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Chapter 7

Sound

(C) Sound

SYLLABUS

(i) Reflection of sound waves; echoes, their use; simple numerical problems on echoes.

Scope of syllabus : Production of echoes, condition for formation of echoes; simple numerical problems; use of echoes by bats, dolphins, fishermen, medical field. SONAR.

(ii) Natural vibrations, damped vibrations, forced vibration and resonance — a special case of forced vibrations.

Scope of syllabus : Meaning and simple applications of natural, damped, forced vibrations and resonance.

(iii) Loudness, pitch and quality of sound.

Scope of syllabus : Characteristics of sound; loudness and intensity; subjective and objective nature of these properties; sound level in dB (as unit only); noise pollution; inter dependence of pitch and frequency, quality and waveforms (with examples).

(A) REFLECTION OF SOUND WAVES AND ECHOES

7.1 SOUND WAVES

In class IX, we have read that *sound is produced when a body vibrates and it reaches us through the vibrations of the particles of surrounding medium. Thus sound requires a medium for its propagation.* The vibrations of the body produce vibrations in the particles of surrounding medium which travel in form of waves with a certain speed depending upon the density and elasticity of the medium. When these vibrations reach our ear, the sound is heard. Our ears are sensitive only to a limited range of frequencies from 20 Hz to 20,000 Hz. This range of frequency is, therefore, called the ***range of audibility***. However, the audibility range of a person decreases as he gets older since the hearing sensitivity of ears falls for both the low and high frequencies. The sound of frequency above 20,000 Hz is called the ***ultrasonic***, while the sound of frequency below 20 Hz is called the ***infrasonic.*** Both the ultrasonic and infrasonic are inaudible to human beings, but they both travel in a medium with the speed same as that of the audible sound.

When sound wave travels in a medium, the maximum displacement of the particle of medium on either side of its mean position, is called the *amplitude* (a) of the wave. The time taken by the particle of medium to complete its one vibration, is called the *time period* (T) of the wave. The number of vibrations made by the particle of the medium in one second, is called the *frequency* (f) of the wave. The frequency of a wave is same as the frequency of the source producing it. The distance travelled by a wave in one time period of vibration of the particle of the medium, is called the *wavelength* (λ). The distance travelled by the wave in one second is called the wave velocity (V). The wave velocity V, frequency f and wavelength λ are related as :

$$\boxed{V = f\lambda} \quad \text{....(7.1)}$$

The time period of wave T and its frequency f are related as :

$$\boxed{f = \frac{1}{T}} \quad \text{...(7.2)}$$

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> ***Note :*** The frequency (or time period) of wave depends on the vibrating source producing the sound, while the velocity of wave and hence its wavelength depends on the properties of the medium in which the wave travels.

The sound waves necessarily require a medium for their propagation. The transfer of energy by waves is through the vibrations of the medium particles about their mean positions. When the medium particles vibrate, there is a change of kinetic energy into the potential energy and vice versa, so sound waves are also called the ***elastic*** or ***mechanical waves***. The mechanical waves are of *two* kinds : (1) longitudinal waves, and (2) transverse waves. If the vibrations of medium particles are along the direction of propagation of the wave, thus forming *compressions* and *rarefactions in the medium*, the wave is called a ***longitudinal wave*** *e.g.* sound waves in air, in solid and inside a liquid. The longitudinal waves can travel in solid, liquid as well as gas. On the other hand, if the medium particles vibrate normal to the direction of propagation of the wave, forming *crests* and *troughs*, the wave is called a ***transverse wave*** *e.g.* sound waves in a solid and on the surface of a liquid. Transverse waves are formed only in those media which possess rigidity and that is why they can travel only in solids and on the surface of a liquid.

The speed V of a longitudnal wave (*i.e.*, sound) in a gaseous medium of density d at a pressure P is given as :

$$\boxed{V = \sqrt{\frac{\gamma P}{d}}} \qquad \ldots(7.3)$$

where γ (the ratio of two specific heats) is 1·4 for air.

Since the density of gas decreases with the increase in temperature and with the increase in humidity in it, so the speed of sound increases with the increase in temperature* and with the presence of humidity in the gas. However the speed of sound is not affected by the change in pressure.

The speed V of a transverse wave in a stretched string depends on the tension T and mass per unit length m of string. It is given as :

$$\boxed{V = \sqrt{\frac{T}{m}}} \qquad \ldots(7.4)$$

When a wave travelling in one medium passes to another medium (*i.e.,* in refraction), the speed, wavelength and intensity* of the wave will change, but the frequency of wave will not change. The direction of travel of wave will also change except for normal incidence (*i.e.,* for $\angle i = 0°$).

The sound waves differ from the ***electromagnetic waves*** (e.g., γ-rays, X-rays, ultraviolet light, visible light, infrared rays, micro waves, and radio waves). The electromagnetic waves are formed by the periodic vibrations of the mutually perpendicular electric and magnetic fields in a plane normal to the direction of wave propagation. The electromagnetic waves are thus the transverse waves, but unlike sound waves they can travel through vacuum also. The speed of electromagnetic waves is different in different media and it is maximum (equal to 3×10^8 m s^{-1}) in vacuum (or air). The electromagnetic waves transfer energy in form of photons.

Distinction between the light and sound waves

Light waves	Sound waves
1. These are the electro-magnetic waves.	1. These are the mechanical waves.
2. They can travel in vacuum	2. They require a material medium for propagation.
3. The speed of light waves is very high (= 3×10^8 m s^{-1} in air).	3. The speed of sound waves is low (= 330 m s^{-1} in air).
4. The wavelength of light waves (visible) is very small, of the order of 10^{-6} m.	4. The wavelength of sound waves is in the range of 10^{-2} m to 10 m.
5. These waves are transverse.	5. In air, these waves are longitudinal.

* For 1°C rise in temperature, the speed of sound in air increases nearly by 0·61 m s^{-1}.

* The change in intensity is because of partial reflection at the boundary surface separating the two media.

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7.2 REFLECTION OF SOUND WAVES

Sound waves, just like any other wave, when strike a hard surface (or boundary of another medium), return back in the same medium obeying the laws of reflection *i.e.* (i) the angle of reflection is equal to the angle of incidence, (ii) the incident ray, reflected ray and normal at the point of incidence, all lie in one plane. *The return of a sound wave on striking a surface such as wall, metal sheet, plywood etc. back in the same medium is called the reflection of sound wave*. The reflection of sound wave does not require a smooth and shining surface like a mirror. Sound waves get reflected from any surface whether smooth or hard. The only requirement for the reflection of sound wave is that the *size of the reflecting surface must be bigger than the wavelength of the sound wave*. The phenomenon of reflection of sound waves is utilized in making the megaphone (or speaking tube), sound board and ear trumpet.

7.3 ECHO

Production (or generation) of an echo

If a person stands at some distance from a wall (or a hillside) and produces a sharp sound, he hears *two* distinct sounds : (i) the original (or direct) sound which is heard almost instantaneously and (ii) the sound heard after reflection from the wall (or hillside) which is called an *echo*. Thus,

The sound heard after reflection from a distant obstacle (such as a cliff, a hillside, wall of a building, edge of a forest, etc.) after the original sound has ceased, is called an echo.

Note : The reflected sound if heard along with the original sound, is not the echo. Only the sound heard after the original sound has ceased (*i.e.*, the sound distinctly separate from the original sound), is called the echo.

Condition for hearing an echo

An echo is heard only if the distance of the person producing sound from the rigid obstacle (or reflector) is long enough to allow the reflected sound to reach the person at least 0·1 *second after the original sound is heard.* The reason is that the sensation of sound persists in our ears for about 0·1 second after the exciting stimulus ceases to act. Hence to hear the echo distinctly (separate from the original sound), it must reach the ears at least 0·1 second after the original sound.

If d is the distance of the observer from the obstacle and V is the speed of sound in the medium, then the total distance travelled by the sound to reach the obstacle and then to come back, is $2d$. The time taken to hear the echo (or reflected sound) is

$$t = \frac{\text{total distance travelled}}{\text{speed of sound}} = \frac{2d}{V}$$

or

$$\boxed{d = \frac{Vt}{2}} \qquad ......(7.5)$$

By putting $t = 0{\cdot}1$ s and $V = 340$ m s^{-1} in air at ordinary temperature, from eqn. (7.5), we get

$$d = \frac{340 \times 0{\cdot}1}{2} = 17 \text{ m}$$

Thus, to hear an echo distinctly, the reflecting surface in air should be at a minimum distance of 17 m *from the listener.* If the distance is less than 17 m, the reflected sound will reach the ears before the original sound dies out and so no echo will be heard.

Note : (1) If the reflector is at a distance less than 17 m, the original sound just mixes up with the reflected sound.

(2) If there are repeated reflections at the reflecting surface, the sound gets prolonged. This effect is known as **reverberation** which can easily be experienced in tombs like Taj Mahal, Sikandra, etc.

Thus to hear the echo distinctly, following *three* conditions must be satisfied :

(1) The minimum distance between the source of sound (or observer) and the reflector in air must be 17 m. It is different in different medium depending upon the speed of sound in that medium. For example, inside sea

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water, $V = 1400$ m s^{-1}, so $d = \frac{1400 \times 0{\cdot}1}{2}$ $= 70$ m. *i.e.*, to hear echo distinctly, the obstacle in sea water should be at a minimum distance of 70 m from the listener.

(2) The size of the reflector must be large enough as compared to the wavelength of the sound wave.

(3) The intensity of sound should be such that the reflected sound reaching the ear is sufficiently intense to be audible.

7.4 DETERMINATION OF SPEED OF SOUND BY THE METHOD OF ECHO

The echo method can be used to determine the speed of sound in air. For this, sound is produced from a place at a known distance say, d at least 50 m from the reflecting surface. The time interval t in which the echo reaches the place from where the sound was produced, is noted by a stop watch having the least count 0·01 s. Then the speed of sound is calculated by using the following relation :

$$V = \frac{\text{total distance travelled}}{\text{time interval}} = \frac{2d}{t} \text{ m s}^{-1} \quad ..(7.6)$$

The experiment is repeated several times and then the average value of speed of sound V is determined.

7.5 USE OF ECHOES

Echoes find their application in *sound ranging* and *echo depth sounding* by using the ultrasonic waves.

The ultrasonic waves (frequency above 20 kHz) are used because of the following *three* reasons :

(1) *They can travel undeviated through a long distance,*

(2) *They can be confined to a narrow beam.*

(3) *They are not easily absorbed in a medium.*

> ***Note :*** Audible sound waves (frequency 20 Hz to 20 kHz) do not possess the above properties. However, *the ultrasonic waves in a medium have the same speed as the speed of audible sound waves in that medium.*

(1) Use of echoes by bats, dolphins and fisherman

Animals have different range of audible frequency e.g. bats, dolphins and dogs have a much higher upper audible limit than the human beings. Bats can produce and detect the sound of very high frequency up to about 100 kHz.

Bats fly with speed much lower than the speed of sound. The sounds produced by the flying bats get reflected back from an obstacle in front of it. By hearing the echo, bats come to know, even in the dark, the location of the obstacle, so they can fly safely without colliding with it. This process of detecting obstacle is called *sound ranging*.

Dolphins detect their enemy and obstacle by emitting the ultrasonic waves and hearing their echo. They use ultrasonic waves for hunting their prey.

A ***trawlerman*** or ***fisherman*** sends a pulse of ultrasonic waves from a source (a very high frequency vibrator) into the sea and receives the waves reflected from the shoal of fish in a detector. The total time t of the *to and fro* journey of the wave is recorded. The distance d of fish is then calculated by using the relation $d = \frac{Vt}{2}$ where V is nearly 1400 m s^{-1} (the speed of ultrasonic waves in sea water).

(2) Use of echoes by 'SONAR'

The word 'SONAR' stands for *sound navigation and ranging*. Fig. 7.1 shows the principle of a sonar in which ultrasonic waves are sent in all directions from the ship. These waves are received after reflection from an obstacle such as the enemy submarine, iceberg, sunken ship, etc.

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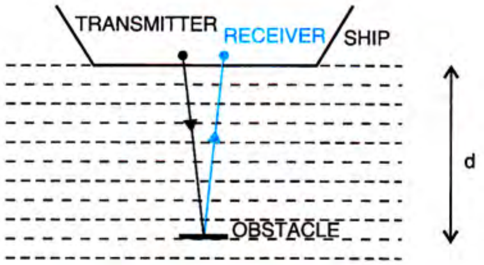

Fig. 7.1 Principle of sonar

To find the distance of obstacle from the ship the time interval t between the instant when waves (pulse) are sent and the instant when waves are received, after reflection from the obstacle is measured. The distance d of the obstacle from the source is then $d = \frac{Vt}{2}$ where V is the speed of ultrasonic waves in water. The depth of sea can also be found by this method. The process is then called *echo depth sounding*.

Note : (1) In **radar** (*radio detection and ranging*), also the echo method is used to detect the presence of an obstacle and also to find its range. A signal of electromagnetic waves (such as radio waves or micro waves) is sent in space which after reflection from the object (such as enemy's aeroplane) in its path, returns to the radar itself.

(2) Both in 'SONAR' and 'RADAR', the transmitter and the receiver are placed close to each other. In Fig. 7.1, they are shown separated just for clarity.

(3) Use of echoes in medical field

In medical field, echo method of ultrasonic waves is used for imaging the human organs (such as liver, gall bladder, uterus, womb, *etc.*) This is called *ultrasonography*. Similarly, echo cardiography is used to obtain the image of human heart.

EXAMPLES

1. The diagram below shows (a) displacement-time, and (b) displacement-distance, graph of a wave travelling in a string with velocity 20 m s^{-1}. In each case, use graph to calculate the frequency and wavelength of the wave.

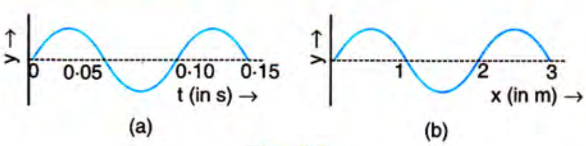

Fig. 7.2

Given : Wave velocity $V = 20$ m s^{-1}

(a) From graph in Fig. 7.2(a), the time for one vibration of wave particle *i.e.* time period $T = 0{\cdot}10$ s

$\therefore$ Frequency $f = \frac{1}{T} = \frac{1}{0{\cdot}10\,s} = $ **10 Hz**

From relation $V = f\lambda$,

Wavelength $\lambda = \frac{V}{f} = \frac{20}{10} = $ **2 m**

(b) From graph in Fig. 7.2(b), length of one wave *i.e.*, wavelength $\lambda = $ **2 m**

From relation $V = f\lambda$,

Frequency $f = \frac{V}{\lambda} = \frac{20}{2} = $ **10 Hz**

2. A sound produced on the surface of a lake takes 4·5 s to reach a boatman. How much time will it take to reach a diver inside water at the same distance if speed of sound in water is 4·5 times the speed of sound in air ?

Given, $V_{water} : V_{air} = 4{\cdot}5$, $t_{air} = 4{\cdot}5$ s, $t_{water} = ?$

From relation $V_{air} = \frac{d}{t_{air}}$ and $V_{water} = \frac{d}{t_{water}}$

or $V_{air} \times t_{air} = V_{water} \times t_{water}$

$\therefore\ t_{water} = \frac{V_{air}}{V_{water}} \times t_{air} = \frac{1}{4{\cdot}5} \times 4{\cdot}5\ \text{s} = $ **1 s.**

3. A boy hears an echo of his own voice from a distant hill after one second. The speed of sound in air is 350 m s^{-1}. What is the distance of hill from the boy ?

Given $V = 350$ m s^{-1}, $t = 1$ s.

Let d be the distance of hill from the boy.

Total distance travelled by the sound in going and then coming back = $2d$.

Now speed of sound $V = \frac{\text{total distance travelled } 2d}{\text{time taken } t}$

or $d = \frac{V \times t}{2} = \frac{350 \times 1}{2} = $ **175 m**

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4. A 'RADAR' is able to detect the reflected waves from an enemy aeroplane after a time interval of 0·02 milli-second. If the velocity of the waves is 3×10^8 m s^{-1}, calculate the distance of aeroplane from the radar.

Given : $V = 3 \times 10^8$ m s^{-1} and

$t = 0{\cdot}02$ milli-second $= 0{\cdot}02 \times 10^{-3}$ s

Let d be the distance of aeroplane from the radar.

Total distance travelled by the waves in going and then coming back $= 2d$

Velocity of waves $V = \dfrac{\text{total distance travelled } 2d}{\text{time taken } t}$

or $\quad d = \dfrac{Vt}{2} = \dfrac{(3\times10^8)\times(0{\cdot}02\times10^{-3})}{2}$

$= 3 \times 10^3$ **m (or 3 km)**

5. A boy standing in front of a wall at a distance of 85 m produces 2 claps per second. He notices that the sound of his clapping coincides with the echo. The echo is heard only once when clapping is stopped. Calculate the speed of sound.

Let d be the distance of wall from the boy.

Given, $d = 85$ m

To hear the echo, sound has to travel a total distance $= 2d = 2 \times 85 = 170$ m

Since 2 claps are produced in one second, therefore each clap is produced after $\frac{1}{2}$ s which is equal to the time taken for the echo to be heard *i.e.*,

$$t = \frac{1}{2} \text{ s} = 0{\cdot}5 \text{ s}$$

Now the speed of sound

$$V = \frac{\text{total distance travelled}}{\text{time taken}} = \frac{170 \text{ m}}{0{\cdot}5 \text{ s}} = \mathbf{340 \text{ m s}^{-1}}$$

6. A boy stands 60 m in front of a tall wall and claps. The boy continues to clap every time an echo is heard. Another boy finds that the time taken between the first and fifty-first clap is 18 s. Calculate the speed of sound.

Distance of boy from the wall $d = 60$ m

Total distance travelled by the sound $= 2d = 120$ m

Time interval between the 1st and 51st clap = 18 s

$\therefore$ Time interval between two successive claps $= \dfrac{18}{50}$ s

or $\quad$ Time taken for the echo to be heard $t = \dfrac{18}{50}$ s

Hence speed of sound $V = \dfrac{\text{total distance travelled } 2d}{\text{time taken } t}$

or $\quad V = \dfrac{120 \text{ m}}{(18/50) \text{ s}} = \mathbf{333 \text{ m s}^{-1}}$

7. A man standing in front of a vertical cliff fires a gun. He hears the echo after 3 s. On moving closer to the cliff by 82·5 m, he fires again and hears the echo after 2·5 s. Find : (a) the distance of cliff from the initial position of man, and (b) the speed of sound.

Fig. 7.3 shows the two positions of the man in front of a cliff.

Let distance of cliff from the initial position of man be d m and speed of sound be V m s^{-1}.

For the first echo, $t = \dfrac{2d}{V} = 3$ s (given) ....(i)

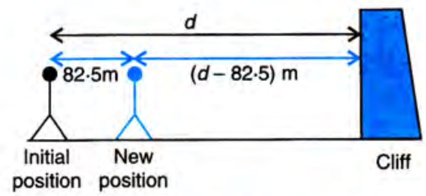

Fig. 7.3

On moving closer to the cliff by 82·5 m, the distance of cliff from the new position becomes $(d - 82{\cdot}5)$ m, then for second echo,

$t = \dfrac{2(d-82{\cdot}5)}{V} = 2{\cdot}5$ s (given) ...(ii)

(a) Dividing eqn. (i) by eqn. (ii), we get

$$\frac{d}{d-82{\cdot}5} = \frac{3}{2{\cdot}5} = \frac{6}{5}$$

or $\quad 6d - 495 = 5d$

or $\quad d =$ **495 m**

(b) From eqn. (i), $V = \dfrac{2d}{t}$

Substituting the value of $d = 495$ m, and $t = 3$ s

$$V = \frac{2\times495}{3} = \mathbf{330 \text{ m s}^{-1}}$$

8. A person standing between the two vertical cliffs and 640 m away from the nearest cliff, produces sound. He hears the first echo after 4 s and the second echo 3 s later. Calculate : (a) the speed of sound in air, and (b) the distance between the cliffs.

Fig. 7.4 shows the two cliffs and the position of the person.

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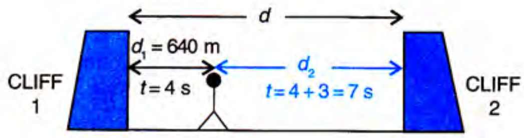

Fig. 7.4

(a) First echo is heard from the nearest cliff.
Let d_1 be the distance of the nearest cliff 1 from the person. Total distance travelled by the sound in going and then coming back = $2d_1 = 2 \times 640$ m = 1280 m

Time taken t = 4 s

$$\therefore \text{Speed of sound} = \frac{\text{total distance travelled } 2d_1}{\text{time taken } t}$$

$$= \frac{1280 \text{ m}}{4 \text{ s}} = \mathbf{320 \text{ m s}^{-1}}$$

(b) The second echo is heard from the farther cliff 2. If d_2 is the distance of the farther cliff 2 from the person, then total distance travelled by the sound in going and then coming back = $2d_2$

Time taken $t = 4 + 3 = 7$ s

Now $V = \frac{2d_2}{t}$

$$\therefore \quad d_2 = \frac{Vt}{2} = \frac{320 \times 7}{2} = 1120 \text{ m}$$

Hence distance between the two cliffs 1 and 2

$= d_1 + d_2$

$= 640 \text{ m} + 1120 \text{ m} = \mathbf{1760 \text{ m}}$

9. In a SONAR, ultrasonic waves are sent into the sea water and the reflected waves from a sunken ship are received after 2·0 s. If the velocity of waves in sea water is 1450 m s^{-1}, find the depth of the sunken ship.

Given, $V = 1450 \text{ m s}^{-1}$, $t = 2{\cdot}0$ s

Depth of the sunken ship $d = \frac{Vt}{2}$

$$= \frac{1450 \times 2{\cdot}0}{2} = \mathbf{1450 \text{ m}}$$

EXERCISE–7(A)

1. What are mechanical waves ?
2. Define the following terms in relation to a wave : (a) amplitude, (b) frequency, (c) wavelength, and (d) wave velocity.
3. A wave passes from one medium to another medium. Mention *one* property of the wave (i) which changes, (ii) which does not change.
   Ans. (i) wavelength (or speed), (ii) frequency
4. State *two* factors on which the speed of a wave travelling in a medium depends.
5. State *two* differences between the light and sound waves.
6. What is meant by an echo ? State *two* conditions necessary for an echo to be heard distinctly.
7. A man is standing at a distance of 12 m from a cliff. Will he be able to hear a clear echo of his sound ? Give a reason for your answer.
8. State *two* applications of echo.
9. Explain how the speed of sound can be determined by the method of echo.
10. State the use of echo by a bat, dolphin and fisherman.
11. How do bats avoid obstacles in their way, when in flight ?
12. What is meant by sound ranging ? Give *one* use of sound ranging.
13. Name the waves used for sound ranging. State *one* reason for their use. Why are the waves mentioned by you not audible to us ?
14. What is 'SONAR' ? State the principle on which it is based.
15. State the use of echo in medical field.

MULTIPLE CHOICE TYPE

1. The minimum distance between the source and the reflector in air, to hear an echo, is approximately :
   (a) 10 m (b) 17 m
   (c) 34 m (d) 50 m. **Ans.** (b) 17 m.
2. To detect the obstacles in their path, bats produce :
   (a) infrasonic waves (b) ultrasonic waves
   (c) electromagnetic waves (d) radio waves.
   Ans. (b) ultrasonic waves.

NUMERICALS

1. The wavelength of waves produced on the surface of water is 20 cm. If the wave velocity is 24 m s^{-1}, calculate : (i) the number of waves produced in one second, and (ii) the time in which one wave is produced. **Ans.** (i) 120 (ii) $8{\cdot}3 \times 10^{-3}$ s

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2. Calculate the minimum distance in air required between the source of sound and the obstacle to hear an echo. Take speed of sound in air = 350 m s^{-1}.

Ans. 17·5 m

3. What should be the minimum distance between the source and reflector in water so that the echo is heard distinctly ? (The speed of sound in water = 1400 m s^{-1}). **Ans.** 70 m

4. A man standing 25 m away from a wall produces a sound and receives the reflected sound. (a) Calculate the time after which he receives the reflected sound if the speed of sound in air is 350 m s^{-1}. (b) Will the man be able to hear a distinct echo ? Explain the answer. **Ans.** (a) 0·143 second (b) Yes
Reason : Original sound persists only for 0·1 s

5. A RADAR sends a signal to an aeroplane at a distance 45 km away, with a speed of 3×10^8 m s^{-1}. After how much time is the signal received back after reflecting from the aeroplane ?

Ans. 3×10^{-4} s.

6. A man standing 48 m away from a wall fires a gun. Calculate the time after which an echo is heard. (The speed of sound in air is 320 m s^{-1}). **Ans.** 0·30 s

7. A ship on the surface of water sends a signal and receives it back from a submarine inside water after 4 s. Calculate the distance of the submarine from the ship. (The speed of sound in water is 1450 m s^{-1}).

Ans. 2·9 km

8. A pendulum has a frequency of 5 vibrations per second. An observer starts the pendulum and fires a gun simultaneously. He hears echo from the cliff after 8 vibrations of the pendulum. If the velocity of sound in air is 340 m s^{-1}, find the distance between the cliff and the observer. **Ans.** 272 m

9. A person standing between the two vertical cliffs produces a sound. Two successive echoes are heard at 4 s and 6 s. Calculate the distance between the cliffs.

(Speed of sound in air = 320 m s^{-1})

[**Hint :** First echo will be heard from the nearest cliff and the second echo from the farther cliff.]

Ans. 1600 m

10. A man fires a gun and hears its echo after 5 s. The man then moves 310 m towards the hill and fires his gun again. This time if he hears the echo after 3 s, calculate the speed of sound.

Ans. 310 m s^{-1}

11. On sending an ultrasonic wave from a ship towards the bottom of a sea, the time interval between sending the wave and receiving it back is found to be 1·5 s. If the velocity of wave in sea water is 1400 m s^{-1}, find the depth of sea. **Ans.** 1050 m

(B) NATURAL, DAMPED AND FORCED VIBRATIONS; RESONANCE

7.6 NATURAL VIBRATIONS

A body clamped at one point when disturbed slightly from its rest position, starts vibrating. The vibrations so produced are called the *natural* or *free vibrations* of the body. *The period* (or *frequency*) *of vibration depends on the shape and size* (or *structure*) *of the body.* The time period of the body is called its *natural period* and the frequency is called its *natural frequency*. Each body, capable of vibrating, vibrates with a constant natural frequency and its amplitude of vibration remains constant. The natural vibrations of a body actually occur only in vacuum because the presence of medium around the body offers some resistance due to which the amplitude of vibration does not remain constant, but it continuously decreases. Thus,

The periodic vibrations of a body in the absence of any external force on it, are called the natural (or *free*) *vibrations.*

Examples of natural (or free) vibrations

(1) If the bob of a simple pendulum is displaced slightly from its mean (or rest) position, it starts vibrating with its natural frequency which is determined by the length l of the pendulum and the acceleration due to gravity g at that place and is given as

$$\text{Frequency } f = \frac{1}{2\pi}\sqrt{\frac{g}{l}} \qquad ..(7.7)$$

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Different pendulums (having different lengths) will vibrate with different frequencies (*i.e.*, they will have different natural frequencies). A simple pendulum of length 1·0 m on earth surface, where the acceleration due to gravity is 9·8 m s^{-2}, has its natural frequency 0·5 Hz.

(2) A load suspended from a spring, when stretched (or compressed) and then released, starts vibrating with its natural frequency. Its frequency is determined by the hardness (or force constant K)* of the spring and the mass m of the load ($f = \frac{1}{2\pi}\sqrt{\frac{K}{m}}$). The frequency will be different for the same load on different springs and it will be different for different loads on the same spring.

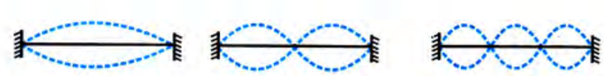
(3) When a tuning fork is struck against a hard rubber pad, it vibrates with its natural frequency. The vibrations form longitudinal waves in air, which when reach our ears, sound is heard. This sound is of a single frequency (*i.e.*, it is a *pure* note).

(4) When we strike the keys of a piano, various strings are set in vibration each at its natural frequency.

(5) When an air column in a flute (or organ pipe) is made to vibrate, it vibrates with its natural frequency which is inversely proportional to the length of air column. In a flute, the notes of different frequencies are produced by changing the effective length of air column when different holes in it are closed. In an organ pipe *open at both ends*, different modes of vibrations are of frequencies in the ratio 1 : 2 : 3 : ..., while in an organ pipe *with one end closed*, the frequencies of different modes are in ratio 1 : 3 : 5 : .....

(6) When the string in the instruments like sitar, guitar, violin, *etc.* is once plucked, the transverse vibrations of a definite natural frequency are produced in the string. The frequency f of vibration in a strictched string depends on (i) the length l ($f \propto 1/l$), (ii) the radius r ($f \propto 1/r$), and (iii) the tension T ($f \propto \sqrt{T}$) in the string. Thus the frequency of note produced by a string stretched between its ends is given as $f = \frac{1}{2l}\sqrt{\frac{T}{\pi r^2 d}}$ where d is the density of material of the string and $\pi r^2 d = m$ is the mass of unit length of the string. The frequency f of the note can be increased (a) by decreasing the length l of the string, (b) by decreasing the radius r (or thickness) of the string, and (c) by increasing the tension T in the string.

(7) A string of a given length stretched between its ends under a given tension can be made to vibrate in different modes by plucking the string at different points. If the string is plucked in the middle, the string vibrates in *one* loop as shown in Fig. 7.5(a). This vibration is called the principal note of frequency f. If the string is plucked at one-fourth length of string from one end, it vibrates in two loops [Fig. 7.5(b)]. This vibration is called the first subsidiary vibration of frequency $2f$. Similarly if the string is plucked at one-sixth length of string from one end, it vibrates in *three* loops as shown in Fig. 7.5(c). This vibration is called the second subsidiary of frequency $3f$. Thus the different modes of vibration in a stretched string are of frequencies in ratio 1 : 2 : 3. If l is the length of string stretched between its ends, the wavelength of different modes in Fig. 7.5 (a), (b) and (c) will be $2l$, $2l/2$ and $2l/3$ respectively *i.e.*, they are in ratio 3 : 2 : 1.



(a) Frequency = f Principal note

(b) Frequency = $2f$ First subsidiary

(c) Frequency = $3f$ Second subsidiary

Fig. 7.5 Different modes of vibrations in a string

* The force constant K of a spring is the force needed to produce unit extension in it.

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Nature of natural vibrations

The natural vibrations are the simple harmonic vibrations under the restoring force, the amplitude and frequency of which remain constant. Once a body starts vibrating, it continues its vibrations with the same amplitude and same frequency forever. Fig. 7.6 shows the displacement-time graph for the natural (or free) vibrations of a body in an *ideal condition.*

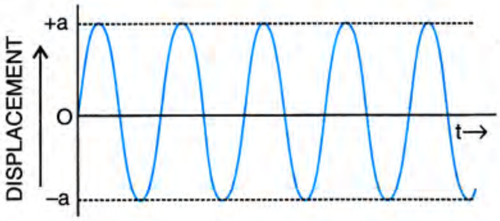

Fig. 7.6 Displacement-time graph for natural or free vibration (in vacuum)

The vibrations of a constant amplitude can occur only in *vacuum*. Since in practice, it is impossible to have vacuum, it is very difficult to *realise such vibrations in practice*. In practice, the surrounding medium offers resistance (or friction) to the motion, so the energy of vibrating body continuously decreases due to which the amplitude of motion gradually decreases.

7.7 DAMPED VIBRATIONS

It is our common experience that when a body is made to vibrate in a medium, the amplitude of the vibrating body continuously decreases with time and ultimately the body stops vibrating. Such vibrations are called the damped vibrations. Thus

> *The periodic vibrations of a body of decreasing amplitude in presence of a resistive force are called the damped vibrations.*

In damped vibrations, *two* forces act on the body : (i) the restoring force, and (ii) frictional (or resistive) force due to the surrounding medium. The amplitude of motion decreases due to the frictional force. The frictional force at any instant is proportional to the velocity* of the body and it has the tendency to resist the motion. As a result, the energy of the vibrating body continuously dissipates in doing work against the force of friction and so its amplitude gradually decreases. After some time, when it has lost all its energy, it stops vibrating. The energy lost by the vibrating body changes contineously into the heat energy and it gets dissipated in the surrounding medium. The rate at which the energy is lost to the surroundings (or the rate of decrease of amplitude) depends on the nature (*i.e.,* viscosity, density, etc.) of the surrounding medium and also on the shape and size of the vibrating body. Fig. 7.7 shows the displacement-time graph for the body executing the damped motion.

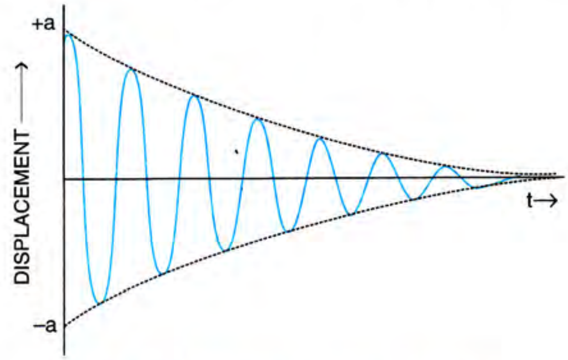

Fig. 7.7 Displacement-time graph for the damped vibrations

Examples of damped vibrations

(1) When a slim branch of a tree is pulled and then released, it makes the damped vibrations.

(2) A tuning fork when stroked on a rubber pad, executes the damped vibrations in air.

(3) A simple pendulum oscillating in air (or any other medium) executes the damped vibrations.

(4) The vibrations of a loaded spring in air are the damped vibrations.

* From relation $F = ma$, if a body moving with velocity v is brought to rest by a resistive force F in time t, then resistive force $F = \frac{mv}{t}$. Thus the resistive force F needed to stop a moving body is proportional to the velocity v of body.

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Difference between the natural (or free) and damped vibrations

Natural vibrations	Damped vibrations
1. The amplitude of the natural vibrations remains constant and the vibrations continue forever.	1. The amplitude of the damped vibrations gradually decreases with time and ultimately the vibrations cease.
2. There is no loss of energy in natural vibrations.	2. In each vibration, there is some loss of energy in the form of heat.
3. No external force acts on the vibrating body. The vibrations are only under the restoring force.	3. In addition of the restoring force, a frictional or damping force acts to oppose the motion.
4. The frequency of vibrations depends on the size and shape of the body and it remains constant.	4. The frequency of vibrations is less than the natural frequency.

7.8 FORCED VIBRATIONS

The amplitude of natural vibrations of a body vibrating in a medium cannot remain constant due to the presence of damping forces of the surrounding medium. However, it is possible to keep the amplitude of vibrations constant by applying an external periodic force such that the external periodic force compensates for the loss of energy in each vibration due to the damping forces. The vibrations of the body then are called the forced vibrations. Thus

The vibrations of a body which take place under the influence of an external periodic force acting on it, are called the forced vibrations.

The body executing the forced vibrations is thus acted upon by *three* forces : (i) the restoring force, (ii) the frictional (or resistive) force, and (iii) the external periodic force. When the external periodic force is applied on the vibrating body, the body no longer vibrates with its own natural frequency, but it gradually acquires the frequency of the applied periodic force. The external applied force is also called the *driving force*.

The amplitude of the forced vibrations depends on the frequency of the external force. If the frequency of the external force is *different* from the natural frequency of the body, the amplitude of oscillations is very small. But if the frequency of the external force is *exactly equal* to the natural frequency of the vibrating body, the amplitude of oscillations is very large. However the amplitude of forced vibration does not change with time.

Examples of forced vibrations

(1) When the stem of a vibrating tuning fork is pressed against the top of a table, the tuning fork forces the table top to vibrate with its own frequency. The vibrations produced in the table top are the forced vibrations. The table top has a much larger vibrating area than the tuning fork, so the forced vibrations of the table top send forth a greater energy and produces a louder (or more intense) sound than that produced by the tuning fork.

(2) The vibrations produced in the diaphragm of a microphone sound box with frequencies corresponding to the speech of the speaker, are the forced vibrations.

(3) In a guitar, an artist applies the periodic force on the strings of the guitar to execute the forced vibrations in them.

(4) In stringed instruments provided with a hollow sound box containing air, strings are made to vibrate by plucking which produces forced vibrations in air of the sound box. The surface area of air in the sound box is large, so the forced vibrations of air send forth a greater energy and cause a loud sound.

Difference between the natural (or free) and forced vibrations

Natural (Free) vibrations	Forced vibrations
1. The vibrations of a body in absence of any resistive or external force are called the natural vibrations.	1. The vibrations of a body in a medium in presence of an external periodic force are called the forced vibrations.
2. The frequency of virbation depends on the shape and size of the body.	2. The frequency of vibration is equal to the frequency of the applied force.

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3. The frequency of vibration remains constant.	3. The frequency of vibration changes with change in the frequency of the applied force.
4. The amplitude of virbation remains constant with time.	4. The amplitude of vibration depends on the frequency of the applied force and it does not change with time.

7.9 RESONANCE (a special case of forced vibrations)

When a body vibrates in a medium under the influence of an external periodic force of frequency *exactly equal* to the natural frequency of vibration of the body, it is said to execute the resonant vibrations. These vibrations are of large amplitude. The amplitude of resonance depends on the frictional forces. Thus,

> *Resonance is a special case of forced vibrations. When the frequency of the externally applied periodic force on a body is equal to its natural frequency, the body readily begins to vibrate with an increased amplitude.* This phenomenon is known as ***resonance***. The vibrations of large amplitude are called the resonant vibrations.

Suppose a body is set to vibrate freely and it vibrates with a frequency f. It is the natural frequency of vibration of the body. Now let a periodic force of frequency n be applied on the vibrating body. If $n = f$, the resonance takes place and the body starts getting energy from the source of the applied periodic force so its amplitude of vibration is increased. In case n is greater or less than f, (*i.e.*, not equal to f), there will be no resonance and the body will execute only the forced vibrations of small amplitude.

Condition for resonance

> *Resonance occurs only when the frequency of the applied force is exactly equal to the natural frequency of the vibrating body and the applied force causes forced vibration in the body.*

At resonance, a loud sound is heard because the body vibrating with a very large amplitude sends forth a large amount of energy in the medium.

Demonstration of resonance

The phenomenon of resonance can be demonstrated by the following experiments.

Experiment (1)-Resonance with tuning forks : Mount two *identical* tuning forks A and B of the *same* frequency on *two* separate sound boxes such that their open ends face each other as shown in Fig. 7.8. If the prong of one of the tuning forks say, A is struck on a rubber pad, it starts vibrating. On putting the tuning fork A on its sound box, we find that the other tuning fork B also starts vibrating and a loud sound is heard.

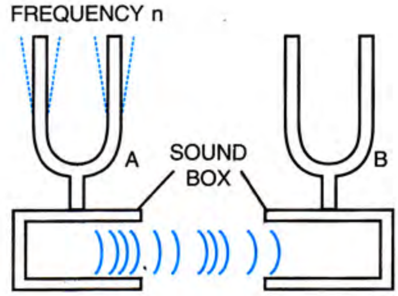

Fig. 7.8 Resonance with tuning forks

Reason – The vibrating tuning fork A produces the forced vibrations in the air column of its sound box. These vibrations are of large amplitude because of large surface area of air in the sound box. They are communicated to the sound box of the fork B. The air column of B starts vibrating with the frequency of fork A. Since the frequency of these vibrations is same as the natural frequency of the fork B, the fork B picks up these vibrations and starts vibrating under resonance. Thus the two sound boxes help in communicating the vibrations and in increasing the amplitude of vibrations.

Experiment (2) – Forced and resonant vibrations of pendulums : Take four pendulums A, B, C and D. Suspend them from the same *elastic* support, say from a piece of stretched rubber string PQ as shown in Fig. 7.9. A and B are the pendulums of the *same length*, so their natural frequency of vibration is same. D is a pendulum which is *longer than* A or B, so its natural frequency is lower than that of A or B.

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The pendulum C is *shorter than* A or B, so its natural frequency is higher than that of A or B. The two unequal ones (*i.e.*, C and D) are being suspended on either side of the pendulum B.

The pendulum A is set into vibration by displacing its bob to one side, normal to the length of the string PQ.

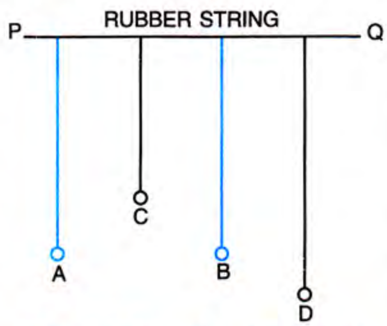

Fig. 7.9 Forced and resonant vibrations of pendulums

Observation : The *pendulum* B *also starts vibrating initially with a small amplitude and ultimately it acquires the same amplitude as the pendulum* A *initially had. When the amplitude of pendulum* B *is maximum, the amplitude of pendulum* A *is minimum (because of energy sharing). After sometime the amplitude of pendulum* B *decreases and that of* A *increases. The vibrations of pendulum* B *are in phase with those of* A (*i.e.,* they reach their extreme positions on either side simultaneously). The pendulums C and D also vibrate, but each of them vibrate with a very small amplitude.

Explanation – The vibrations produced in pendulum A are communicated as forced vibrations to the other pendulums B, C and D through the rubber string PQ. *The pendulums* C *and* D *remain in the state of forced vibrations, while the pendulum* B *comes in the state of resonance.* This is because the natural frequency of pendulum B is equal to that of A (being of the same length), and therefore there is an exchange of energy only between the pendulums A and B, so resonance takes place. When the amplitude of pendulum B increases, the amplitude of pendulum A decreases and vice-versa. The pendulum B, therefore, vibrates with the frequency of pendulum A and it remains in phase with the pendulum A.

Experiment (3)-Resonance in air column : Fig. 7.10 shows an arrangement for studying the resonance in an air column. It consists of a long cylindrical tube A and a cylindrical vessel B. The tube A is fixed, while the vessel B can be moved up or down and it can be clamped at a desired position. Both the tube and the vessel are connected at their lower ends by a rubber tube and they are partially filled with water. The movable vessel B serves as a *reservoir*. The vibrating source (*i.e.,* a tuning fork) is kept just above the mouth of the tube A so that the tube A serves as a *closed end air pipe* with water surface in it forming the closed end (*i.e.,* the reflecting surface). Thus, an air column is formed in the tube A between the water surface and its mouth. When the air column is made to vibrate, it will vibrate with its natural frequency which depends on its length (since $f \propto 1/l$). By moving the reservoir B up or down, the length of air column in tube A can be changed due to which the natural frequency of air column of tube A changes.

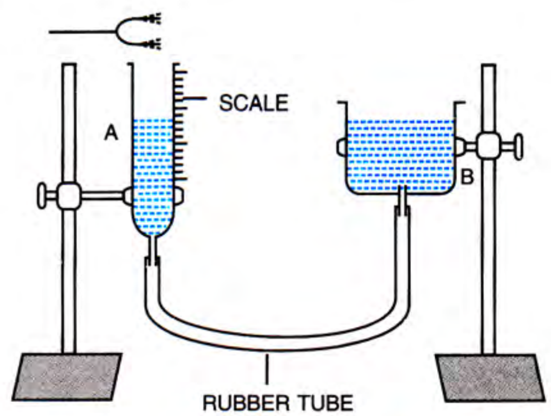

Fig. 7.10 Resonance in air column

While performing the experiment, the tube A is first filled with water up to the top. Then a vibrating tuning fork is placed just above the mouth of tube A and the level of water in it is gradually lowered.

Observation : A loud sound is heard at a certain level of water. On further lowering the level of water in tube A, the loud sound ceases, but when the length of air column in the tube becomes *three times* the previous one, a loud sound is heard again.

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Explanation – The vibrating tuning fork held just above the mouth of tube A, produces forced vibrations in the air column of tube A. When the frequency of air column is decreased by increasing the length of the air column (*i.e.*, lowering the water level in the tube), at a certain level of water in tube A, a loud sound is heard. This happens when the natural frequency of the air column becomes equal to the frequency of the tuning fork, *i.e.,* the vibrations of the air column are in resonance with those of the fork. On further lowering the water level in tube A, the frequency of air column does not remain equal to the frequency of the fork, so the loud sound ceases. But on further lowering the level of water, a stage is again reached when a loud sound is heard. At this stage, the frequency of air column again becomes equal to the frequency of tuning fork when the length of air column becomes *three times* the previous length*, so the resonance occurs again.

Difference between the forced and resonant vibrations

Forced vibrations	Resonant vibrations
1. The vibrations of a body under an external periodic force of frequency different from the natural frequency of the body, are called the forced vibrations.	1. The vibrations of a body under an external periodic force of frequency exactly equal to the natural frequency of the body, are called the resonant vibrations.
2. The amplitude of vibration is usually small.	2. The amplitude of vibration is very large.
3. The vibrations of the body are not in phase with the external periodic force.	3. The vibrations of the body are in phase with the external periodic force.
4. These vibrations last for a very small time after the periodic force has ceased to act.	4. These vibrations last for a long time after the periodic force has ceased to act.

* Though in an air column of given length with one end closed, the frequencies of different modes of vibrations are in ratio 1 : 3 : 5 : ...., but if length of air column with one end closed, is tripled, the frequency of vibration of air column remains same because the wavelength remains same.

7.10 SOME EXAMPLES OF RESONANCE

(1) ***Resonant vibrations of pendulums :*** As discussed earlier in experiment (2), if two pendulums of same length are suspended from a rubber string and one pendulum is made to vibrate, the other pendulum also starts vibrating with a large amplitude and in same phase because of resonance.

(2) ***Resonance in machine parts :*** When a vehicle is driven, the piston of the engine makes to and fro motion at a frequency depending upon the speed of the vehicle. The vibrations caused by the movement of piston are transmitted to all parts of the vehicle. It is just possible that at a certain speed of the vehicle some parts of the vehicle (or its frame) may have natural frequency of vibration equal to the frequency of to and fro movement of the piston. At this particular speed of the vehicle, that particular part starts vibrating vigorously due to *resonance* and a *rattling sound* is heard. If this part is not tightly fixed, such vibrations may cause the part to drop out. To stop these vibrations, the speed of vehicle is changed, so that the condition of resonance does not hold.

> *Note :* In this manner resonance can occur in all kinds of machines while operating in a particular condition.

(3) ***Resonance in a stretched string and sound box of musical instruments and sonometer :*** A vibrating string by itself produces a very weak sound which cannot be heard at a distance. Therefore all musical stringed instruments such as guitar and sonometer are provided with a *sound box* (*i.e.* a hollow chamber). *The box is so constructed that the column of air inside it, has a natural frequency which is same as that of the string stretched on it*, so that when the string is made to vibrate, the air column inside the box is set into forced vibrations, the frequency of which is same as that of the string. Since the sound box has a large area, it sets a large volume of air into

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vibrations, so due to resonance, a loud sound is produced.

(4) ***Resonance in air column and tuning fork :*** As described in experiment (3), when the frequency of air column becomes equal to the frequency of the tuning fork vibrating over its mouth, a loud sound is heard due to resonance.

(5) ***Resonance in a bridge :*** *When a troop crosses a suspension bridge, the soldiers are asked to break their steps.* The reason is that when soldiers march in steps, each soldier exerts a periodic force in same phase and therefore the bridge executes the forced vibrations of frequency equal to the frequency of their steps. Now if the natural frequency of the bridge happens to be equal to the frequency of the steps, the bridge will vibrate with a large amplitude due to resonance and the suspension bridge may collapse.

(6) ***Resonance in radio and TV receivers :*** The tuning of a radio and TV receivers is based on resonance. The radio and TV receivers have electronic circuits which produce electromagnetic vibrations, the frequency of which can be changed by changing the values of the electronic components (either the capacity of condenser or the inductance of coil)*. When we want to tune a radio (or TV) receiver, we merely adjust the values of the electronic components to produce vibrations of frequency equal to that of the radio waves which we want to receive. When both the frequencies match, resonance occurs and only the energy of signal of that particular frequency is received from the waves present in space, leaving the signals of other frequencies which do not match with the frequency of the receiver circuit. The signal received is then amplified in the receiver set.

* Usually the capacity of condenser is changed.

EXAMPLES

1. Fig. 7.11 shows three different modes of vibration of a string of length l.

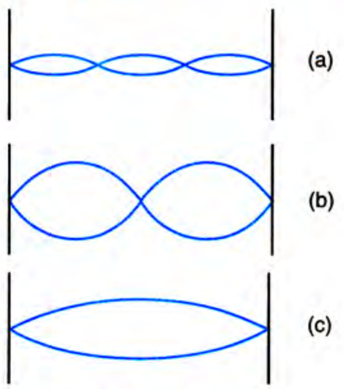

Fig. 7.11

(i) Which of the vibration is of largest amplitude ?

(ii) Which of the vibration is of least frequency ?

(iii) What is the ratio of frequency between (a) and (c) ?

(iv) What is the ratio of wavelength between (b) and (a) ?

(i) The vibration in Fig. (b) is of largest amplitude.

(ii) The vibration in Fig. (c) is of least frequency.

(iii) If the frequency of the principal note in Fig. (c) is f, the frequency of note in Fig (a) is $3f$.

Thus, $f_a = 3f$ and $f_c = f$

Ratio of frequency between (a) and (c) is

$$f_a : f_c = \mathbf{3 : 1}$$

(iv) $l = \dfrac{2\lambda_b}{2} = \dfrac{3\lambda_a}{2}$ $\quad \therefore \lambda_b : \lambda_a = \mathbf{3 : 2}$

2. The stem of a vibrating tuning fork is pressed against a table top.

(a) Will it produce an audible sound ?

(b) Does it cause the table top to set in vibrations ? If yes, what type of vibrations are they ?

(c) Under what condition does it lead to resonance ?

(a) Yes.

(b) Yes, the vibrations caused in the table top are the forced vibrations.

(c) It leads to resonance if the natural frequency of vibrations of the table top becomes equal to the frequency of the vibrating tuning fork.

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3. A vibrating tuning fork is placed over the mouth of a burette filled with water. The tap is opened and the water level gradually falls.

(a) What do you observe ? Name the phenomenon. When does it happen ?

(b) If the water level in the burette falls further, will you notice the same observation again ?

(a) ***Observation :*** As the water level is allowed to fall gradually, at a particular level of water (*i.e.,* for a certain length of air column), a loud sound is heard.

Name of the phenomenon : **Resonance**.

It happens when the natural frequency of air column (which depends on its length) becomes *exactly equal* to the frequency of the vibrating tuning fork. The air in the column now vibrates with a large amplitude conveying more energy to the ears so a loud sound is heard.

(b) **Yes**. If the water level in burette falls further, a loud sound will again be heard when the length of air column becomes three times. At this stage again the natural frequency of air column will become equal to the frequency of the vibrating tuning fork and resonance will occur.

4. Sometimes when a vehicle is driven at a particular speed, a rattling sound is heard. Explain briefly, why does this happen and give the name of the phenomenon taking place. Suggest *one* way by which the rattling sound could be stopped.

At a particular speed of the vehicle, when the natural frequency of vibration of some parts of the vehicle **becomes equal** to the frequency of the to and fro movement of the piston of its engine, **resonance** occurs due to which those parts of the vehicle start vibrating violently and a rattling sound is heard.

To stop the rattling sound, the **speed of the vehicle should be changed**.

5. A string vibrates with a natural frequency of 256 Hz. Which of the tuning fork given below will resonate with the string ?
(i) A of frequency 512 Hz, (ii) B of frequency 256 Hz, and (iii) C of frequency 128 Hz. Give resaon.

B of frequency 256 Hz.

Reason : For resonance, frequency of driver should be exactly equal to the natural frequency of driven.

EXERCISE–7(B)

1. What do you understand by the natural vibrations of a body ? Give *one* example.

2. What is meant by the natural frequency of vibrations of a body ? Name *two* factors on which it depends.

3. (a) Draw a graph between displacement and time for a body executing the natural vibrations.

   (b) Where can a body execute the natural vibrations ?

4. State *one* condition for a body to execute the natural vibrations.

5. Name *one* factor on which the frequency of sound emitted due to vibrations in an air column depends.

   Ans. length of air column

6. State *one* way of increasing the frequency of a note produced by an air column.

   Ans. by decreasing the length of the air column

7. State *two* ways of increasing the frequency of vibrations of a stretched string.

   Ans. (a) by increasing the tension in the string
   (b) by decreasing the length of the string.

8. What adjustments would you make for tuning a stringed instrument for it to emit a note of a desired frequency ?

9. The diagram below in Fig. 7.12 shows *three* ways in which the string of length l in an instrument can vibrate.

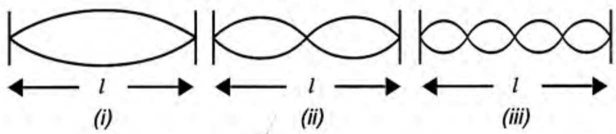

Fig. 7.12

   (a) Which of the diagram shows the principal note?

   (b) Which vibration has the frequency four times that of the first ?

   (c) Which vibration is of longest wavelength ?

   (d) What is the ratio of frequency of the vibrations in diagram (i) and (ii) ?

   Ans. (a) i (b) iii (c) i (d) 1 : 2

10. Explain why strings of different thickness are provided on a stringed instrument.

    [**Hint :** Natural frequency of vibration of a stretched string is inversely proportional to the radius (or thickness) of string so notes of different frequencies can be obtained by producing vibrations in the different strings.]

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11. A blade, fixed at one end, is made to vibrate by pressing its other end and then releasing it. State *one* way in which the frequency of vibrations of the blade can be lowered.

Ans. by increasing the length of the blade or by sticking a small weight on the blade at its free end so as to increase its mass.

12. How does the medium affect the amplitude of the natural vibrations of a body ?

13. What are the damped vibrations ? How do they differ from the free vibrations ? Give *one* example of each.

14. The diagram in Fig. 7.13 shows the displacement-time graph of a vibrating body.

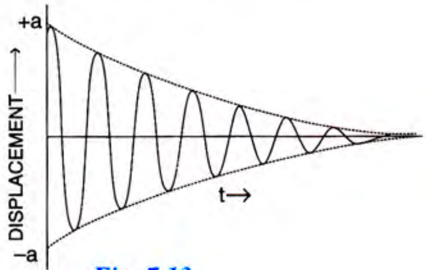

Fig. 7.13

(i) Name the kind of vibrations.

(ii) Give *one* example of such vibrations.

(iii) Why is the amplitude of vibrations gradually decreasing ?

(iv) What happens to the vibrations of the body after some time ?

15. A tuning fork is vibrating in air. State whether the vibrations are natural or damped ?

Ans. damped

16. Draw a sketch showing the displacement against time for a body executing the damped vibrations.

17. What are the forced vibrations ? Give *one* example to illustrate your answer.

18. Distinguish between the natural and forced vibrations.

19. What is meant by resonance ? Describe a simple experiment to illustrate the phenomenon of resonance and explain it.

20. State the condition for the occurrence of resonance.

21. Complete the following sentence :

Resonance is a special case of .... vibrations, when frequency of the driving force is .... natural frequency of the body.

Ans. forced, equal to the

22. Differentiate between the forced and resonant vibrations.

23. Why is a loud sound heard at resonance ?

Ans. At resonance, the body vibrates with a large amplitude thus conveying more energy to the ears, so a loud sound is heard.

24. Fig. 7.14 shows two tuning forks A and B of the same frequency mounted on two separate sound boxes with their open ends facing each other. The fork A is set into vibration. (a) Describe your observation. (b) State the principle illustrated by this experiment.

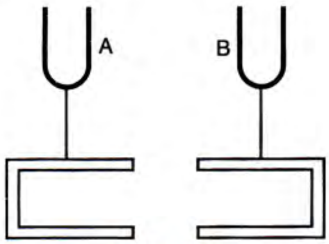

Fig. 7.14

25. In Fig. 7.15, A, B, C and D are the four pendulums suspended from the same elastic string XY. The lengths of pendulum A and D are equal, while the length of pendulum B is shorter and of the pendulum C is longer. The pendulum A is set into vibrations. (a) What is your observation about the virbations of pendulum D ? (b) Give reason for your observation in part (a). (c) What type of vibrations take place in pendulums B and C ? (d) Give reason for the answer in part (c).

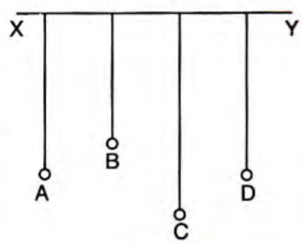

Fig. 7.15

26. A vibrating tuning fork, held over an air column of a given length with its one end closed, produces a loud audible sound. Name the phenomenon responsible for it and explain the observation.

27. In Fig. 7.15, A, B, C and D represent the test tubes each of height 20 cm which are filled with water up to heights of 12 cm, 14 cm, 16 cm and 18 cm respectively. If a vibrating tuning fork is placed over the mouth of test tube D, a loud sound is heard.

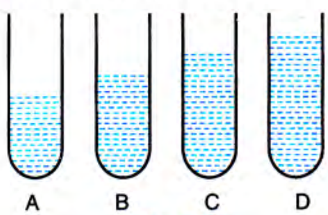

Fig. 7.15

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(a) Describe the observations with the tubes A, B and C when the vibrating tuning fork is placed over the mouth of these tubes.

(b) Give the reason for your observation in each tube.

(c) State the principle illustrated by the above experiment.

Ans. (a) No loud sound is heard with the tubes A and C, but a loud sound is heard with the tube B.

(b) Frequency of air column in tube D is equal to the frequency of tuning fork. Resonance occurs with the air column in tube B whereas no resonance occurs with the air column of tubes A and C. The frequency of vibrations of air column in tube B is same as the frequency of vibrations of air column in tube D because the length of air column in tube D is 20 – 18 = 2 cm and that in tube B is 20 – 14 = 6 cm (*i.e.*, three times). On the other hand, the frequency of vibrations of air column in tubes A and C is not equal to the frequency of vibrations of air column in tube D.

(c) When the frequency of vibrations of air column is equal to the frequency of the vibrating tuning fork, resonance occurs.

28. When a troop crosses a suspension bridge the soldiers are asked to break their steps. Why ?

29. Why are the stringed instruments like guitar provided with a hollow sound box ?

30. How do you tune your radio set to a particular station ? Name the phenomenon involved in doing so and define it.

MULTIPLE CHOICE TYPE

1. A wire stretched between the two fixed supports, is plucked exactly in the middle and then released. It executes (neglect the resistance of the medium) :

(a) resonant vibrations (b) natural vibrations
(c) damped vibrations (d) forced vibrations.

Ans. (b) natural vibrations

2. When a body vibrates under a periodic force, the vibrations of the body are :

(a) natural vibrations (b) damped vibrations
(c) forced vibrations (d) resonant vibrations.

Ans. (c) forced vibrations

3. A tuning fork of frequency 256 Hz will resonate with another tuning fork of frequency :

(a) 128 Hz (b) 256 Hz
(c) 384 Hz (d) 512 Hz. **Ans.** (b) 256 Hz

(C) CHARACTERISTICS OF SOUND & THEIR SUBJECTIVE AND OBJECTIVE NATURE

7.11 CHARACTERISTICS OF SOUND

Two sounds can be distinguished from one another by the following *three* different characteristics :

(1) loudness,
(2) pitch (or shrillness), and
(3) quality (or timbre).

The above characteristics of a given sound can be obtained from the wave pattern of that sound. Fig. 7.17 shows a set-up to obtain the wave pattern of a sound wave, using a microphone and a cathode ray oscilloscope (C.R.O.). The sound to be studied is produced before the microphone connected to the Y-input of C.R.O. The wave pattern of sound (*i.e.*, displacment-time graph) is obtained on the screen of C.R.O.

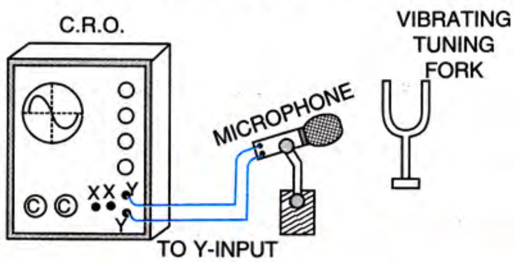

Fig. 7.17 Set-up to study the sound pattern

(1) Loudness and intensity

> *Loudness is the characteristic by virtue of which a loud sound can be distinguished from a faint one, both having the same pitch and quality.*

Take a tuning fork. Strike it *softly* and bring it in front of the microphone. You will hear a feeble (or soft) sound. Sketch the trace you observe on the screen of C.R.O. Now strike the same tuning fork *hard* and bring it near the microphone. A loud sound is heard. Again sketch

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the trace observed on the screen of C.R.O. Fig. 7.18 shows two such sketches.

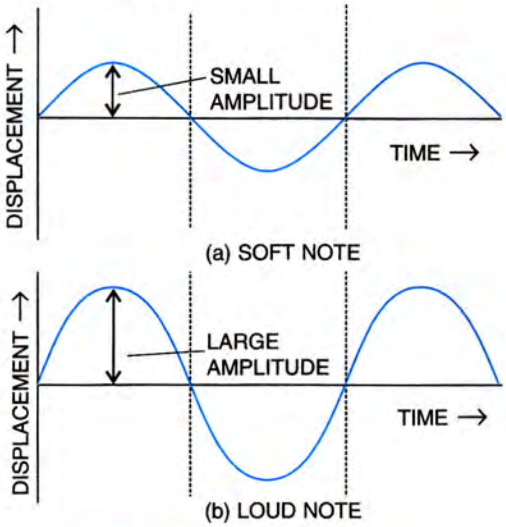

Fig. 7.18 Soft and loud notes

In Fig. 7.18, the two waves have same frequency and same wave form (sine wave), but they differ in amplitude. Obviously, the *loud sound corresponds to the wave of large amplitude.*

Similarly if the key of a piano is hit hard or a pipe is blown hard, we put more energy in the vibrating system due to which the amplitude of vibrations is increased and a loud sound is produced. Thus,

Loudness of sound depends on the amplitude of the wave.

Intensity : *The intensity of a sound wave at a point of the medium is the amount of sound energy passing per second normally through unit area at that point.* Its unit is watt per metre^2 (W m^{-2}). The intensity of ordinary sound is nearly 10^{-6} W m^{-2}, while minimum intensity of sound audible to ears is 10^{-12} W m^{-2}. *Greater the energy carried by a sound wave, greater is the intensity of sound.* The intensity of a sound wave in air is proportional to (a) the square of the amplitude of vibrations, (b) the square of the frequency of vibrations, and (c) the density of air.

Subjective nature of loudness and objective nature of intensity

The loudness of a sound depends on (i) the intensity *i.e.*, the energy conveyed by the sound wave near the eardrum of the listener, and (ii) the sensitivity of the ears of the listener. Thus loudness of sound of a given intensity may differ from listener to listener *i.e.*, the sound of the same intensity may appear to be of different loudness to different persons. Further, two sounds of the same intensity, but of different frequencies may differ in loudness even to the same listener because the sensitivity of ears is different for different frequencies. For normal ears, the sensitivity is maximum at the frequency 1 kHz. *Thus for a sound wave loudness has a subjective nature, while intensity, being a measurable quantity, has an objective nature.*

Factors affecting the loudness of sound

The loudness of sound heard at a place depends on the following *five* factors :

(i) *Loudness is proportional to the square of the amplitude* : When a body vibrates with a greater amplitude, it sends forth a greater amount of energy and hence the energy received by the eardrum is large, so the sound appears louder.

(ii) *Loudness varies inversely as the square of distance from the source* : If the listener is close to the source of sound, he hears it quite louder, but if he is far away, the sound becomes feeble. If he moves further away from the source, a stage may reach when the sound becomes inaudible. Thus, *closer the source, louder is the sound.*

(iii) *Loudness depends on the surface area of the vibrating body :* A large vibrating area sends forth a greater amount of energy. Hence larger the surface area of the vibrating body, louder is the sound heard.

For this reason, the bell in schools, temples etc. is made big in size.

When a tuning fork is sounded in air, the sound given by it is feeble, but when it is placed on a table top, the sound becomes much louder. The reason is that

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the table top provides comparatively a large surface area of air to vibrate and so the sound energy reaching our ears increases. Similarly in case of the stringed instruments, a sound chamber is provided to increase the volume of air to vibrate and hence the loudness of sound increases.

(iv) *Loudness depends on the density of the medium* : More the density of medium, more is the loudness.

(v) *Loudness depends on the presence of resonant bodies* : The presence of resonant bodies near the vibrating body increases the loudness of sound.

Relationship between loudness and intensity

Although loudness of sound depends on its intensity, but *loudness is not same as intensity. Intensity is a measurable quantity, while loudness is a sensation*. Experimentally, Weber and Fechner established a relationship between the loudness L and intensity I which is given as :

$$\boxed{L = \mathrm{K} \log_{10} I} \quad .....(7.8)$$

where K is a constant of proportionality. Obviously, loudness increases with the increase in intensity, but *not in the same proportion*.

Units of loudness and sound level (phon and decibel) : The unit of loudness is *phon*. The level of sound is expressed in decibel (dB). The loudness of a sound in phon is the loudness in decibel of an equally loud pure sound of frequency 1 kHz. Thus both the phon and the decibel scales agree at the frequency 1 kHz.

From eqn. (7.8), the loudness L is related to the intensity I as $L = \mathrm{K} \log_{10} I$. If at a given frequency, I_1 and I_0 are the intensities of two sounds of which loudness are L_1 and L_0 respectively, then

$$L_1 = \mathrm{K} \log_{10} I_1 \text{ and } L_0 = \mathrm{K} \log_{10} I_0.$$

Hence difference in loudness of the two sounds is

$$L = L_1 - L_0 = \mathrm{K} (\log_{10} I_1 - \log_{10} I_0)$$

or $$\boxed{\mathrm{L} = \mathrm{K} \log_{10} \frac{I_1}{I_0}} \quad ...(7.9)$$

If I_0 is the minimum intensity ($= 10^{-12}$ W m^{-2}) of audible sound at frequency 1 kHz, then L is called the *sound level*.

Taking K = 1, the sound level is written as

$$L = \log_{10} \left(\frac{I_1}{I_0}\right) \text{ bel}$$

or $$L = \left\{10 \log_{10} \left(\frac{I_1}{I_0}\right)\right\} \times \frac{1}{10} \text{ bel}$$

If we write $\frac{1}{10}$ bel as decible (dB), then

$$\boxed{\mathrm{L} = 10 \log_{10} \left(\frac{I_1}{I_0}\right) \text{ decibel (dB)}} \quad ....(7.10)$$

Here bel or decibed (dB) is the unit of loudness level, named after the scientist Alexander Graham Bel, the inventor of telephone.

Obviously for $I_1 = I_0$, sound level $L = 0$ dB *i.e.* sound of intensity 10^{-12} W m^{-2} at frequency 1 kHz has the loudness zero dB. If intensity at a point increases from I_0 to $I_1 = 100\, I_0$, the increase in sound level will be $10 \log_{10} 100 = 20$ dB. For an increase in intensity from I_0 to $I_1 = 100{,}00\, I_0$, the increase in sound level will be $10 \log_{10} 100{,}00 = 40$ dB.

Now if L = 1 dB, then $10 \log_{10} \left(\frac{I_1}{I_0}\right) = 1$

or $\log_{10} \left(\frac{I_1}{I_0}\right) = \frac{1}{10}$

or $\frac{I_1}{I_0} = \text{Antilog} \left(\frac{1}{10}\right) = \text{Antilog } (0{\cdot}1) = 1{\cdot}26$

Thus 1 dB is defined as the change in level of loudness when the intensity of sound changes by 26%.

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Level of sound produced by different objects

Object producing sound	Sound level (dB)
Jet at takeoff	140
Pop concert	130
Police car siren	120
Heavy hammering machine	110
Diesel lorry	90
Motorcycle or car	80
Vacuum cleaner	60
Normal conversation	50
Soft whisper	30
Recording studio	20
Leaves rusting	10
Dropping pin (minimum audible sound)	0

Noise pollution :

Disturbance produced in the environment due to undesirable loud and harsh sound, of level above 120 dB, from various sources such as loudspeaker, siren, moving vehicles, *etc.* is called noise pollution. *A constant hearing of sound of level above* 120 dB *can cause headache and permanent damage to the ears of the listener.* The safe limit of level of sound for hearing is from 0 to 80 dB. Sound of level 30 dB to 10 dB has a soothing sensation, while the sound of level 0 dB represents the lower *limit of hearing*.

Note : The limit of hearing should not be confused with the limit of audibility. The limit of audibility refers to the frequency of sound 20 Hz to 20 kHz which a man can hear, while the limit of hearing is the lowest level of loudness (= 0 dB) which a man can hear.

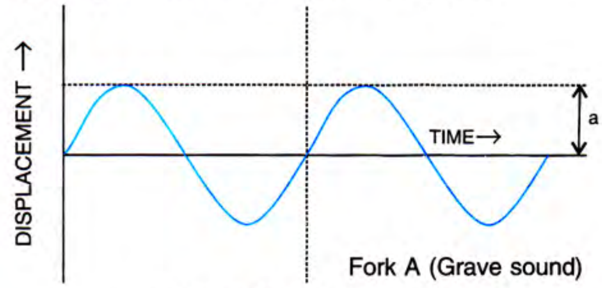
(2) Pitch (or shrillness) and frequency

Pitch is that characteristic of sound by which an acute (or shrill) note can be distinguished from a grave or flat note.

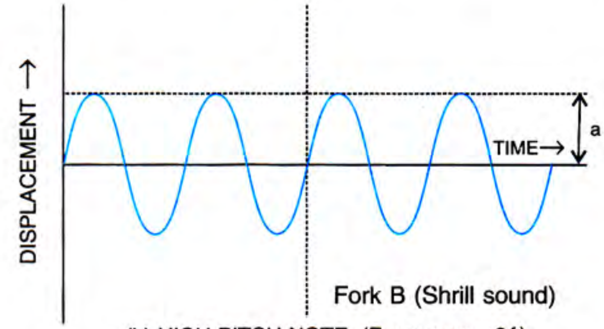
Pitch refers only to the musical sounds and each musical note has a definite pitch. If the pitch is high, the sound is *shrill* and if the pitch is low, the sound is *flat*. In a tape recorder (or TV), *bass* and *treble* refer to low and high pitch respectively. At a bass (or woofer on), low pitch (*i.e.*, grave) sound produced by tabla or *dholak* becomes predominant, while at treble, high pitch (*i.e.*, shrill) sound produced by flute or *ghoonghroo* (ankle bells) becomes predominant.

Pitch of a note depends on its frequency. *Two notes sounded on the same instrument with same amplitude, will differ in pitch when their vibrations are of different frequencies.*

Fig. 7.19 shows the traces of two waves obtained on the screen of C.R.O. when two tuning forks A and B of frequencies 256 Hz and 512 Hz respectively are separately made to vibrate one after the other (by striking them with the same force on a rubber pad) in front of the microphone of the experimental set-up shown in Fig. 7.17. Both the traces have the same amplitude and the same wave form (*i.e.*, sine wave), but they differ in frequency. On hearing the sounds of the two tuning forks, it is observed that the sound of tuning fork B of frequency 512 Hz is shriller than the sound of tuning fork A of frequency 256 Hz. Thus more the frequency of wave, higher is its pitch and less the frequency of wave, lower is its pitch.



(a) LOW PITCH NOTE (Frequency = f)



(b) HIGH PITCH NOTE (Frequency = $2f$)

Fig. 7.19 Waves of different pitch

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Examples of change in pitch : (a) Instruments such as piano, violin and guitar have several strings of different thickness under different tensions. Since the frequency of vibrations of a string depends on the tension, and thickness of a string, they can produce notes of different pitch. A note of higher pitch can be obtained by vibrating the string under high tension or by vibrating a thinner string.

(b) In case of a flute, a lower note is obtained by closing some more holes so that the length of the vibrating air column increases.

(c) As the water level in a pitcher kept under a water tap rises, the length of air column decreases, so the frequency of sound produced increases *i.e.*, the sound becomes shriller and shriller. Thus by hearing the sound from a distance, one can get the idea of water level in the pitcher.

(d) The voice of a women is usually of higher pitch than that of a man.

Subjective nature of pitch and objective nature of frequency

Pitch is not the same as frequency. *The pitch refers to the sensation as perceived by the listener*. It may be different for a sound of a particular frequency to the different listeners (*i.e.*, pitch is subjective). On the other hand, *frequency is a measurable quantity.* It depends on the source producing the sound. It has a definite value for a given sound which is equal to the frequency of its source. It has nothing to do with the listener, so frequency is an objective quantity.

(3) *Quality (or timbre) and wave form*

> *Quality (or timbre) of a sound is that characteristic which distinguishes the two sounds of the same loudness and same pitch, but emitted by two different instruments.*

Fig. 7.20 shows the wave patterns of two sounds of same loudness (*i.e.*, same amplitude) and same pitch (*i.e.*, same frequency), but emitted by two different sources. They produce different sensations in our ears because they differ in wave form, one is a sine wave while other is a triangular wave.

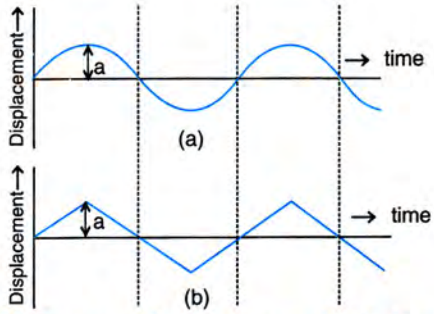

Fig. 7.20 Two sounds of same amplitude (i.e., same loudness) and same frequency but of different wave forms

> *The quality of a musical sound depends on the wave form.*

Usually the sound from an instrument does not contain a note of single frequency, but it contains a combination of vibrations of different frequencies and different amplitudes. The vibration of lowest frequency and maximum amplitude is called the *principal* (or *fundamental) vibration* and the vibrations of frequency integer multiples of it, are called the *subsidiary* (or *secondary) vibrations*. The subsidiary vibrations are of small amplitudes. *The resultant vibration obtained by the superposition of all these vibrations, gives the wave form of the sound which we hear.*

Now suppose with the set-up of Fig. 7.17, first a tuning fork of frequency 256 Hz is struck and placed in front of the microphone and next a note of frequency 256 Hz is produced by a piano in front of the microphone. The traces obtained on the screen of C.R.O. for the two cases are shown in Fig. 7.21. The sketch (a) shows a pure note (sine curve) of single frequency produced by the tuning fork, while the sketch (b) is of same amplitude and same frequency (or same pitch), but it has a different wave form due to the presence of a mixture of subsidiary vibrations alongwith the principal vibration. The subsidiary vibrations

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present in the musical note make the wave form complex. It is not a sine curve.

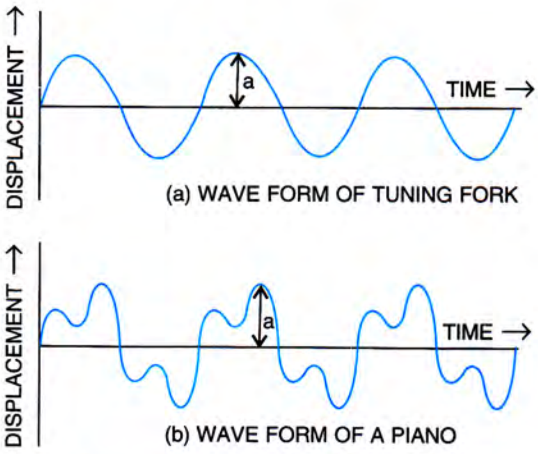

Fig. 7.21 Pure note and musical note

> Thus, *the quality of a musical sound depends on the number of the subsidiary notes and their relative amplitudes present alongwith the principal note.*

Different instruments produce different subsidiary notes. A note played on a piano has a large number of subsidiary notes, while the same note when played on a flute contains only a few subsidary notes. Thus, we can easily distinguish between the sounds of a piano and a flute by their different wave forms, though they may be of exactly the same loudness and same pitch.

Recognision of the sources of two sounds by their quality : Each vibrating body has its characteristic wave form. This makes it possible for one to recognise the vibrating body even without seeing it. You generally recognise a person by hearing his voice on telephone without seeing him. It is because the vibrations produced by the vocal chord of each person have a characteristic wave form which is different for different persons. Similarly, one can distinguish and recognise the sounds of two different musical instruments because of their different wave forms even if they are of same pitch and same loudness.

To summarize, the table below gives the factor affecting the different characteristics of sound.

Characteristics →	Loudness	Pitch	Timbre or quality
Factor →	Amplitude	Frequency	Wave form

7.12 MUSIC AND NOISE

All sounds, which produce the sensation of hearing, can be roughly divided into *two* categories : (1) *music,* and (2) *noise.*

(1) Music : *It is a pleasant, continuous and uniform sound produced by the regular and periodic vibrations.* For example, the sounds produced by a violin, piano, flute, tuning fork, etc. are the musical sounds. Their sound level is usually between 10 dB to 30 dB.

(2) Noise : The sounds other than the musical sound are called noise. *It is a sound produced by an irregular succession of disturbances and is usually a discontinuous sound.* It is discordant and unpleasant to the ears. For example, the sound produced when a stone is thrown on a tin shade is a noise. Usually all the sounds of level above 120 dB are termed as noise.

Fig. 7.22 shows the wave forms of a music and a noise.

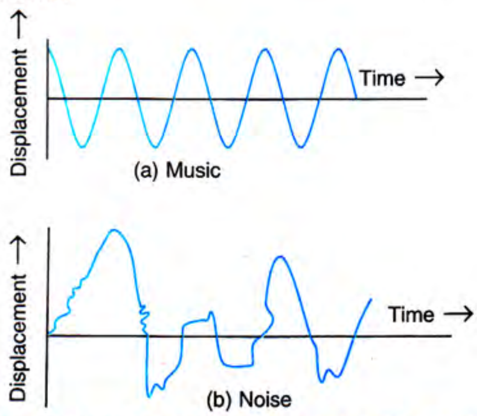

Fig. 7.22 Wave forms of a music and a noise.

> *Note :* The distinction between a music and noise is not very sharp, *it is rather subjective.* A sound which is music to someone, may be a noise to others. For example, pop song is music for the young generation, while it may be a noise for the old generation.

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COMPARISON BETWEEN THE MUSIC AND NOISE

Music	Noise
1. It is regular, smooth and pleasant to the ears.	1. It is harsh, discordant and unpleasant to the ear.
2. It is produced by the vibrations which are periodic.	2. It is produced by an irregular succession of disturbances.
3. All the component waves are similar without any sudden change in their wavelength and amplitude.	3. The component waves change their character suddenly and they are of short duration.
4. The sound level is low (between 10 dB to 30 dB).	4. The sound level is high (above 120 dB).
5. The wave form is regular.	5. The wave form is irregular.
Example : The sound produced by the musical instruments.	*Example* : The sound produced by an aeroplane, road roller, industrial machines, etc.

EXAMPLES

1. In Fig. 7.23, A and B represent the displacement-distance graphs for two sound waves when they pass through air. (a) What is the relation between their (i) velocities, (ii) wavelengths, (iii) pitch, and (iv) loudness ? (b) How do they differ in quality ?

(a)(i) Velocity of both the waves A and B is **same**, since it depends on the medium through which they pass which is the same (*i.e.*, air) in both the cases *i.e.*, $V_A = V_B$.

(ii) From Fig. 7.23, it is obvious that there are three vibrations of wave A while two vibrations of wave B in the same distance (= $2x$). Therefore, $3\lambda_A = 2\lambda_B$

or $\quad \dfrac{\lambda_A}{\lambda_B} = \dfrac{2}{3}$ or $\lambda_A : \lambda_B = $ **2 : 3**

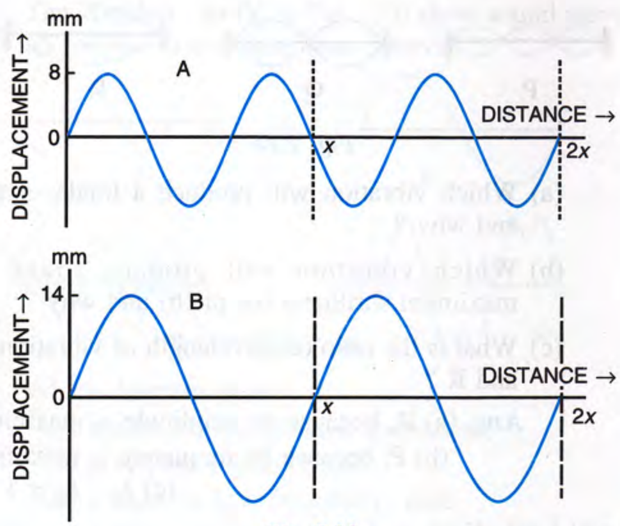

Fig. 7.22

(iii) $\dfrac{\text{Frequency of A } (f_A)}{\text{Frequency of B } (f_B)} = \dfrac{V/\lambda_A}{V/\lambda_B}$

Since V is same for both.

$\therefore \quad \dfrac{f_A}{f_B} = \dfrac{\lambda_B}{\lambda_A}$ But $\dfrac{\lambda_B}{\lambda_A} = \dfrac{3}{2}$

Hence $\quad \dfrac{f_A}{f_B} = \dfrac{3}{2} = 1{\cdot}5$

i.e., **pitch of A is 1·5 times that of B.**

(iv) The wave B has a larger amplitude (= 14 mm) than A (= 8 mm), therefore the **wave B will produce a louder sound than A.**

$\dfrac{\text{Loudness of B}}{\text{Loudness of A}} = \left(\dfrac{14}{8}\right)^2 = \dfrac{49}{16} = $ **nearly 3 : 1**

(b) The two wave forms are same so they have the **same** quality.

2. A certain sound has a frequency of 256 hertz and a wavelength of 1·3 m.
(a) Calculate the speed of sound.
(b) What difference would be felt by a listener between the above sound and another sound travelling at the same speed, but of wavelength 2·6 m ?

(a) For first sound, $f = 256$ Hz, $\quad \lambda = 1{\cdot}3$ m

$\therefore$ Speed $V = f\lambda = 256 \times 1{\cdot}3 = $ **332·8 m s^{-1}**.

(b) For second sound, $V = 332{\cdot}8$ m s^{-1}, $\lambda = 2{\cdot}6$ m

$\therefore$ Frequency $f = \dfrac{V}{\lambda} = \dfrac{332{\cdot}8}{2{\cdot}6} = 128$ Hz

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The frequency (*i.e.*, pitch) of the first sound is 256 Hz which is twice that of the second sound (which is 128 Hz). Hence to the listener, the first sound will **be shriller** than the second sound.

3. The ratio of amplitudes of two waves is 3 : 4. Find the ratio of their (i) loudness, and (ii) pitch.

Given : $a_1 : a_2 = 3 : 4$

(i) Since loudness ∝ (amplitude)^3 or $L \propto a^2$

$$\therefore \frac{L_1}{L_2} = \left(\frac{a_1}{a_2}\right)^2 = \left(\frac{3}{4}\right)^2 = \mathbf{9 : 16}$$

(ii) The pitch of a sound does not depend on its amplitude, so the ratio of pitch $f_1 : f_2$ = **1 : 1**.

EXERCISE–7(C)

1. Name *three* characteristics of a musical sound.

2. (a) Which of the following quantity determines the loudness of a sound wave ?
   (i) wavelength, (ii) frequency, and (iii) amplitude.
   (b) How is loudness related to the quantity mentioned above in part (a) ?
   Ans. (a) (iii) amplitude (b) loudness ∝ (amplitude)^2

3. If the amplitude of a wave is doubled, what will be the effect on its loudness ?
   Ans. loudness will become four times

4. Two waves of the same pitch have amplitudes in the ratio 1 : 3. What will be the ratio of their (i) loudness, and (ii) frequencies ? **Ans.** (i) 1 : 9 (ii) 1 : 1.

5. How does the wave pattern of a loud note differ from a soft note ? Draw a diagram.

6. Name the unit in which loudness of sound is measured. **Ans.** phon

7. Why is the loudness of the sound heard by a plucked wire increased when it is mounted on a sound board ?

8. Define the term intensity of a sound wave. State the unit in which it is measured.

9. How is loudness of sound related to the intensity of wave producing it ?

10. Comment on the statement 'loudness of sound is of subjective nature, while intensity is of objective nature.'

11. State *three* factors on which loundess of sound heard by a listener depends.

12. Name the unit used to measure the sound level.
    Ans. decibel

13. What is the safe limit of sound level in dB for our ears ? **Ans.** below 80 dB

14. What is meant by noise pollution ? Name *one* source of sound causing the noise pollution.

15. What determines the pitch of a sound ?

16. Name the subjective property of sound related to its frequency. **Ans.** pitch

17. Name and define the characteristic which enables one to distinguish two sounds of same loudness, but of different frequencies, given by the same instrument.

18. Draw a diagram to show the wave pattern of high pitch note and a low pitch note, but of the same loudness.

19. How is it possible to detect the filling of a bottle under a water tap by hearing the sound at a distance ?

20. The frequencies of notes given by flute, guitar and trumpet are respectively 400 Hz, 200 Hz and 500 Hz. Which one of these has the highest pitch ?
    Ans. Trumpet

21. Complete the following sentences :
    (a) The pitch of sound increases if its frequency ....
    (b) If the amplitude of a sound is halved, its loudness becomes ....
    Ans. (a) increases (b) one-fourth

22. The diagram below shows three different modes of vibration P, Q and R of the same string.

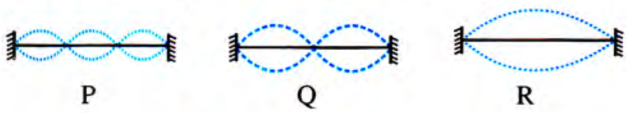

Fig. 7.24

   (a) Which vibration will produce a louder sound and why ?
   (b) Which vibration will produce sound of maximum shrillness (or pitch) and why ?
   (c) What is the ratio of wavelength of vibrations P and R ?
   Ans. (a) R, because its amplitude is maximum
   (b) P, because its frequency is maximum
   (c) $\lambda_P : \lambda_R = 1 : 3$

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23. Name the characteristic which enables one to distinguish the sound of two musical instruments even if they are of the same pitch and same loudness.
Ans. quality

24. How does the two sounds of same loudness and same pitch produced by different instruments differ ? Draw diagrams to illustrate your answer.

25. Two identical guitars are played by two persons to give notes of the same loudness and pitch. Will they differ in quality ? Give a reason for your answer.

26. Two musical notes of the same pitch and same loudness are played on two different instruments. Their wave patterns are shown in Fig. 7.25.

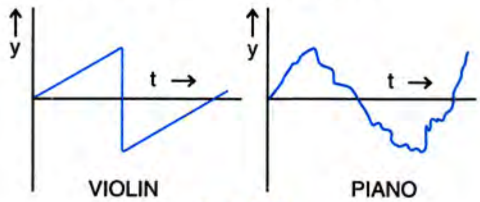


Fig. 7.25

Explain why are the wave patterns different.

27. Which characterstic of sound makes it possible to recognise a person by his voice without seeing him?

28. State the factor that determines
(i) the pitch of a note,
(ii) the loudness of the sound heard, and
(iii) the quality of the note.
Ans. (i) frequency (ii) amplitude (iii) wave form.

29. Name the characterstic of the sound affected due to a change in its (i) amplitude, (ii) wave form, and (iii) frequency.
Ans. (i) loudness (ii) quality (iii) pitch.

30. In what respect does the wave pattern of a noise and music differ ? Draw diagram to explain your answer.

31. The sketches I to IV in Fig. 7.26 show sound waves, all formed in the same time interval.

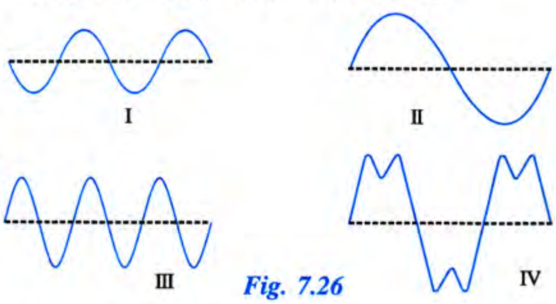


Fig. 7.26

Which diagram shows
(i) a note from a musical instrument,
(ii) a soft (or feeble) note,
(iii) a bass (or low frequency) note.
Ans. (i) IV (ii) I (iii) II

32. Fig. 7.27 shows the wave patterns of *three* sounds A, B and C. Name the characteristic of sound which is same between (i) A and B, (ii) B and C, and (iii) C and A.

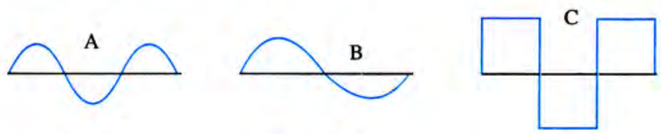
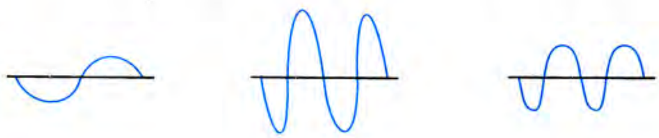


Fig. 7.27

Ans. (i) loudness and quality (ii) none (iii) pitch

33. A microphone is connected to the Y-input of a C.R.O. Three different sounds are made in turn in front of the microphone. Their traces (a), (b) and (c) produced on the screen are shown in Fig. 7.28.



(a) (b) (c)

Fig. 7.28

(i) Which trace is due to the loudest sound ? Give reason for your answer.
(ii) Which trace is due to the sound with the lowest pitch ? Explain your answer.
Ans. (i) b, since amplitude is largest
(ii) a, since frequency is lowest.

34. State *one* difference between a musical note and a noise.

MULTIPLE CHOICE TYPE

1. By reducing the amplitude of a sound wave, its :
(a) pitch increases (b) loudness decreases
(c) loudness increases (d) pitch decreases.
Ans. (b) loudness decreases

2. Two sounds of same loudness and same pitch produced by the two different instruments differ in their :
(a) amplitudes (b) frequencies
(c) wave forms (d) all the above.
Ans. (c) wave forms

3. Two sounds A and B are of same amplitudes, same wave forms but of frequencies f and $2f$ respectively. Then :
(a) B differ in quality from A
(b) B is grave, A is shrill
(c) B is shrill, A is grave
(d) B is louder than A.
Ans. (c) B is shrill, A is grave.

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