2 Longitudinal Waves

Activity 4.2

Apparatus: A slinky, a piece of ribbon

Place the slinky on a table and fix one end. Tie a ribbon on one coil and move the free end of the slinky forward and backward as shown in Figure 4.9. When the free end is pushed forward, the coils near that end are bunched up. This is called a compression. When the free end is pulled back, the coils will stretched-out. This is called a rarefaction.

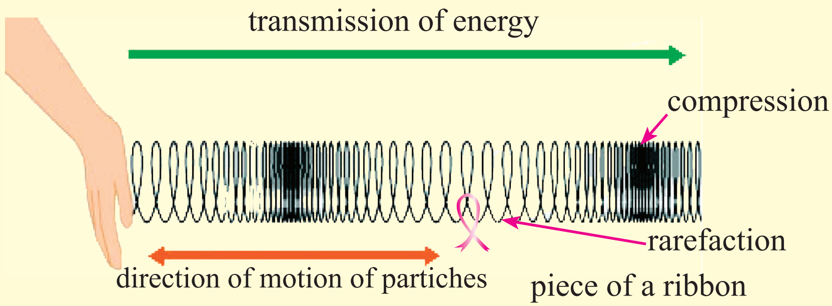


Figure 4.9. Demonstration of the formation of longitudinal waves using a slinky

Compressions are formed when the slinky is pushed forward while rarefactions are formed when the free end is moved backward. As a result of this, a wave propagates along the slinky. By observing the motion of the ribbon you can see the in which direction the parts of the spring move.

If the particles of the medium oscillate parallel to the direction of wave propagation, such waves are known as longitudinal waves. You will observe that the waves formed in the slinky in this activity are longitudinal waves.

Sound a tuning fork and touch one of its two arms with your finger tip. You will sense a small vibration in your finger tip. The reason for this is the alternative contacts and removal of contact of the tuning fork arm with your finger. The back and forth motions in the arms of the tuning fork are known as **vibrations**. We can hear sounds through the waves generated by such vibrations. Such waves that cause the sensation of hearing are known as sound waves. Sound waves generated in air are another example for longitudinal waves.

Transverse Waves	Longitudinal Waves
Particles move perpendicular to the direction of wave propagation.	Particles move parallel to the direction of wave propagation.
Propagate along the surfaces of solids and liquids or along strings, wires etc. Eg : Water waves	Propagate through solids, liquids and gases. Eg : Sound waves

4.1.3 Physical quantities associated with wave motion

Waves are disturbances that spread from one point to another. Therefore waves have variations that depend on both time and distance. In the waves that we observe in nature, quite often these variations show complex forms. However, in this lesson we will only consider waves of a very simple form known as **sinusoidal waves**.

The graph in Figure 4.10 shows how the displacement from the central position of a particle taking part in the wave motion varies with time.

For example, at time t_0 the displacement of that particle is zero. With time, the displacement of this particle increases and at time t_1 it takes a maximum positive value. After that the displacement starts to decrease, becomes zero at time t_2 and then increases in the negative diraction. At time t_3 it takes a maximum negative value and then becomes zero again at t_4 . The motion of the particle from time t_0 to t_4 is called one oscillation. In addition to the word oscillation, the word vibration is also used to describe such motions. If this motion is slow, it is called an oscillation and if it is fast, it is called a vibration.

The graph in Figure 4.11 shows how the displacement from the central position of each particle along the travel path of the wave varies with the distance from the source to each of the particles.

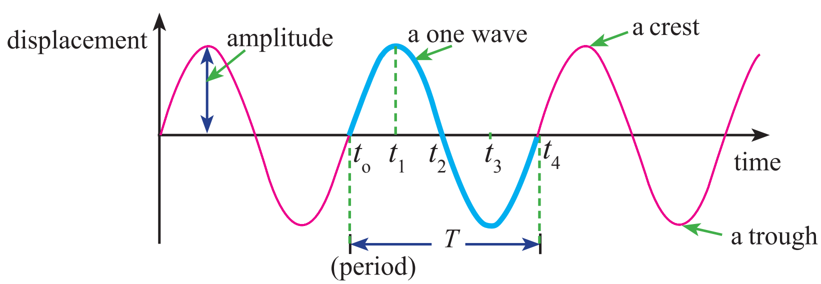


Figure 4.10 – Variation of displacement of a single particle, with time

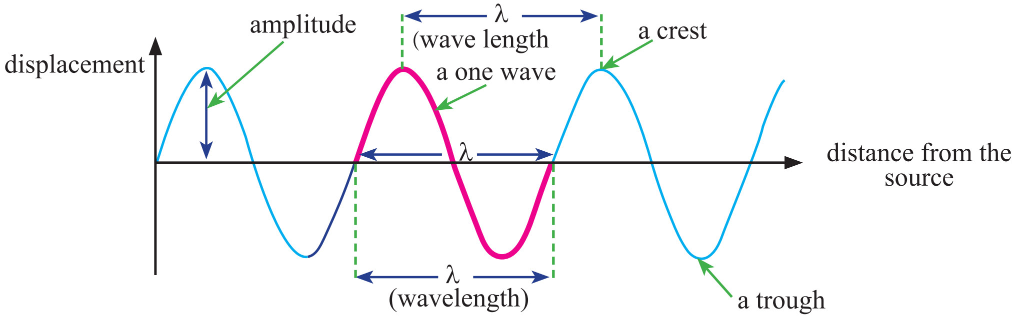


Figure 4.11 (b) – Variation of displacement of particles with the distance from the source, at a given moment

The shape of a transverse wave that we see in a single moment, like the wave traveling along a string shown in figure 4.8, is the same as the shape of the graph of Figure 4.11 (b) showing the variation of the displacement of the particles with the distance from the source at a given instance. Because the particle displacement in longitudinal waves takes place in the same direction as the direction of wave propagation, we can not see the form of the graph in a similar manner as for transverse waves. However, if we somehow measure and plot the variation of the displacement with distance we will obtain a graph like that shown in Figure 4.11 (b).

With the help of these graphs we can define some physical quantities associated with waves.

• Amplitude of a Wave

The maximum displacement shown by the particles taking part in the wave motion is known as the **amplitude** of the wave.

• Wave length of a Wave

The distance between one particle and the closest next particle taking part in the wave motion having the same state of motion is known as the **wavelength** (λ) of the wave. As an example, a particle on a trough or a crest of the wave shown in Figure 4.10 has reached its maximum displacement. A particle on the next trough or crest also has the same state of motion. Therefore, the distance between these two particles, that is the distance between two consecutive troughs or crests is equal to the wavelength.

• Period

The time taken by a particle for a complete oscillation is known as the **period (*T*)**. The time taken by a wave to travel a distance equal to the wavelength is also equal to the period. (figure 4.10)

- **Frequency**

The number of oscillations carried out by aparticle in a unit time is known as the **frequency (f)**. Frequency is equal to the reciprocal of the period. The unit used to measure the frequency is known as **Hertz (Hz)** and one Hertz is defined as one oscillation per second.

$$\boxed{f = \frac{1}{T}}$$

- **Speed**

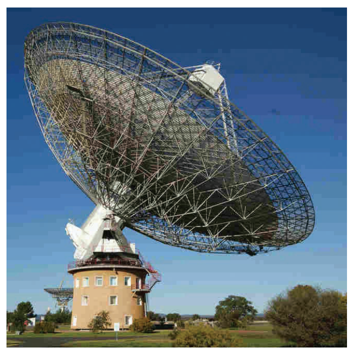
A wave travels a distance equal to the wavelength (λ) in a time interval equal to the period (T). Therefore its speed is given by $v = \lambda / T$ or $v = f\lambda$.

Extra Knowledge

Speed (v)	=	frequency (f)	×	wavelength (λ)
m s^{-1}		Hz		m

4.2 Electromagnetic Waves

The figure shown here is a photograph of a radio telescope. The antenna of this telescope receives radio waves emitted at by very distant stars. Understanding the information contained in those waves helps us to understand more about the history of the universe. Radio waves are electromagnetic waves. Now let us consider more about electromagnetic waves.



The participation of material particles of a medium is not required for the propagation of electromagnetic waves. While electromagnetic waves consist of electric fields and magnetic fields that oscillate in directions perpendicular to each other, the wave propagates in a direction perpendicular to the directions of both the electric and magnetic fields as shown in Figure 4.12. Therefore electromagnetic waves belong the class of transverse waves.

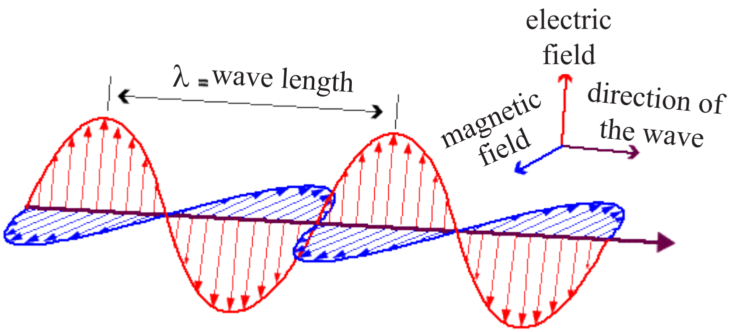


Figure 4.12 - Electric and magnetic fields of an electromagnetic wave.

All electromagnetic waves propagate with the speed of 2.988×10^8 ms^{-1} in a vacuum (It is often taken as 3×10^8 m s^{-1} in calculations). Speed of electromagnetic waves in material media is less than the speed in a vacuum and accordingly the wavelength also changes. For electromagnetic waves, the speed c is given by the relationship $c = f\lambda$ where f is the frequency and λ is the wavelength.

Characteristics of electromagnetic waves

- Electromagnetic waves are not affected by external electric or magnetic fields.
- They do not require a material medium for propagation.
- They travel at a speed of 3×10^8 m s^{-1} in a vacuum.

4.2.1 Electromagnetic Spectrum

The characteristics of electromagnetic waves vary significantly in various frequency ranges. Various frequency ranges identified by such characteristics are known as the electromagnetic spectrum. Main types of electromagnetic waves belonging to the electromagnetic spectrum are listed in the table below.

Type of Waves	Frequency range (Hz)
Gamma rays	$> 3 \times 10^{19}$
X rays	3×10^{17} - 3×10^{19}
Ultra-violet rays	7.69×10^{14} - 3×10^{17}
Visible rays	4.28×10^{14} - 7.69×10^{14}
Infra - red rays	3×10^{12} - 4.28×10^{14}
Micro waves	3×10^{9} - 3×10^{12}
Radio waves	$< 3 \times 10^{9}$

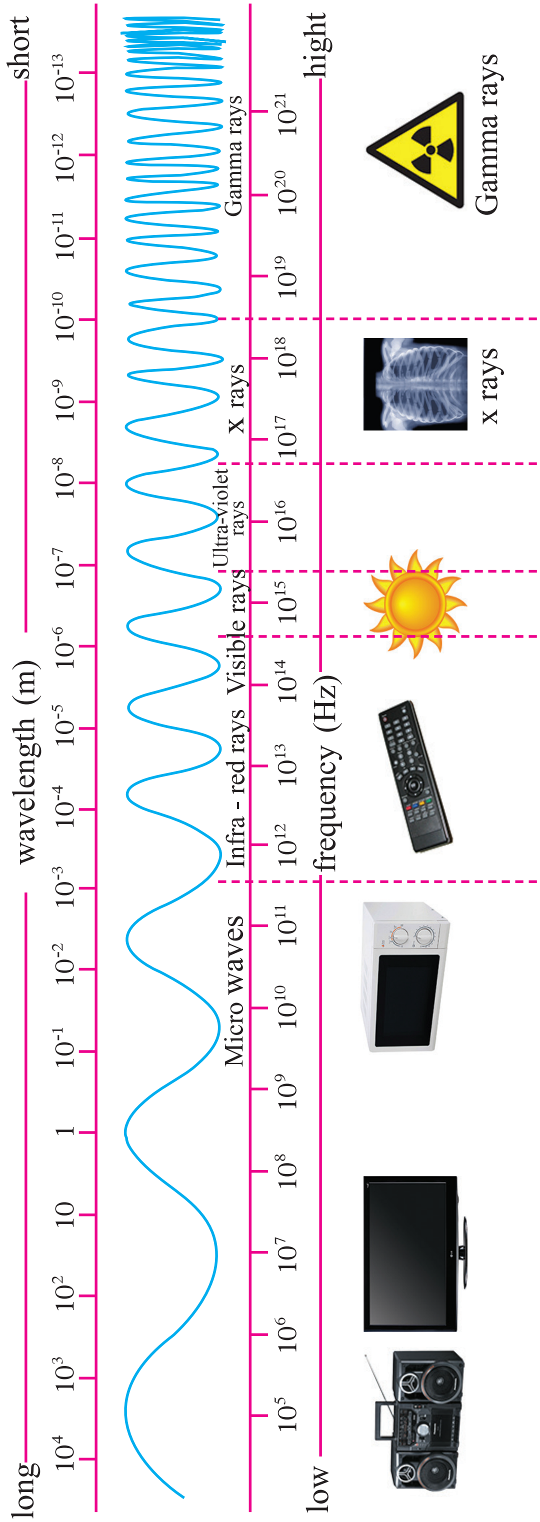


Figure 4.13 – Electromagnetic spectrum

4.2.2. Applications of Electromagnetic Waves

- ### Visible Light

Visible light is the range of the electromagnetic spectrum to which our eyes are sensitive. It is only a narrow band in the electromagnetic spectrum. The frequencies of the visible light range from 4.28×10^{14} Hz to 7.69×10^{14} Hz corresponding to a wavelength range from 690 nm to 400 nm. The region containing the lowest wavelength (highest frequency) in this range appears violet to the human eye. When the wavelength increases (frequency decreases) gradually the color changes to indigo, blue up to red. These are the colors that we identify as the seven colors in the rainbow.

- ### Gamma rays

Gamma rays are a type of waves emitted by radioactive elements. Frequencies of gamma rays are extremely high and so are the energies possessed by them. Gamma rays have the ability even to penetrate thick sheets of steel as well as concrete slabs. Since gamma rays can destroy living cells they are used to destroy cancer cells.

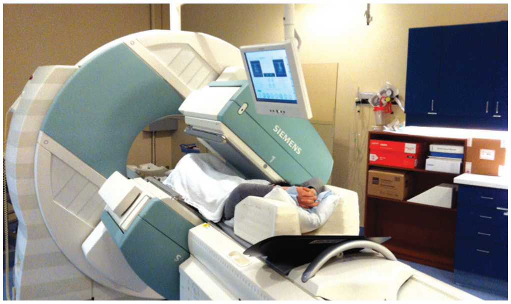


Figure 4.14 – An instance where gamma rays are used

Gamma rays are also used to sterilize utensils used for food and surgical instruments.

- ### X - rays

X–rays are mostly used to take photographs of internal organs of the human body. Although X-rays travel quite easily through the soft tissues in the body, their intensity decreases rapidly when traveling through the bones of the body. When the X–ray generator is turned on, X–rays propagate through the relevant part of the body of the person being photographed and thus forms an image of that part of the body. Excessive exposure to X–rays can cause cancers.

X–rays are generated by bombarding high speed electrons on metal targets. Then part of the kinetic energy of the electrons gets converted to X–rays.

X–rays are also used to examine the baggage of airline passengers and cargo inside containers transported by ships, without opening them.


Figure 4.15 – X – ray imaging

Extra knowledge

X - rays are generated by allowing a fast beam of electrons to hit a metal target. A part of the kinetic energy of the electrons is then converted to X - rays.

• Ultraviolet radiation

Ultraviolet means 'above violet'. **Violet** is the color having the highest frequency out of the seven colors that form the visible spectrum. Ultraviolet radiation is a type of rays having a frequency range above that of violet and is invisible to the human eye. Although ultraviolet rays are invisible to the human eye, it has been found that insects like bees can detect ultraviolet rays. Sunlight contains a small amount of ultraviolet rays. Ultraviolet rays are also produced in electric discharge and from mercury vapor lamps.

Since these rays produce vitamin D in the human body, it is useful to be exposed to sunlight to some extent. However, over exposure to ultraviolet rays can cause cataract in the eye and cancers in the skin.

Ultraviolet radiation is used in hospitals to kill germs. Certain chemical substances show a glitter when exposed to ultraviolet radiation. This phenomenon is used in places like banks to check hidden symbols in currency notes. Such chemicals are also added to some washing powders. Clothes washed with such washing powders show a brightness when exposed to sunlight.

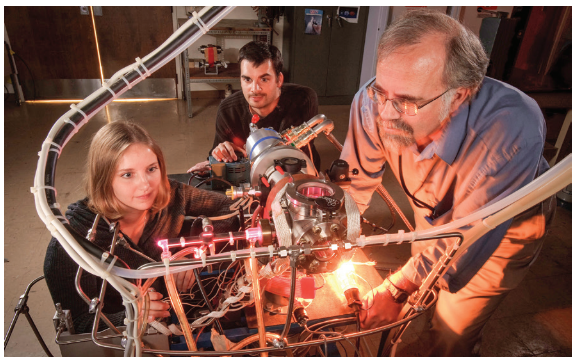


Figure 4.16 – An instance of generating ultraviolet rays

• Infrared Radiation

The range of frequencies below the red color that is not visible to us is known as **infrared radiation**. Because infrared radiation is emitted by heated bodies and we feel a warm sensation when infrared radiation falls on our skin, infrared radiation is often referred to as **heat rays**.

Infrared radiation is emitted by our bodies too. Heat photographs are taken with the aid of heat rays emitted by body organs. Certain diseases can be identified using such photographs.

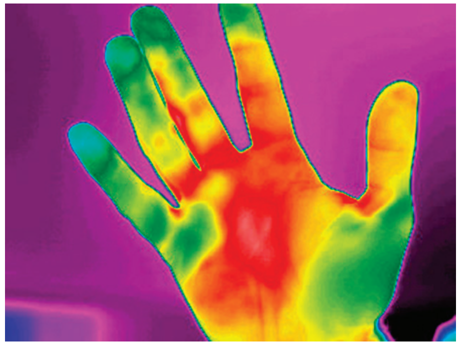
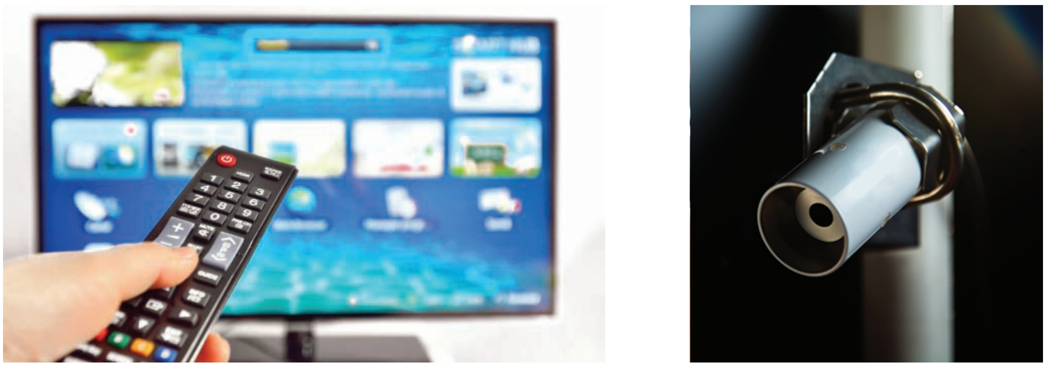


Figure 4.17 - A heat photograph

Infrared radiation is used to send signals to television sets from remote controls. Most of the cameras in mobile telephones and computers are sensitive to infrared radiation. Infrared radiation is also used for physiotherapy treatments.



(a) A remot control (b) An infrared camera

Figure 4.18 – Instances of using infrared waves

- ## Microwaves

The range of frequencies below the infrared frequencies is known as **microwaves**. Microwaves are used in RADAR systems, mobile telephones, and microwave ovens.

Extra knowledge

Water and fat in food have the ability to absorb microwaves and convert that energy into vibrational kinetic energy (heat). This is the principle behind the operation of microwave ovens.

An instrument known as the magnetron is used to produce microwaves in microwave ovens and radar systems that need high power microwaves for their operation.

Microwaves too can cause adverse effects on our bodies. Generally microwave ovens are produced so that microwaves do not leak out from the oven. However as a precautionary measure it is better not to stay too close to microwave ovens when they are in operation. It is suspected that the excessive use of mobile telephones can cause harm to the brain.

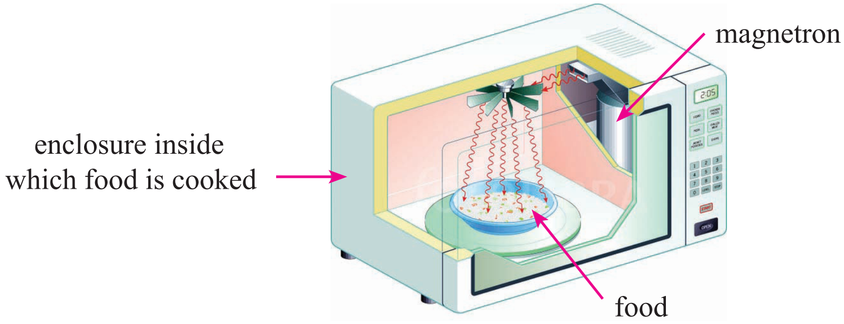


Figure 4.19 – A microwave oven

- **Radio Waves**

Radio waves have the longest wavelengths and the shortest frequencies of the electromagnetic spectrum. They are used in long distance communications. Radio waves are produced using radio frequency oscillators. When radio waves fall on an aerial, it received the information carried by the wave.

Antennas are used for transmitting and receiving radio waves. Information is transmitted through radio waves by modifying the amplitude or the frequency of a radio wave according to the information to be transmitted.

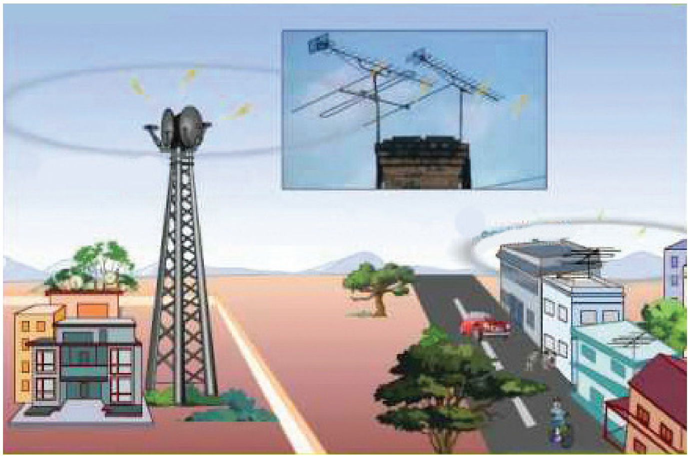


Figure 4.20 – Transmission & receiving of radio waves

4.3 Sound

If you listen carefully to various sounds in your surroundings early in the morning, you would hear many sounds. It is by listening that you would be able to enjoy when the musical instruments are played. The type of energy that produces the sensation of hearing in our ears is known as acoustic energy.

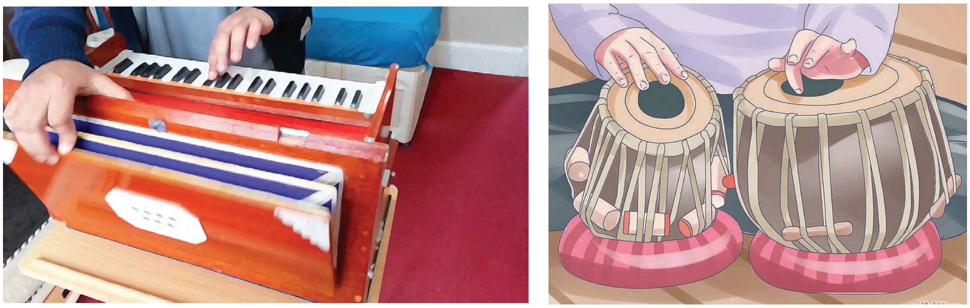


Figure 4.21 – Playing oriental music

Figure 4.22 – Hyla tree frog

The type of frogs known as hyla tree frog shown in figure 4.22 is found in South America. They are capable of amplifying their voice using an inflatable balloon like body organ under their throat. Only the male frog can generate this sound and their voice travels about ten time further than the sounds from other varieties of frogs. This sound is generated when the air dispelled by the balloon passes through two stretched membranes at the bottom of the mouths of the frogs giving rise to vibrations in the membranes.

Many animals have the capability of producing sounds by vibrating an organ in their body. A buzzing bee makes sound waves by moving its wings to and fro repeatedly very fast.

Crickets make their sound by rubbing their wings together.

Not only animal sounds but, all sounds are generated by vibrations of objects. We hear those sounds when the resulting sound waves propagate through air and reach our ears. Our vocal cords vibrate, causing the air around them to vibrate and producing sound waves in the air.

We will investigate the propagation of acoustic or sound waves, their characteristics and applications in this lesson.

4.3.1 Propagation of Sound Waves

In order to understand how sound waves propagate in air, let us consider a sound wave generated by a loud-speaker. Sound is generated by a loud-speaker when a membrane inside the loud-speaker is set into vibrations.

Figure 4.23 (a) shows the distribution of air molecules can be seen in front of the loud speaker. when the membrane is not vibrating.

Suppose that the membrane starts vibrating by first moving to the right. When the membrane moves to the right the air molecules in front of it are pushed forward giving rise to a layer of compressed air as shown in Figure 4.23 (b).This compressed region moves forward with the kinetic energy transferred to the air molecules by the membrane.

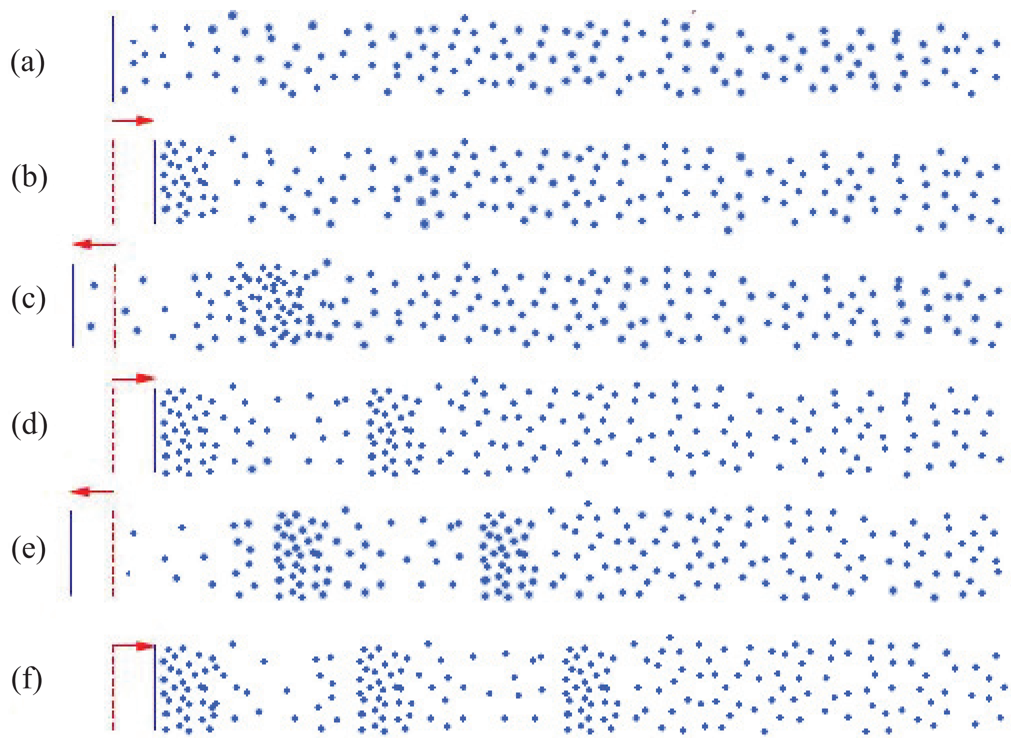


Figure 4.23 – Propagation of sound as longitudinal waves

When the membrane moves to the left, a region of rarefactions is formed in the air layer adjacent to it as shown in Figure 4.23 (c). When the membrane moves to the right again, another layer of compressed air is formed which too moves to the right as shown in Figure 4.23 (d).

The membrane alternatively generates compressions and rarefactions in the air, all of which travel forward with the same speed. These compressions and rarefactions are known as sound waves. Note that each air molecule only vibrates back and forth around a mean position although the compressions and rarefactions move forward. Sound is longitudinal waves. The speed of sound in dry air at room temperature is 330 m s^{-1}.

Sound propagates not only through air. Sound propagates through water even faster than through air. That is why there are methods of communication through water. Whales use sound waves to communicate amoung themselves.

Sound waves travel through water with a speed of about 1400 ms^{-1}. Sound propagation is even better through solids.

Figure 4.24 - Communication by whales using sound waves

Speed of sound waves through steel is about 5000 m s^{-1}. That is why the sound of a train approaching from a distance can be clearly heard through the steel rails.

Snakes can detect vibrations in the ground through its lower jaw bone. These vibrations are then transmitted to its ear through the bones. This way, the snake hears the foot-steps of its prey.

Figure 4.25 – Perception of sound by a snake through vibrations in the ground

Unlike light, a medium is essential for sound to spread. That means sound waves are mechanical waves. Therefore they do not travel through a vacuum. The following simple experiment illustrates that sound does not travel through a vacuum.

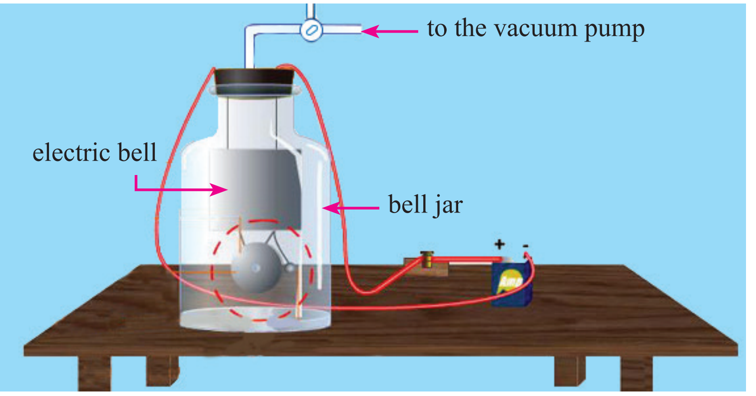


Figure 4.26 – Illustrating that sound waves needs a medium for propagation

As shown in Figure 4.26, an electric bell is fixed inside a bell jar and its connecting wires are connected to a power supply and a switch outside the jar. The bell jar is connected to a vacuum pump. The vacuum pump can pump out the air from inside the jar. After starting the ringing of the electric bell, the vacuum pump is turned on. You will observe that the sound of the electric bell becomes fainter gradually and finally no sound is heard.

The instance that the sound is no longer heard is when the interior of the bell jar becomes a vacuum. When the vacuum pump is turned on, the air inside the bell jar is gradually removed and ultimately it becomes a vacuum. This experiment illustrates that sound cannot propagate through a vacuum and that a medium is essential for sound waves to travel through.

4.3.2 Speed of Sound


Figure 4.28 – Light is seen a short while before the sound of thunder from a lightning strike

We hear the sound of thunder a short while after we see the light from a lightning strike taking place at a distant point. We see the light emitted in a lightning strike when that light travels towards us and enters our eyes. Light travels at the speed of 300 000 km s^{-1} (3×10^8 m s^{-1}). Therefore it takes only a very short time for us to see the light from a lightning strike. There is a short time gap between seeing the light and hearing the thunder because it takes a longer time for the sound wave to travel to our ear than it takes for the light to travel to our eyes from the point where the lightning strike took place.

The characteristics of waves discussed in section 4.1.3 are common to sound waves too.

- The speed of sound at 0 °C in dry air is about 330 m s^{-1}. As the temperature increases, the speed of sound waves in air also increases. The speed of sound at 30 °C in dry air is about 350 m s^{-1}.
- The speed of sound in water is about 1400 m s^{-1}. This means that the speed of sound in water is about four times as the speed of sound in air. The speed of sound through a steel rod is about 5000 m s^{-1}.

4.3.3 Characteristics of Sound

The sound of some musical instruments is of a high pitch. The sound emitted by the violin in soft. The sound of thunder caused by a lightning strike is loud. The above statements describe some characteristics of sound waves.

Properties of sound that makes it possible to distinguish different sounds are called sound characteristics. That means, sound characteristics are the sensations produced in the ear that helps us to distinguis different sounds.

There are three main characteristics of sound.

1. Pitch
2. Loudness
3. Quality of sound

• Pitch

Activity 4.3

- Clamp a hack saw blade between two blocks of wood so that its free end juts out about 10 cm.
- Vibrate the blade and listen to the sound it generates.
- Increase the length of the blade jutting out in steps of 5 cm at time listening to the sound emitted. You will notice that the sharpness of the sound decreases gradually.
- Pitch is the quality of sound depends on by the physical quantity frequency.

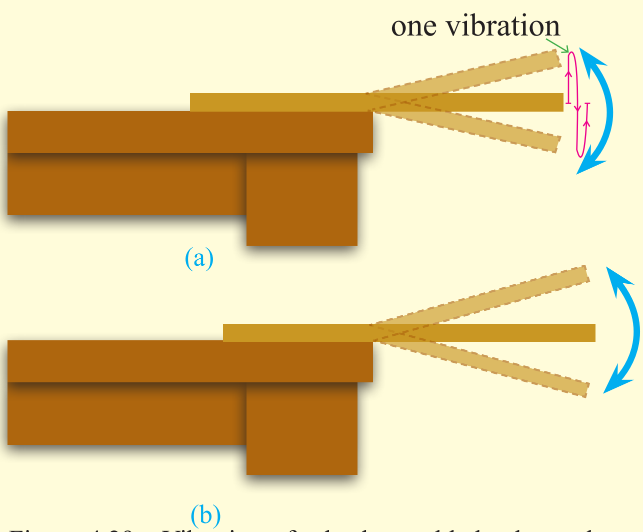


Figure 4.29 - Vibration of a hack saw blade clamped at one end

When the length of the free end of the blade is increased, the frequency of vibrations of the blade decreases gradually. Accordingly, the pitch of the sound generated by the blade also decreases. The pitch of the sound generated by an object increases when its frequency of vibration increases while the pitch of the sound decreases when its frequency of vibration decreases. Out of the musical notes, the frequency of the note middle C is 256 Hz. The frequency of the note higher C is 512 Hz. Therefore the pitch of the higher C is twice as high as the pitch of the middle C.

The oscillation of the air molecules around their central position when a sound wave travels in air can be observed using a cathode ray oscilloscope in the form of a graph plotted against time. When a microphone is connected to an oscilloscope as shown in Figure 4.30, and strike a tuning fork on a rubber stopper to generate a sound, the oscilloscope screen displays the graph corresponding to the sound wave generated. The shape of the graph displayed on the cathode ray oscilloscope is known as the wave form of the sound wave that gave rise to the graph.

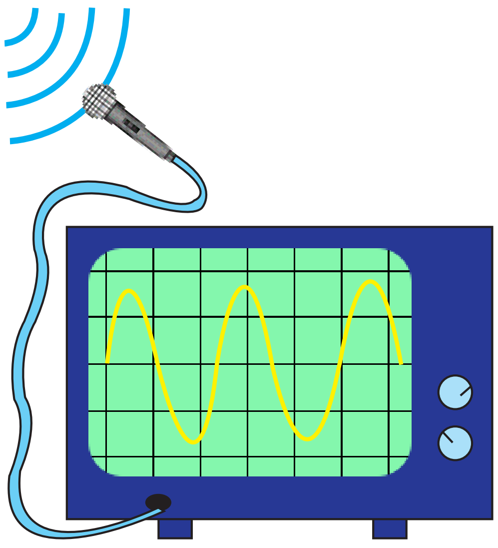
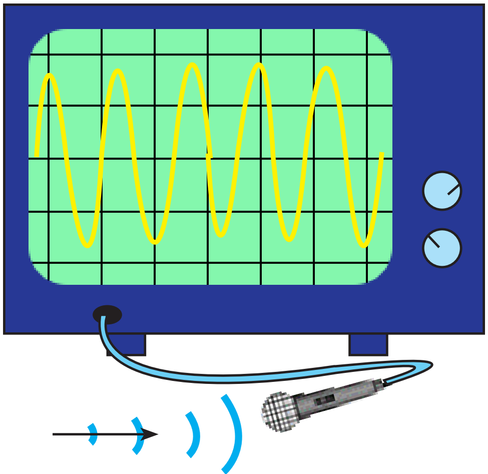


Figure 4.29 - The shape of a sound wave displayed on the screen of a cathode ray oscilloscope

Figure 4.30 shows the shapes of two sound waves generate from two tuning forks one with a high pitch or high frequency and the other with a lower pitch or lower frequency.



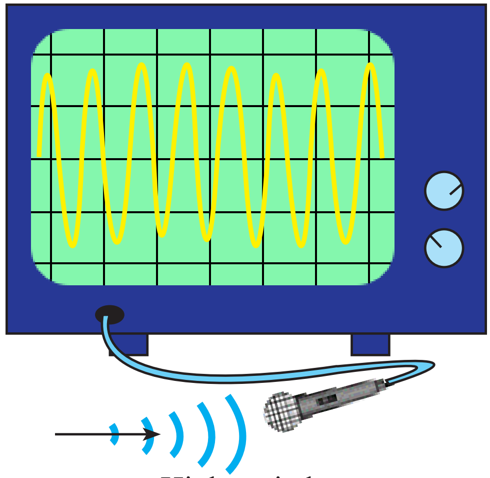


Figure 4.30 - The shapes of two sound waves of different pitch displayed on the screen of a cathode ray oscilloscope

- ## Loudness

Tap softly on a drum. Next tap the drum with a larger force. Study the difference in the sound level. The difference is the difference in the loudness. The loudness of a sound wave depends on the amount of energy it carries to the ear. Therefore, loudness is the sensation in the ear that depends on the amount of energy carried by the sound wave.

The sound generated by plucking a stretched string is louder when it is plucked harder so as to displace it further from its stationery position. In order to displace the string further, a larger amount of work has to be done on the string. Then the string imparts a larger amount of energy to the sound wave it generates. When the string is displaced further from the stationery position, the amplitude of the vibration becomes larger and the amplitude of the sound wave generated by the string also becomes large. This means that there is a relationship between the loudness of a sound and the amplitude of the corresponding sound wave. Therefore, loudness can also be considered as the characteristic of sound that varies according the amplitude of a sound wave. Loudness increases with increasing amplitude. Loudness decreases with when the amplitude decreases. Figure 4.31 shows wave forms of two sound waves viewed using a cathode ray oscilloscope, one with a higher level of loudness and the other with a lower level of loudness.

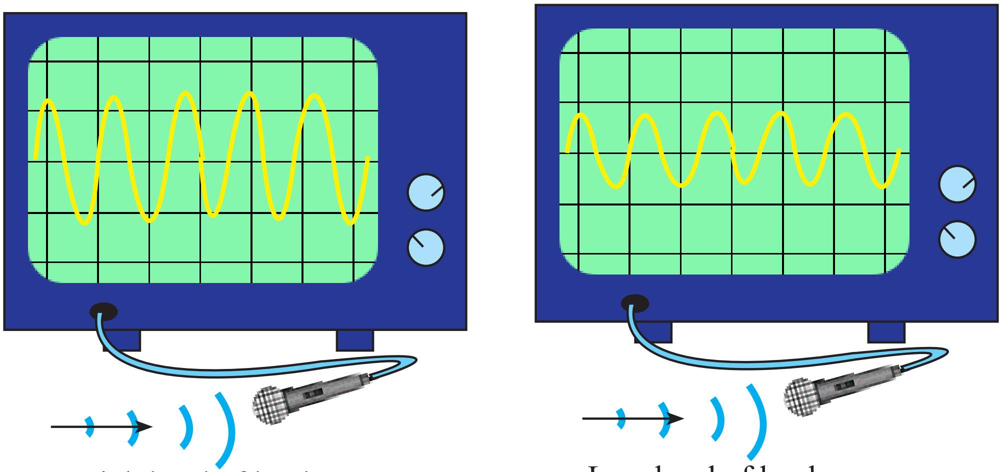


Figure 4.31 – Waveforms of two notes with high and low levels of loudness

• Quality of Sound

When a piano and a violin are played, even if both of them play a note with the same pitch and same loudness it is still possible to identify the sound of each instrument. Such an identification is possible due to a characteristic known as the quality of sound.


Figure 4.32 - Playing a piano and a violin

Figure 4.33 shows the wave forms of a musical note played with the same pitch using a tuning fork, a violin and a piano when viewed through a cathode ray oscilloscope.

Even though all three waves have the same frequency, it is clear from figure 4.33

that their wave forms are different. The reason for being able to identify each instrument playing the note is the difference in their wave forms. Therefore, the quality of sound is the sensation in the ear which varies according to the wave form of a given sound.

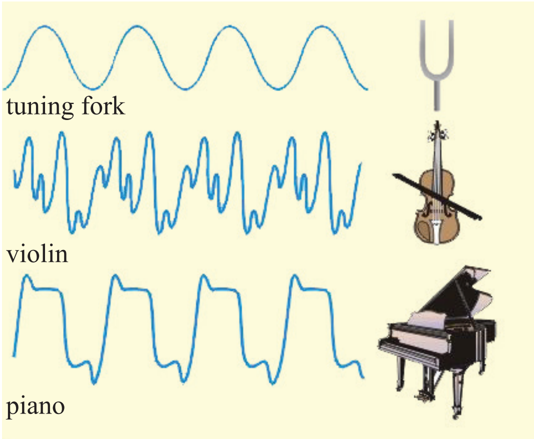


Figure 4.33 – Wave forms of the same note with the same pitch played by different instruments

4.3.4 Hearing Range

We cannot hear all the sounds in our surroundings. Certain sounds that we cannot hear are heard by other animals. While animals such as elephants that have large ears can hear sounds of very low frequencies, the ears of animals like bats and whales are sensitive to very high frequencies. It is generally considered that the frequency range that can be heard by the human ear is from 20 Hz to 20,000 Hz. This frequency range is known as hearing range of human ear. However, the high frequency limit audible to the human ear decreases gradually with age.

Sounds of frequency below 20 Hz are called **infra-sound** and sounds of frequency above 20000 Hz are called **ultrasound**. Therefore, ultrasound waves are sound waves with frequencies above the hearing range of humans.

While Rabbits, dolphins and bats can hear frequencies above 20,000 Hz (ultrasound), elephants can hear frequncies below 20 Hz (infrasound). Dogs can hear sounds up to about 40,000 Hz.

Bats make use of ultrasound waves to fly avoiding obstacles at night. Bats emit ultrasound waves while flying. These waves are reflected back if they encounter an obstacle. When the bat receives the reflected waves it can judge the position of the obstacles and fly avoiding them.

Figure 4.34 - A bat flying by avoiding obstacles with the use of utrasound

Dolphins use ultrasound waves to find small fish for prey and to avoid sharks that attack the dolphins. Dolphins also use ultrasound waves to communicate among themselves.

Figure 4.35 - Dolphins use uttrasound waves to communicate amoung themselves

Uses of Ultrasound

Ultrasound waves are used for various important tasks. Ultrasound waves are employed to find the depth of the sea. For this, an instrument called SONAR (Sound Navigation and Ranging) fixed to the bottom of a ship emits an ultrasound pulse. The depth of the sea can be found by measuring the time taken by these ultrasound pulses to return to the original position after being reflected from the bottom of the sea

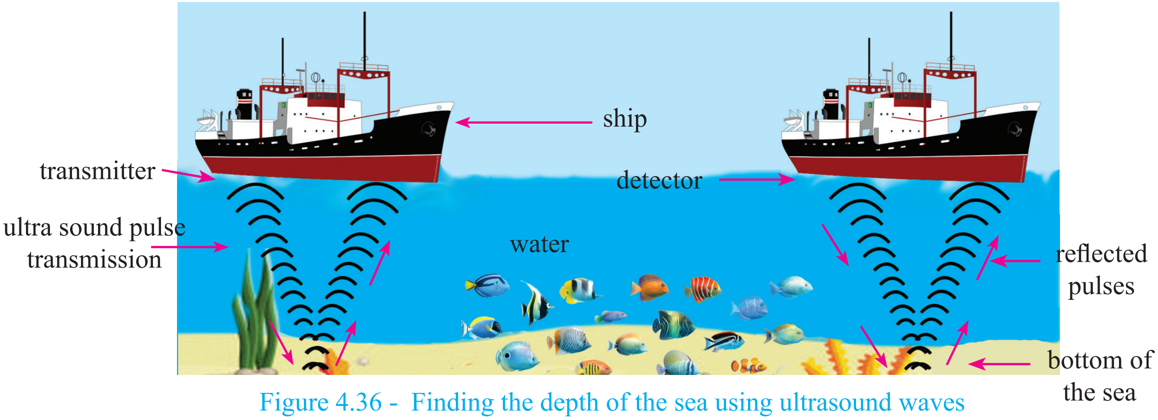


Figure 4.36 - Finding the depth of the sea using ultrasound waves

In addition to measuring the depth of the sea, ultrasound waves are used to investigate schools of fish and to detect remnants of capsized ships.

Example 1

If the time taken by ultrasound waves transmitted by a ship to reach the detector again after reflection from the sea bottom is 4 s, find the distance between the ship and the bottom of the sea. (Assume that the speed of sound in water is 1440 m s^{-1}).

$$\text{Distance the sound travel in 4 s} = 1440 \times 4$$

$$\text{Distance between the ship and the bottom of the sea} = \frac{1440 \times 4}{2} = 2880 \text{ m}$$

Ultrasound waves are used in ultrasound spectacles worn by blind people.

Ultrasound waves are used to examine internal organs of the human body. This is known as ultrasound scanning. Ultrasound waves emitted by an ultrasound transmitter placed on the chest of a patient are reflected back from the internal walls of his heart. Using the reflected wave, information regarding the volume of blood sent out during a single compression of the heart, the size of the heart and pulse rate of the heart can be revealed.

Furthermore, ultrasound waves can be used to observe the womb and the condition of the fetus inside the womb of a pregnant mother.

Figure 4.37 – Examining a pregnant mother using ultrasound waves

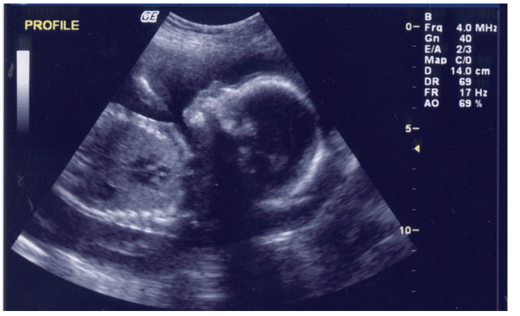


Figure 4.38 – An image of a fetus inside a womb taken using ultrasound waves

An instance where ultrasound waves are used to treat diseases is the blasting of bladder stones or calcium oxalate crystals by sending ultrasound waves to places where bladder stones are found (This technology is known as lithotripsy).

Figure 4.39 – Blasting bladder stones using ultrasound waves

High frequency ultrasound waves do not enter air after traveling through a solid medium. If an ultrasound wave traveling in a solid comes across an air gap, the wave does not penetrate through the air gap. This principle is used to detect dangerous air gaps and fractures in solid components of air planes.

Extra knowledge

Ultrasound waves are also used to solder metals. This is done by placing the metals to be soldered in contact with one another and impinging the required place with ultrasound waves. The vibrations that result cause the two metals to rub each other generating a large amount of heat. This heat melts the metals at the contact position soldering the two metals.

4.3.5 Musical Instruments

Constantly we hear various sounds. Some sounds are pleasing to the ear while some are not. The wave forms observed on a cathode ray oscilloscope screen by playing a tuning fork, a violin and a piano were shown in Figure 4.33. Although the wave forms were different, they all show repeating patterns.

The wave form of the noise emitted by machinery in a factory, if observed through a cathode ray oscilloscope, would look like the wave shown in Figure 4.40.

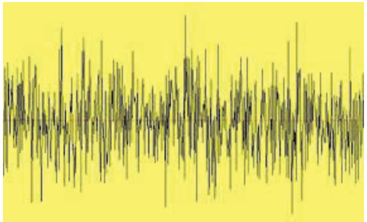


Figure 4.40 – Wave form of a noise

This wave does not show a repeating pattern. This wave is composed of irregular vibrations. The instruments that generate sound that is pleasing to the ear are known as musical instruments. Musical instruments are built in such a way that they generate periodic vibrations.

There are three main types of musical instruments.

- String instruments
- Percussion instruments
- Wind instruments

• String instruments

Musical instruments that generate sound by the vibrations of a stretched string such as the violin, Sitar, Guitar, Banjo and Cello are known as **string instruments**.

Figure 4.41 – Some string instruments

The frequency of sound generated by stringed instruments depends on the following factors.

1. Length of the vibrating string
2. Tension of the string or the extent that the string is stretched
3. Mass of a unit length of the string

• Percussion instruments

Instruments generating sound by the vibration of stretched membrane, metal rods or metal plates are known as **percussion instruments**. Such instruments have to be tapped in order to generate sound.

4.42 – Some percussion instruments

Thabla, rabana, dawula, udekki and thammattama are examples for percussion instrumens. The xylophone is an instrument with vibrating metal rods. Thalampata and the bell are instruments with vibrating metal plates.

In percussion instruments, the pitch depends on the area and the tension of the membrane or the metal plate.

- **Wind Instruments**

Instruments like flute, saxophone, trumpet and clarinet generate sound by the vibrations of air columns and are known as **wind instruments**.

Figure 4.44 – some wind instruments

The pitch of wind instruments depend on the length of the air column.

Exercise 4.1

(1) Group of children studied the spreading water waves generated in a pond with still water by throwing stones onto the water surface.

(i) What happens to the energy of the waves?

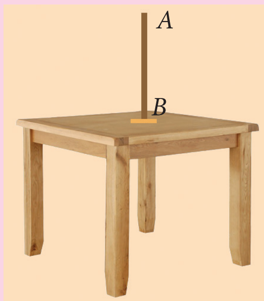
(ii) Suppose you place a paper boat on the water surface and disturb the water surface a small distance away from the boat. What change would you observe in the paper boat? What does it illustrate?

(iii) Sketch a diagram to show what happens to the water surface.

(iv) Which type of mechanical waves do water waves belong to?

(v) In what way do the above waves differ from the sound waves traveling in air?

(2) The end *B* of the metal blade *AB* shown below is clamped to a table



(i) It is made to vibrate by a force applied to the end A. Give a rough sketch to illustrate one vibration generated in the blade. (Use the letters C and D to show the maximum displacements.)

(ii) Describe what is meant by the amplitued using the points marked as *A, C* and *D*.

(iii) If 50 vibrations take place during 5 seconds, find the frequency of vibrations of the metal blade.

(iv) Vibrations of the metal blade gives rise to compressions and rarefactions in air.

To what physical quantity related to sound waves in air is the distance between two consecutive compressions equal to?

(v) (a) What is the sound characteristic that depends on the frequency?

(b) What is the sound characteristic that depends on the amplitude?

(c) The same musical note was played with several musical instruments, each one could be identified separately. What characteristic of sound does this depend on?

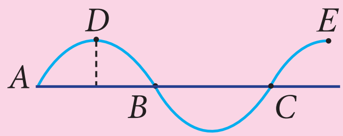
(3) Electromagnetic waves do not need a medium for propagation.

(i) Write down three characteristics of electromagnetic waves.

(ii) (a) What is the angle between the electric field and magnetic field generated together in an electromagnetic wave?

(b) What is the angle between these two fields and the direction of propagation of the electromagnetic wave?

(4) The figure below shows a segment of a string along which a transverse wave is propagating.



(a) What physical quantity of a wave is the distance between the points D and E equal to?

(b) The same distance above is shown by the distance between two other points in the figure. What are these two letters?

(5) There are many musical instruments in the music room of your school.

(i) Name

(a) Two string instruments

(b) Two percussion instruments

(c) Two wind instruments

that you expect to find in the music room.

(ii) (a) Write down two factors on which the frequency of the sound generated by a string instrument depends on.

(b) Write down two factors on which the frequency of the sound generated by a wind instrument depends on.

(c) Write down two factors on which the frequency of the sound generated by a percussion instruments depends on.

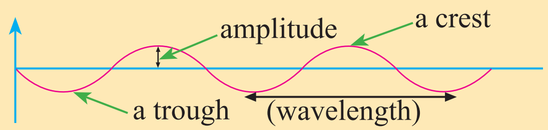
(6) Explain the following scientifically.

(i) When a ringing bell is held by hand, it stops ringing.

(ii) The pitch of a flute when played while the holes are opened one by one becomes different from the pitch when all holes are closed.

(iii) Although the lightning and thunder both happen at the same time, there is a delay between seeing the light and hearing the sound of thunder.

Summary

- A wave is a disturbance traveling in a medium or in space.
- Waves that need a material medium to travel are called mechanical waves.
- Waves that propagate in a direction perpendicular to the direction of particle motion are called transverse waves.
- Waves that propagate in the same direction as the particle motion are called longitudinal waves.
- 

- The time taken by one particle to complete a single oscillation is called the period of oscillation.
- The number of oscillations of a single particle in one second is called frequency.
- Electromagnetic waves do not need a material medium for propagation.
- Sound waves are a type of longitudinal waves.
- Sound waves need a medium for propagation.
- Pitch, loudness and quality of sound are three main characteristics of sound.
- The pitch of a sound depends on the frequency of the wave.
- The loudness depends on the amplitude of the wave.
- The quality of sound depends on the shape of the wave form.
- Sounds with regular periods are pleasing to the ear. Sounds without regular periods produce noise.
- String instruments produce sounds through vibrations of strings, percussion instruments make sounds by vibrations of membranes, rods or metal plates and wind instruments make sounds by vibrations of air columns.
- The frequency range that can be heard by an animal is known as hearing range of that animal.
- Sounds of frequency below 20 Hz are called **infra-sound** and sounds of frequency above 20000 Hz are called **ultrasound**.

Glossary

Mechanical waves	- යාන්ත්‍රික තරංග	- பொறிமுறை அலைகள்
Transverse waves	- තිර්යක් තරංග	- குறுக்கலைகள்
Longitudinal waves	- අන්වායාම තරංග	- நெட்டாங்கு அலைகள்
Period	- ආවර්ත කාලය	- ஆவர்த்தன காலம்
Frequency	- සංඛ්‍යාතය	- மீடிறன்
Electromagnetic waves	- විද්‍යුත් චුම්බක තරංග	- மின்காந்த அலைகள்
Electromagnetic spectrum	- විද්‍යුත් චුම්බක වර්ණාවලිය	- மின்காந்தத் திருசியம்
Ultraviolet radiation	- පාරජම්බුල කිරණ	- கழியூதாக் கதிர்ப்பு
Infrared radiation	- අධෝරක්ත	- செங்கீழ்க் கதிர்ப்பு
Micro waves	- ක්ෂුද්‍ර තරංග	- நுணுக்கலைகள்
Sound waves	- ධ්වනි තරංග	- ஒலி அலைகள்
Hearing range	- ශ්‍රව්‍යතා සීමාව	- கேள்தகு வீச்சு
Infrasound	- අධෝධ්වනි	- கீழொலி
Ultrasound	- අතිධ්වනි	- கழியொலி
Pitch	- තාරතාව	- சுருதி
Quality of sound	- ධ්වනි ගුණය	- ஒலியின் பண்பு
Loudness	- හඬේ සැර	- உரப்பு
Amplitude	- විස්තාරය	- வீச்சம்