13 WAVES

13.1 : Wave motion

1.(a) What do you understand by the term "waves"?

Waves are vibrations that transfer energy from one place to another but not particles.

(b) Distinguish between the following classes of waves:

(i) transverse and longitudinal waves.

Transverse waves are those in which the particles vibrate perpendicular to the direction of the wave motion, e.g. water waves, radio waves, waves in strings, microwaves, x-rays, r-rays, ultra violet rays and infrared rays.

Longitudinal waves are those in which the particles of the medium oscillate in a direction parallel to the direction of the wave, e.g. sound and waves in springs, earthquakes etc.

(ii) Stationary and progressive waves.

Progressive waves are those whose wavetrain is in continuous motion.

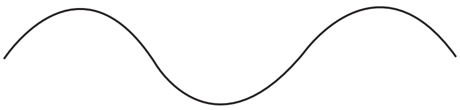


Fig 13.1 : A wave motion

Stationary (standing) wave is a wave which is formed as a result of two opposite waves with the same wavelength, frequency and about the same amplitude overlap. e.g. in a guitar.

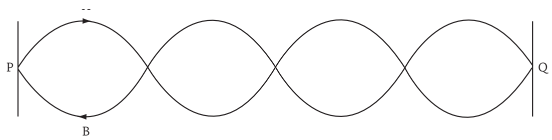


Fig 13.2 : Stationary wave

(iii) Plane and circular wave.

A plane wave is that whose wave trains or wave fronts are parallel to each other.

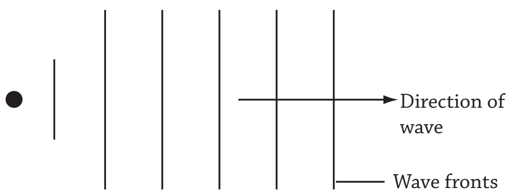


Fig 13.3 : A plane mirror

A circular wave is that in which the wave fronts are circular in nature.

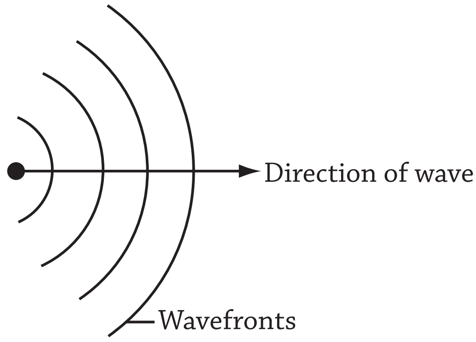


Fig 13.4 : A Circular wave

(iv) Mechanical and electromagnetic waves.

Mechanical waves are those that need a medium to travel e.g. water waves, spring waves, sound waves.

Electromagnetic waves are those that do not need a medium to travel, e.g. light, x-rays, radio waves, microwaves.

2. Define the following terms as used in waves:

(i) amplitude.

Amplitude (A) is the maximum displacement of a particle of a medium from its rest position.

(ii) wavelength.

Wave length (λ), is the distance between two successive particles that are in phase or the distance between two successive troughs or crests.

(iii) crest and trough.

Crest is the point of maximum displacement of a particle of a medium while trough is a point of minimum displacement of particles of a medium during transfer of a wave.

(iv) velocity.

Velocity (V), is the distance travelled by a wave per second. It's measured in metres per second (ms^{-1}).

(v) frequency.

Frequency (f), is the number of vibrations per second by a wave source or the number of cycles produced by a wave source per second, in Hertz (Hz).

(vi) period.

Period (T), is the time taken for each vibration of a wave source or the time taken to produce one cycle of a wave. The time taken by a particle of a medium to make one complete oscillation/cycle.

3. Fig 13.5 represents a wave motion of a vibrating particle.

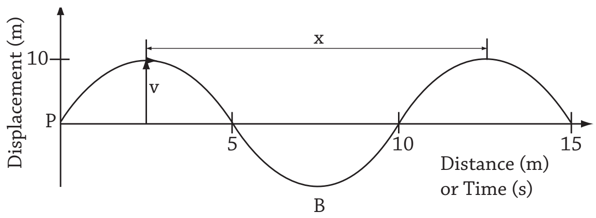


Fig 13.5 : A wave motion

(a) Identify what the following letters represent:

X – Wavelength or period.

Y – Amplitude.

(b) Determine:

(i) amplitude.

= 10 m

(ii) velocity of the wave.

$V = \lambda f$, $T = 10$ s

$f = \frac{1}{10} = 0.1$ Hz

$V = 0.1 \times 10$

$= 1$ m/s

4.(a) Write down an expression relating:

(i) period T and frequency f.

$\text{period} = \frac{1}{\text{frequency}}$

i.e. $T = \frac{1}{f}$ (s) or $f = \frac{1}{T}$ (Hz)

(ii) velocity (v), frequency f and wavelength λ ; as used in waves.

If a source of wave produces of frequaency waves (cycles) per second each having wave length λ in time, t(s) The wave covers a distance of:

distance = $(f \times \lambda \times t)$ metres

velocity, $v = \frac{f\lambda t}{t}$

$\therefore$ velocity, V = wavelength × frequency

$V = f\lambda$

(b) (i) Calculate the speed of the yellow colour of light in air if the wave length is 5.0×10^{-7} m and the frequency 5.0×10^{14} Hz.

$V = f\lambda$

$= 5 \times 10^{14} \times 5 \times 10^{-7}$

$= 25 \times 10^{7}$

$= 2.5 \times 10^{8}$ ms^{-1}

(ii) A hospital uses X–rays of wave length 1×10^{-11} m. Calculate the frequency of the X–rays if its velocity is 3×10^{8} m/s.

Using $V = f\lambda$

$3 \times 10^{8} = f \times 1 \times 10^{-11}$

$f = \frac{3 \times 10^{8}}{1 \times 10^{-11}}$

$= 3 \times 10^{19}$ Hz

5.(a) (i) A simple pendulum has a periodic time of 2 s. What is its frequency?

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

$= \frac{1}{2} = 0.5$ Hz

(ii) A wheel of a car is rotating at 1200 revolutions per minute. Calculate its periodic time.

f = 200 revolutions per minute

$= \frac{200}{60}$ revolutions per second

= 3.333 Hz

But, $T = \frac{1}{f}$

$= \frac{1}{3.333} = 0.3$ s

(b) Fig 13.6 below shows a progressive wave travelling in air.

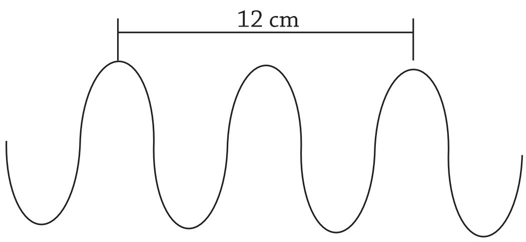


Fig 13.6 : Progressive wave

Find:

(i) the wave length of the wave.

From the definition of λ (distance between 2 successive crests)

$\lambda = \frac{12}{2}$ cm = 6 cm

$\therefore \lambda = 6$ cm

(ii) the frequency of the wave if the velocity of the wave in air is 330 ms^{-1}.

$$V = f\lambda, \quad \lambda = \frac{6}{100}\text{ m}$$

$$330 = f \times \frac{6}{100}$$

$$\therefore f = \frac{330}{6} \times 100$$

$$= 5\,500\text{ Hz}$$

13.2 : Properties of waves

6.(a) Give any four properties of electromagnetic waves.

- They have the same speed (3×10^8 ms^{-1}) i.e. speed of light in a vacuum.
- They are transverse waves.
- They do not need a medium to transfer.
- They carry no charge.
- They transfer energy from one place to another.
- They undergo interference, difraction, reflecttion and refraction.

(b) Infra-red, Gamma rays, visible light, ultra-violet, radio waves, X-rays and microwaves are electromagnetic waves in the electromagnetic spectrum. Arrange them in the order of:

(i) Increasing wavelength.

Gamma rays, X-rays, Infra-red, visible light, ultra-violet, microwaves and radio waves.

(ii) Increasing frequencies

Radio wave, microwaves, ultra-violet, visible light, Infra-red, X-rays and Gamma rays.

(c) State and define four common properties of all waves.

- Reflection. It is the bouncing of a wave when it meets a hard surface.
- Refraction. It is a change in direction of a wave as it leaves one medium for another.
- Diffraction. It is the emergence of a wave through a slit in an obstacle or around the corner of the obstacle.
- Interference. It is the overlapping of a wave whenever they meet.

7. On each of the following diagrams, complete the reflected wave pattern.

(i) Circular wave with concave reflector.

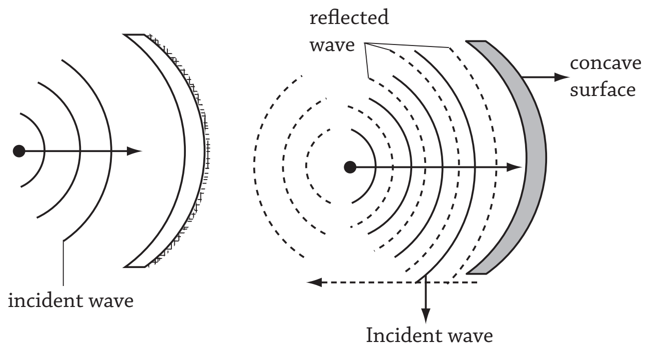


Fig 13.7 (a) : Reflection on concave surface

(ii) A circular wave with a convex reflector.

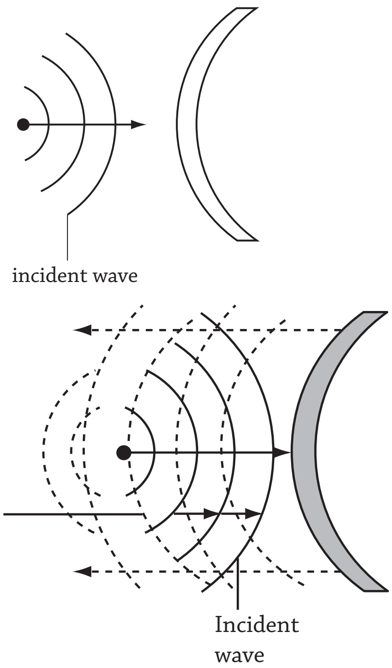
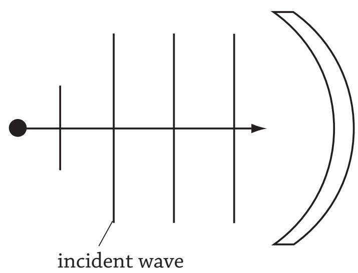


Fig 13.7 (b) : Reflection on cenvex mirror

(iii) A plane wave on a concave reflection.



(iv) A plane wave with a convex mirror.

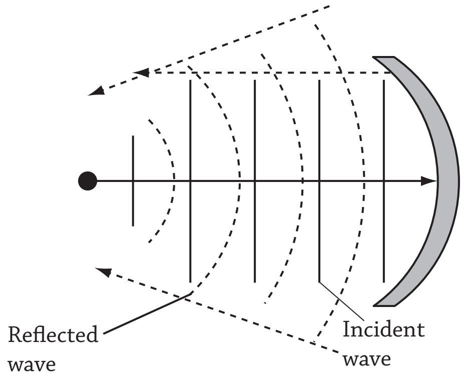
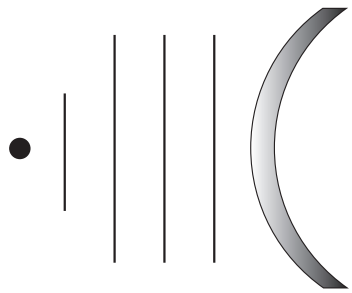


Fig 13.7 (c) : Flat source and reflection on a concave mirror

(v) A plane wave with a straight reflector.



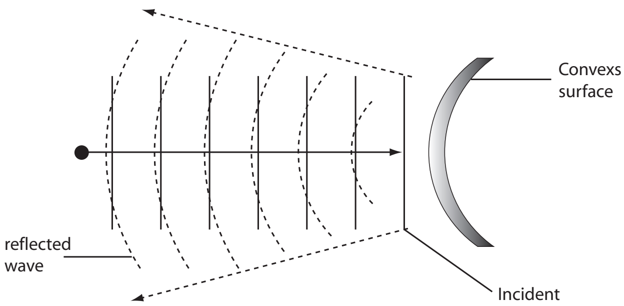
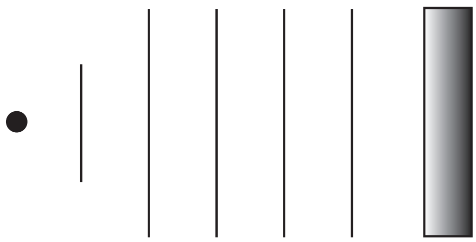


Fig 13.7 (d) : A plane wave with convex surface

(vi) A plane wave with a straight reflector.



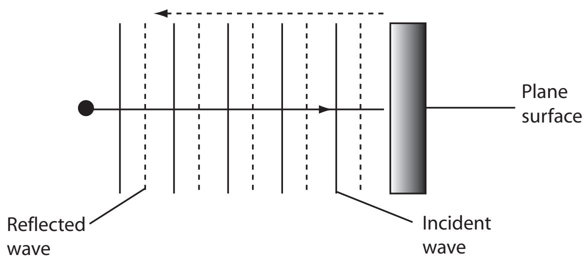


Fig 13.7 (e) : A plane wave with flat reflector

8.(a) Define the following terms as used in waves.

(i) wave front.

A wave front is a surface/line through a wave joining particles that are in phase. Particles are in phase if they have the same energy, speed and the same frequency.

(ii) ray.

A ray is a path followed by a wave.

(iii) ripples.

Ripples are terms used to describe water waves.

(b) Describe briefly how you would generate:

(i) continuous straight wave.

In a ripple tank straight (plane) waves are produced by lowering a frame (metal plate) on which a running motor is mounted so that it just touches water surface. Continuous straight waves will be produced as the motor sets the vibrator in action.

(ii) continuous circular waves in a ripple tank.

To produce circular ripples rapidly, dip your finger into water in a ripple tank or set the vibrator to vibrate in the water itself or use a small ball called a dipper fitted to the bar by allowing it to just touch the water surface.

(c) (i) What are coherent sources of waves.

Coherent sources are any two adjacent (nearby) sources that are in phase i.e. have the same frequency and wave length, e.g. two nearby bulbs of some output.

(ii) A disc stroboscope is used to freeze water waves in ripple tank. What is to "freeze"?

To "freeze" means to "hold in a state of no motion". This is usually done to enable us study the nature of waves produced on the water surface in a ripple tank.

9.(a) Fig 13.8 shows plane wave in a ripple tank travelling from region A to B. Clearly explain the changes that take place as the wave moves from A to B.

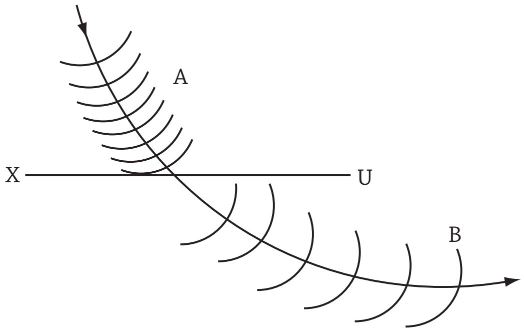
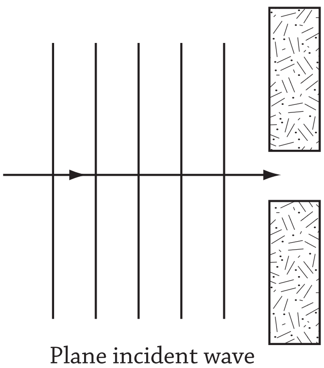


Fig 13.8 : Plane wave in a ripple tank

In region A, the wave has a smaller wavelength than in B. This means that B is deeper than A. Wavelength increases with depth in water. The direction of the wave in a deeper part is away from the normal; unlike in shallow water where they move towards the normal.

(b) Figures 13.9 and 13.10 shows plane waves incident onto slits in a barrier. Copy and complete the diagrams.

(i)



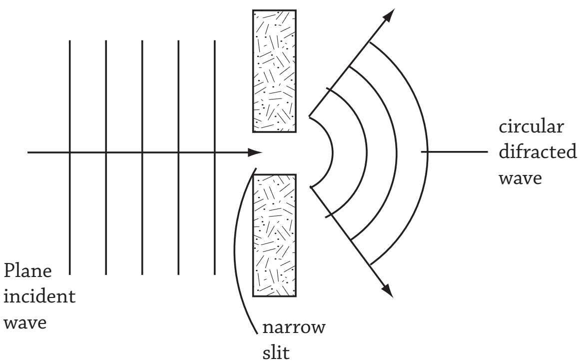
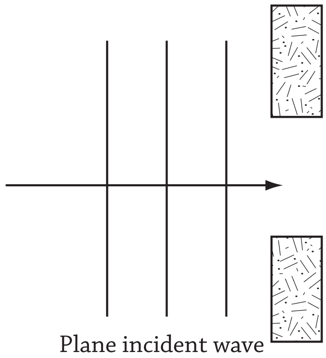


Fig 13.9 : Difraction at a smaller gap

(ii)



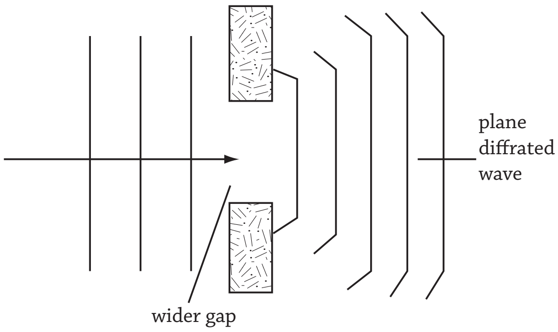


Fig 13.10 : Difraction at a wider gap

(c) With the aid of a diagram, explain constructive and destructive interference.

Interference is the overlapping of waves travelling through the same medium in the same direction.

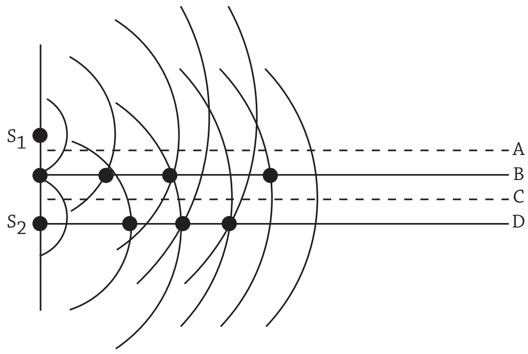


Fig 13.11 : Interferences

Considering the above; A and C represent destructive interference i.e. where two waves which are out of phase, meet to give a resultant amplitude which is smaller or is zero.

$\cup + \cap$ = – or $\cap$ or $\cup$

Band D represents constructive interference i.e. where two waves that are in phase meet to produce a resultant amplitude which is higher than each of the two waves.

$\cap + \cap = \bigcap$

(d) State conditions necessary for interference to occur.

Two waves must be travelling in the same direction.

The waves should have same frequency.

Two waves must have same wave length.

Two wave must have equal amplitude.

10.(a) State three conditions under which stationary waves are formed.

- Two waves travelling in opposite directions.
- Two waves having the same frequency.
- Two waves with same wavelengths.
- Two waves with same speed.

(b) Describe an experiment to demonstrate stationary waves in strings.

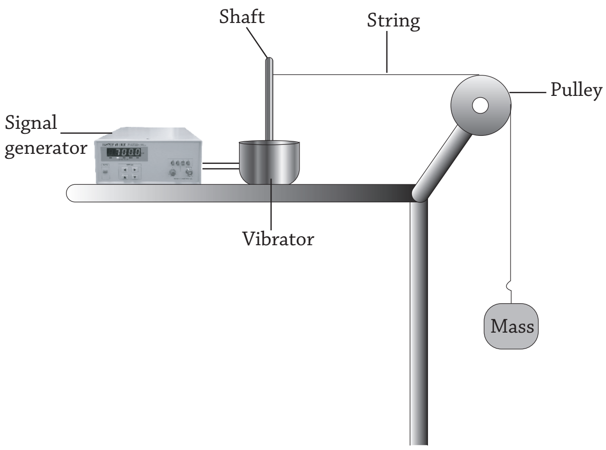


Fig 13.12 : Demonstarting stationary wave

A mass is joined to the shaft of a vibrator by passing it over a pulley. The signal generator is then set to vibrate causing the string connected to the vibrator to vibrate in segments. For clear view. Set the generator to have a low frequency of vibration. If the frequency is increased, the amplitude will increase. The segments will show the nodes (N) and anti-nodes (A) of the wave.

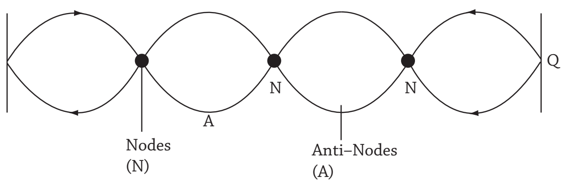


Fig 13.13 : Stationary wave

(c) Distinguish between nodes and anti-nodes as used in waves.

A node is a position of zero displacement of a particle of a wave.

Anti-node is a position of maximum displacement of particle of a wave.

11.(a) Define wavelength of a stationary wave.

A stationary wave can be defined as one where there is no energy propagation.

The wave length of a stationary wave is the distance between two successive nodes or anti–nodes.

(b) Give any three differences between stationary and progressive wave.

Progressive wave	*Stationary wave*
There is a continuous energy transfer through the medium.	There is no energy transfer.
Crests and troughs are formed.	Nodes and anti-nodes are formed.
All particles vibrate with maximum amplitude.	Some particles do not vibrate at all.
A single wave moves in one direction.	Two identical waves moving in opposite directions overlap.

Table 13.1

(c) A source sends out waves each of wavelength 3.30 m at a speed of 330 ms^{-1}. How many complete waves are sent out by the source in 20 s?

$V = f\lambda$

$f = \frac{330}{3.3}$, $f = 100$ Hz

100 waves are sent out in 1 second.

(20×100) waves are sent out in 20 s.

$= 2000$ waves

12.(a) (i) Distinguish between compressions and rarefactions.

Compression is a region in a longitudinal wave where particles are pressed close together (squashed).

Rarefaction is a region in a longitudinal wave where the molecules are spaced out (region of low pressure).

(f) (ii) Show on the diagram below, compression, rarefaction and wave length.

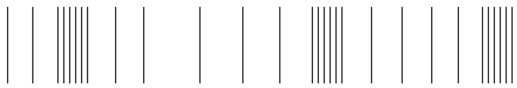
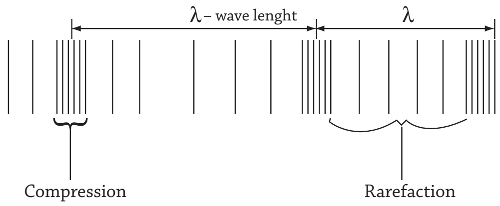


Fig 13.14 : Propogation of sound



(iii) If the periodic time is 0.02 s, find the frequency and speed of the wave if it has a wave length of 300 cm.

$T = 0.02s\ ,\ f = \frac{1}{T} = \frac{1 \times 100}{0.02 \times 100}$

$f = 50\text{ Hz}\ ,\ \lambda = \frac{300}{100} = 3.0\text{ m}$

$V = f\lambda = 50 \times 3.0 = 150\text{ ms}^{-1}$

(b) State and explain applications of the properties of waves.

- Refraction allows sound to be heard very clearly at night.
- Interference enables one to hear sound very loudly in a hall.
- Use of interference in amplifiers enables one to hear a loud sound from a distance without straining the ears.
- Diffraction causes a loud sound made in a room to be heard over many places.
- The bats are able to detect or locate their pray by reflection: high frequency sounds (ultrasonic) are sent out by the bat which will enable it to detect and determine the type of object.
- A small source of sound can be heard over many places due to reflections (echoes).
- Reflection can help in determining the depth of a lake or sea.
- One is able to see all corners of the room with only one bulb lit because of reflection.

13.3 : Sound waves

13.(a) (i) What is sound?

Sound is a longitudinal wave that is produced when objects vibrate.

(ii) Explain factors that affect the speed of sound in gases.

Density. The higher the density, the lower the speed of sound for any gases.

Humidity. Sound travels faster in higher humidity than in low

humidity this is because particles are to each other e.g. in the morning sound travels faster and more clearly because the air is more humid.

Temperature. The speed of sound is higher at lower temperatures than at higher temperatures, e.g. sound travels faster and is heard more clearly at night than during the day.

Wind. This depends on the direction. The speed of sound will increase if wind blows in the direction of the sound, and reduce if wind blows opposite to the direction of sound.

(b) Describe an experiment to show that sound requires medium to travel.

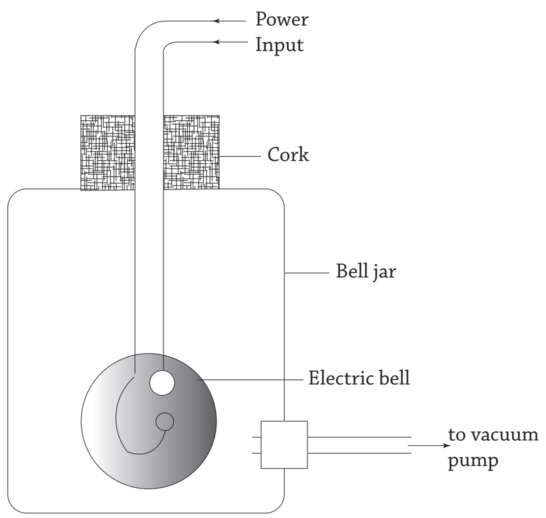


Fig 13.15 : Propogation of sound

The electric bell is set ringing as the bell jar is slowly evacuated by a vacuum pump.

The loud sound of the bell is heard at first and it slowly dies away until no sound is heard at all, but the bell is seen ringing. This happens when the bell jar is completely evacuated.

If the air is slowly returned into the bell jar, the sound of the bell increases to a maximum. This shows that sound needs a medium (air) to travel.

(c) Explain why a distant coming train could be detected easily from the rails than if one is standing far from the rails.

Sound is detected faster from the rails than from the air while standing. This is because sound travels faster in metals (solids) than in air.

(d) Sound is clearer at night than during day. Explain this phenomenon.

At night, air is more dense than during the day. The air nearer the atmosphere is denser than the one above it. The sound produced in the lower dense air will then be totally internally reflected within the lower denser air, without wastage in the atmosphere. On the contrary during day the air nearer the earth surface is less dense than the one above it. Sound will only pass through the layer up into the atmosphere, except for those waves travelling directly to the observer.

14. Describe how you would determine the speed of sound in air using:

(i) echo method.

Two people standing together at about 100 m from an obstacle (a all building, cliff). With a clapper and the other with a timer (stop watch). Using the clapper, several claps say, n claps, are made as the time for the n claps to be heard is noted and recorded.

Repeat the experiment several times and determine the velocity of sound from:

Net time for n claps be t (s)

Time for 1 clap = $\frac{t}{n}$

$\therefore$ The time for sound to go to the obstacle, then back.

But velocity = $\frac{\text{Distance by sound}}{\text{Time taken}}$

If the distance between the clapper/timer and obstacle is x (m).

The distance by sound to go and return is (2x).

$$\therefore \text{Speed of sound} = \frac{2x}{\frac{t}{n}} = \frac{2x}{t} \times n$$

$$V = \frac{2nx}{t}$$

(ii) resonance method.

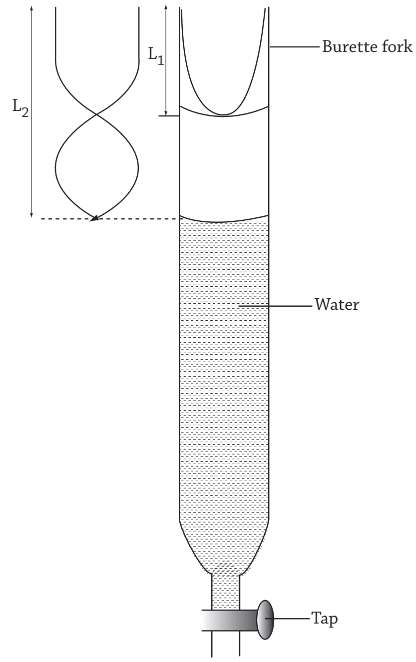


Fig 13.16 : Estimation of speed of sound by resonance method

Fill a burette with water.

Bang a tuning fork on a table to vibrate and bring it close to the mouth of the burette, meanwhile open the lap for water to flow out.

A point is reached when a loud sound is heard; close the tap and measure the length, L, of the air column above the water. The loud sound is due to resonance because at that point the air in the column is vibrating at the same frequency as the tuning fork.

The distance, L_1, corresponds to the first position of resonance.

i.e. $L_1 = \frac{1}{4}\lambda$ .... (i)

$\lambda = 4\,L_1$

using $V = f\lambda$

$V = 4\,f\,L_1$

Where f is the frequency of the tuning fork and it is known.

If the tap is opened again to determine the next position of resonance.

The distance L_2 is obtained.

$L_2 = \frac{3}{4}\lambda$ .... (ii)

Subtraction (ii) from (i)

$$(L_2 - L_1) = (\frac{3}{4}\lambda - \frac{1}{4}\lambda) = \frac{1}{2}\lambda$$

$$\lambda = 2\,(L_2 - L_1)$$

Using $V = f\lambda$

$V = 2f(L_2 - L_1)$ hence the speed of sound is deposited

15.(a) (i) Explain the meaning of the term resonance?

Resonance is a phenomenon where a system is set to oscillate at its natural frequency by a nearby oscillating system, e.g. A student rhythmically dancing to the tune of a guitar.

(ii) Illustrate resonance in a coupled pendulum.

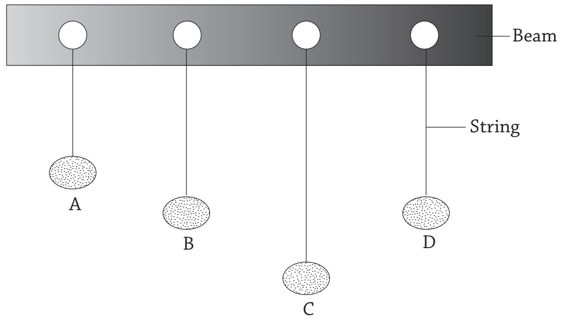


Fig 13.17 : Resonance in coupled pendulum

The system shows in fig 13.17 a coupled pendulum with B and D of the same length but the others of different length.

If any one of the pendulum (A,B, C and B) is pulled and then released, it will exert a periodic force on the beam, this force will be transmitted to all the other pendulums.

All the pendulums (pendula) will begin to oscillate but with different amplitude except for B and D will be equal. B and D are then said to be resonating.

(b) Demonstrate resonance using a sonometer.

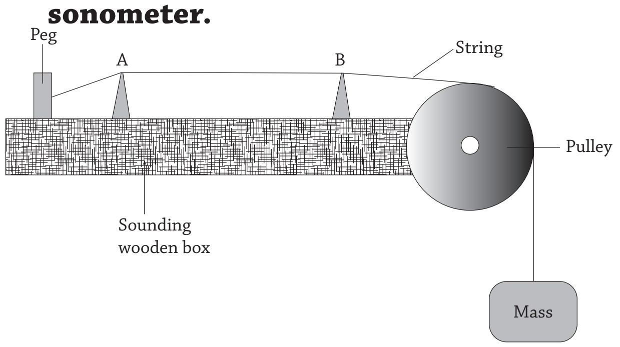


Fig 13.18 : Showing resonance using sonometer

A and B are bridges. A sonometer is a hollow long (about 1 m) wooden sounding box with a string stretched on its top. The string, tied to a peg passes over two pegs A and B and stretched by masses that passes over a pulley. To study resonance, bang a tuning fork on a table and bring it close to the string as you pluck it slowly. Meanwhile you could be adjusting the movable bridge B as you pluck (frequency α length) . In addition to adjust the bridge, you could also add or reduce the weight (frequency α tension). A point is reached when the frequency of the string is similar or same as that of the tuning fork. The sonometer is then said to be in tune.

16. Define the following terms :

(i) Echoes.

Echoes are reflected sound waves. It is produced when sound wave meets an obstacle.

(ii) Reverberation.

Reverberation is the prolonged sound heard when echo interferes with the original sound.

It can be minimised by using acoustics (e.g. soft boards) in buildings such as concert halls, cathedrals.

(iii) Pitch.

Pitch is the highness and lowness of a sound note. Pitch is proportional to frequency of the sound i.e. high pitch means high frequency.

(iv) Beats.

Beats is a periodic rise and fall in the intensity of sound. They are produced when two waves of nearly the same frequency superpose.

(v) Loudness.

Loudness is a characteristics of sound that depends on amplitude.

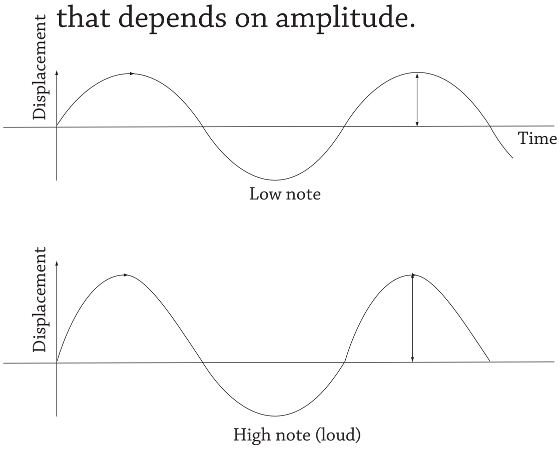


Fig 13.19 : A wave motion to compare loudness of sound

Higher amplitude produces a louder sound.

(vi) Quality (timbre).

Quality (or timbre) is the characteristics of a musical note which enables us to distinguish a note produced by one instrument from another of the same pitch and intensity produced by different instrument, e.g. The ear can successfully detect sound from a thumb piano and a guitar and from Adungu though all are vibrating at high frequency (pitch).

(vii) Fundamental frequency.

Fundamental frequency (f_o). This is the lowest frequency that can be obtained from an instrument.

(viii) Octane

Octane is the interval between the 8^{th} and the 1^{st} note on a musical scale.

17. (a) (i) Distinguish between subsonies and ultra-sonis.

- Subsonies are sounds produced at frequency lower than (20 Hz); that cannot be heard by a normal ear.
- Ultra-sonis or super sonnis are sound waves produced at very high frequency (> 20 Khz); that a normal human ear cannot detect, e.g. A fast moving plane might only be seen and not heard.
- A normal ear detects frequencies of (20Hz – 20 000 Hz) i.e. audio frequency range.

(ii) Give any four uses of ultra-sonies.

- Ultra-sound scanning in hospitals.
- By bats for detecting their obstacles and their pray at night.
- Echo sounders for measuring the depth of sea/lake.
- Metal scanners.

(b) Explain why a dog is able to detect a duker passing by through hearing before a hunter moving together with it.

A running duker produces sound wave of a lower frequency. A human ear can only detect wave (sound) of frequency 20 Hz to 20 000 Hz. The dog will hear the by-passing duker because it is able to hear sound that is lower than the hunter is able to hear.

18. (a) A girl standing in front of a cliff shouts and hears an echo 2 s later. If the velocity in air is 340 ms^{-1}, calculate the distance between the girl and the cliff.

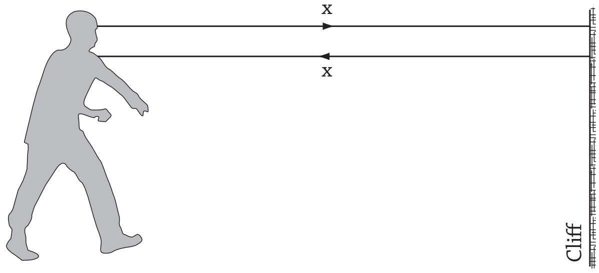


Fig 13.20 : Determining speed sound in air

Let the distance between the cliff and the girl be, x.

The distance by sound = 2 x

$$\text{Speed} = \frac{D}{t} \Rightarrow V = \frac{2x}{t}$$

$$340 = \frac{2x}{2}$$

$$\therefore \quad x = 340 \text{ m}$$

(b) A boy standing midway between two cliffs makes a loud sound. He hears the first echo after 3 s. Calculate the distance between the two cliffs if the velocity of the sound in air is 330 ms^{-1}.

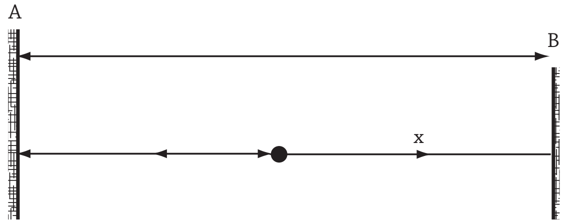


Fig 13.21 : Echo methods determining speed of sound

Let the distance between the boy and each of the cliffs be x.

The distance by sound in the 3 s is 2x

$$\text{Speed} = \frac{D}{t} = \frac{2x}{t}$$

$$330 = \frac{2x}{3}$$

$$\frac{2x}{2} = \frac{330 \times 3}{2}$$

$$= \frac{900}{2} = 495 \text{ m}$$

$\therefore$ The distance between the two cliffs is 495 m.

Revision Exercise 13

1. Distinguish between:
   (a) longitudinal wave and transverse wave.
   (b) Stationary wave and progressive wave.
2. Distinguish between the terms 'pulse' and 'wave'.
3. Define the terms compression and rarefaction.
4. (a) By taking measurements from Fig. 13.22, write down
   (i) the wavelength of the wave,
   (ii) the amplitude of the wave,

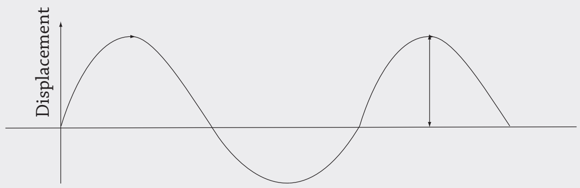


Fig 13.22

   (b) If the periodic time of the wave is 0.02 s, calculate
   (i) the frequency of wave motion,
   (ii) the speed of the wave motion.
5. The range of frequencies used in telecommunication varies from 1.0×10^6 Hz to 2.0×107 Hz. Determine the shortest wavelength in this range (speed of the waves is 3×10^8 m/s.
6. What is an echo? State two conditions that must be satisfied for the echo to be produced and heard clearly.
7. A drummer stands 170 m away from a tall cliff and beats the drum at a steady rate so that each beat coincides with the echo of the one before. If the speed of sound in air is 340 m/s, calculate the rate at which he beats the drum.
8. The flying mammal bat emits a sound of frequency 6.8×104 Hz.
   (a) Calculate the wavelength of sound produced by the bat, if the speed of sound in air is 340 m/s.
   (b) Can you hear the sound produced by the bat? Explain your answer.
9. Light waves are electromagnetic waves. What property of these waves show that light waves are transverse in nature?
10. Name two types of electromagnetic radiations whose frequencies are less than that of visible light.
11. State three properties of light that are different from sound waves.
12. One range of frequencies used in braodcasting varies from 0.75×10^6 Hz to 2×10^6 Hz. What is the longest wavelength in this region?
13. Heat radiation of frequency 2×10^{12} Hz from furnace has a wavelength of 0.15 mm. calculate the speed with which heat is emitted.
14. (a) What do you understand by diffraction?
    (b) Copy and complete
    Figure 13.23 (a), (b) to show the shapes of the wavefronts after passing through the gap in (a) and (b).

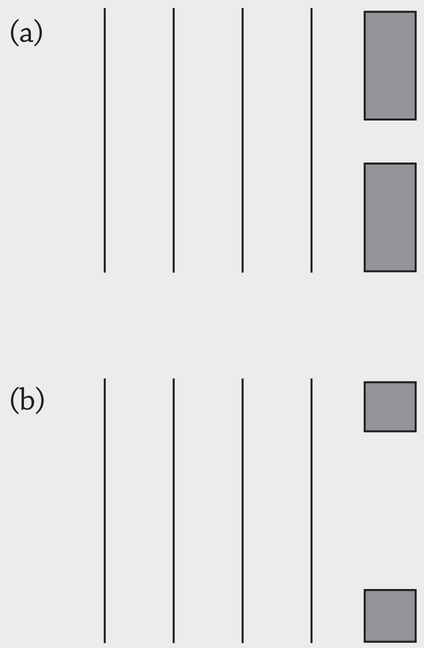


Figure 13.23