14. Show that in the case of progressive longitudinal waves
Particle velocity=Wave velocity × Compression. *(Panjab)*

15. Deduce the equation of a simple harmonic wave travelling in the positive x direction in the form

$$y = a \sin \frac{2\pi}{\lambda}(vt - x)$$

and explain how energy is distributed in such a progressive wave. *(Delhi)*

CHAPTER 5

Velocity of Sound

5.1. Origin of Sound

Sound is produced by a vibrating body. When the gong of a bell is struck with a hammer, sound is produced. The bell is set into vibration and sound is propagated through air. These vibrations reach the ear and the ear drum is set into vibration. These vibrations are communicated to the brain. By touching the gong with the hand, one can feel the vibration of the gong. Similarly the cycle bell produces sound due to the vibrations produced by the gong. When the cycle bell is touched with hand, the vibrations are stopped and the bell does not produce sound. If a pith ball pendulum is held in contact with the edges of a vibrating gong, the pith ball moves to and fro. This shows that the gong vibrates as long as the sound is produced.

A tuning fork is set into vibration by striking one of its prongs against a rubber pad. The vibration of the prongs of the tuning fork can be seen. Similarly, vibrating strings, air columns, vibrating plates etc. produce sound.

5.2. Material Medium is a Necessity

It can be proved by means of an experiment that a material medium is a necessity for the propagation of sound waves. In the absence of a medium, no sound waves can travel.

Experiment. Take a jar and fix a bell inside it as shown. The connecting wires pass through an air tight rubber cork fixed to the neck of the jar. The electric bell is connected to a battery and a key outside the jar (Fig. 5.1). The jar is placed on the platform of an air pump. Insert the key. The bell rings and the sound is heard. When the air in the jar is removed gradually, the sound becomes fainter although the same current is passing

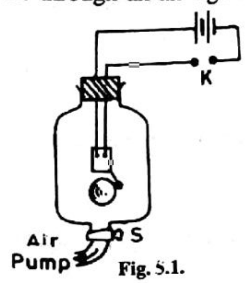


Fig. 5.1.

through the bell. After some time, when the pressure of air inside the jar is extremely low, only a very feeble sound is heard. It is not possible to create perfect vacuum with an air pump. In vacuum, no sound travels. Hence, material medium is a necessity for the propagation of sound waves.

5.3. Velocity of Longitudinal Waves in Gases

Consider a long tube of area of cross-section a. Let A and B be two cross-sections of the tube. Suppose, in the region of normal density, the medium moves from right to left along the length of the tube with a velocity U. The sound waves travel from left to right with a velocity U. In such a case, the

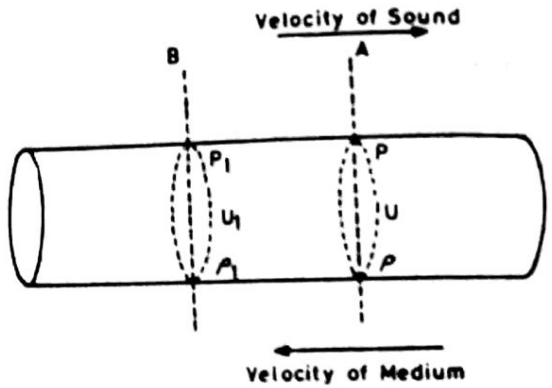


Fig. 5.2.

positions of the condensations and rarefactions in the tube with respect to the ground will remain fixed. For any small region, the pressure, velocity and density of the medium remain constant. The values of pressure, velocity and density of the medium will be different at different cross-sections of the tube.

Let A correspond to the region of normal density and B correspond to the region of condensation. At A, the pressure is P, density is ρ and velocity of the medium is U. At B, the pressure is P_1, density is ρ_1 and velocity of the medium is U_1.

As there is no change in the average density of the medium, the masses of the medium crossing the sections A and B in one second are equal.

Mass of the medium entering the cross-section at A in one second

$$= a \times U \times \rho$$

Mass of the medium leaving the cross-section at B in one second

$$= a \times U_1 \times \rho_1$$

$$m = a\,U\rho = aU_1\rho_1 \qquad \ldots (1)$$

If B is at a region of condensation, its density will be higher than the normal density ρ at A.

$$\therefore \qquad \rho_1 > \rho$$

and $$U_1 < U$$

The momentum per second of the medium entering at $A = mU$

The momentum per second of the medium leaving at $B = mU_1$

Change in momentum per second $= mU - mU_1$. This change in momentum per second is due to the difference in pressure $(P_1 - P)$ between A and B. Since the tube has an area of cross section a, the force applied,

$$F = (P_1 - P)\,a.$$

Also, according to Newton's second law of motion, rate of change of momentum is equal to the applied force.

$$\therefore \qquad (P_1 - P)\,a = mU - mU_1$$

$$(P_1 - P)\,a = m(U - U_1)$$

$$(P_1 - P)\,a = mU\left(1 - \frac{U_1}{U}\right) \qquad \ldots (1)$$

Substituting the value of $m = a\,U\rho$,

and $\dfrac{U_1}{U} = \dfrac{\rho}{\rho_1}$, from equation (1), we get

$$(P_1 - P)\,a = aU^2\rho\left(1 - \frac{\rho}{\rho_1}\right)$$

$$(P_1 - P)\,a = U^2\rho\left(\frac{\rho_1 - \rho}{\rho_1}\right)$$

$$\therefore \qquad U^2\rho = \frac{(P_1 - P)}{\left(\dfrac{\rho_1 - \rho}{\rho_1}\right)} \qquad \ldots (2)$$

The bulk modulus of elasticity of the medium,

$$E = \frac{(P_1 - P)}{\left(\dfrac{V - V_1}{V}\right)}$$

But $$V \propto \frac{1}{\rho}$$

$$\therefore \qquad \frac{V - V_1}{V} = \frac{\rho_1 - \rho}{\rho_1}$$

$$\therefore \qquad E = \frac{(P_1 - P)}{\left(\dfrac{\rho_1 - \rho}{\rho_1}\right)} \qquad \ldots (3)$$

From equations (2) and (3)

$$U^2 \rho = E$$

$$U^2 = \frac{E}{\rho}$$

or

$$U = \sqrt{\frac{E}{\rho}}$$

The formula is true only in the case of *plane waves* where the original disturbance is of very small amplitude. This requirement is fulfilled by sound waves of ordinary intensity. The relation also holds good for the velocity of simple harmonic plane waves through homogeneous isotropic media *viz.*, solids, liquids and gases.

This relation is also applicable to torsional waves in solids and transverse vibrations in strings. However, in the case of transverse vibrations of bars and plates, the formula needs modification.

5.4. Newton's Formula for Velocity of Sound

The velocity of sound in a medium—solid, liquid or gas, depends on the elasticity and density of the medium.

$$U = \sqrt{\frac{E}{\rho}}$$

where U is the velocity of sound in the medium, E the elasticity and ρ the density of the medium.

Newton also found that the elasticity of air is equal to its pressure. He assumed that the temperature of air remains constant when sound waves travel through air. The process is isothermal and Boyle's law can be applied. At the point of condensation, pressure increases and volume decreases.

Suppose, initial pressure $= P$
Initial volume $= V$
Increase in pressure $= p$
Decrease in volume $= v$
Final pressure $= (P + p)$
Final volume $= (V - v)$

$$\therefore \quad (P+p)(V-v) = PV$$

$$PV + pV - Pv - pv = PV$$

(pv is negligibly small)

$$pV = Pv \text{ or } P = \frac{pV}{v} \qquad \ldots (1)$$

From the definition of elasticity of the medium

$$E = \frac{\text{Change in pressure}}{\frac{\text{Change in volume}}{\text{Original volume}}}$$

$$E = \frac{P}{\frac{v}{V}} = \frac{pV}{v} \qquad \ldots (2)$$

Equating (1) and (2)

$$E = P$$

$\therefore$ Substituting $E = P$ in the original formula

$$U = \sqrt{\frac{P}{\rho}} \qquad \ldots (3)$$

Taking normal pressure $P = 0{\cdot}76$ m of Hg

$$= 0{\cdot}76 \times 136 \times 10^3 \times 9{\cdot}81 \text{ N/m}^2$$

and density of air at NTP $= 1 \cdot 293$ kg/m^3

$$U = \sqrt{\frac{0{\cdot}76 \times 13{\cdot}6 \times 10^3 \times 9{\cdot}81}{1{\cdot}293}} \text{ cm/s } 280 \text{ m/s}$$

The experimental value determined from various experiments gives the velocity of sound at NTP

$$= 332 \text{ m/s.}$$

Therefore, there is a difference of about 52 m/s between the theoretical and the experimental values. The large difference cannot be attributed to the experimental errors. Newton was unable to explain the error in his formula and the correction was explained by a French scientist Laplace.

Laplace correction. According to Laplace, when sound waves travel through air, there is condensation and rarefaction in the particles of the medium. Where there is condensation, particles come near each other and are heated up. Where there is rarefaction, particles go apart and there is fall in temperature. Therefore, the temperature does not remain constant when sound waves travel through air or any other gas. The process is not isothermal but it is adiabatic. The total quantity of heat of the system as a whole remains constant. It neither gains nor loses any heat to the outside. During an adiabatic process

$$PV^\gamma = \text{constant}$$

Suppose, initial pressure $= P$
Initial volume $= V$
Change in pressure $= p$
Change in volume $= v$

$$PV^\gamma = (P+p)(V-v)^\gamma$$

Noise. The sound that produces jarring effect or displeasing effect on the ear is called a noise. The noise succeeds at irregular intervals and there is sudden change in loudness. The sounds produced by the gun and by a plate falling on the ground are examples of noise [Fig. 7.13 (*b*)].

Technically noise is defined as the result of the combination of single frequency sounds or pure tones. Noise has a continuous frequency spectrum but possesses irregular amplitude and waveform. Airborne noise is mainly due to the variations in air pressure with respect to the mean atmospheric pressure. Structural-borne noise is due to mechanical vibrations in elastic bodies. Liquid-borne noise is caused by changes in liquid pressure about the mean static pressure.

Noise in general disturbs the normal work, sleep or recreation of human beings. Sometimes it also produces strain, irritation and headache. Noise of high intensity has an adverse cumulative effect on the human ear. Noise of high intensity may produce temporary or permanent deafness. Psychologically speaking, noise affects in an adverse way the output of workers and will decrease their efficiency. Persons working in noisy surroundings are liable to make errors.

7.17. Speech

The speech basically refers to the structure of language and its main characteristics are loudness, pitch, timbre and interpretive aspect. If a speech is well recognized and understood it is said to be intelligible. Speech sounds are complex audible acoustic waves which provide the listners with a number of clues for understanding.

An intelligible speech depends upon the acoustic power delivered during the speech, the characteristics of speech, sensitiveness to hearing and noises in the surroundings.

7.18. Human Voice

The human voice is a natural source of sound. Human voice has four main parts :

(1) **Power generator.** This comprises of diaphragm, lungs, bronchi, trachea and muscles.

(2) **Vibrator.** It is called larynx.

(3) **Resonators.** The acoustic resonators in the human system are nose, mouth, throat, other empty spaces in the mouth and sounding board *e.g.*, head, chest etc.

(4) **Articulators.** These are lips, tongue, teeth etc.

The loudness of sound in a human voice primarily depends upon the stream of air forced through the vocal cords from the lungs. The frequency of the human voice is dependent upon the elasticity and vibrations of the vocal cords. The quality of sound depends on the resonators.

7.19. Human Ear

Human ear is a natural sound receiver. The human voice and the human ear together form a fundamental and natural sound system.

The hearing mechanism is a highly sensitive electro-acoustic transducer. The human ear responds to sound waves of a wide range of frequencies, wave forms and intensity. It communicates acoustic pressure variation of the ear drum into pulses in the auditory nerve system. These pulses are communicated to the brain which in turn indentifies and interprets these pulses. The brain converts these pulses into aural sensations *viz.*, perception of sound.

The human ear responds to frequencies in the range 20 to 20,000 hertz. The range of sound intensity over which the ear is sensitive is 1 watt/ m^2 to 10^{-12} watt/m^2. The human ear is more sensitive to variations in frequencies as compared to variations in sound intensities. The human ear is comparatively more sensitive to sound of low intensity.

7.20. Characteristics of Musical Sound

There are three characteristics of musical sounds : (1) loudness or intensity, (2) pitch and (3) quality or timbre.

1. **Loudness or Intensity**. The amount of sound energy crossing per unit area around a point in one second is known as intensity of sound. Loudness depends upon intensity and also upon the sensitiveness of the ear. Loudness and intensity are related to each other by the relation

$$L \propto \log I$$

where L represents the sensations of loudness and I, the intensity of sound.

Loudness or intensity depends upon the following factors :

(*i*) **Amplitude.** Loudness is directly proportional to the square of the amplitude of the sounding body. The amplitude of sound produced by men is large and hence loud sound is produced. The amplitude of sound produced by ladies or children is small, therefore, the sound produced is feeble. Mosquito also produces a wave of small amplitude, therefore, the sound produced by a mosquito is also feeble.

(*ii*) **Surface area.** Loudness is directly proporional to the surface area of the sounding body. A tuning fork of large size produces a loud sound as compared to a tuning fork of small size. Beating drums with large surfaces produce a loud sound as compared to the beating drums with small surface area. A tuning fork ordinarily produces a feeble sound. When its stem is pressed against a table, a loud sound is produced. The particles of the table are forced to vibrate with the frequencty of the tuning fork and the apparent surface area increases, hence a loud sound is produced.

(*iii*) **Distance between the source and the listener.** The intensity of sound is inversely proportional to the square of the distance between the source and the listener, provided the source produces sound waves in all directions. Therefore, the sound becomes feeble and feeble with increase in distance between the listener and the source.

(*iv*) **Density of the medium**. The greater the density of the medium, the louder is the sound. When the density of the medium is decreased, the sound becomes feeble.

(*v*) **Motion of air.** If air is blowing in the direction of propagation of the sound waves, loudness increases. If air is blowing in a direction opposite to the direction of propagation of the sound waves, loudness decreases.

2. **Pitch.** It is a sensation that depends upon the frequency. A shrill sound is produced by a source of high frequency whereas the pitch is lower if the frequency is lower. Pitch does not depend upon loudness or quality. The voice produced by ladies and children has high pitch because the frequency is high. The voice of an old man has low pitch and is hoarse because the frequency of sound is low. The frequency of the sound produced by a mosquito is of high pitch due to high frequency. The pitch of sound changes due to Droppler's Principle when either the source or the observer or both are in motion.

3. **Quality or Timbre.** It depends on the presence of overtones. The quality of sound enables us to distinguish between two sounds having the same loudness and pitch. A sounding body produces waves of frequency $2n$, $3n$, $4n$ etc. where n is the fundamental frequency. Nature has provided different overtones in the voice of different persons. Due to the quality of sound, one can recognise his friend from his voice without seeing him.

Suppose a person is calling you. The loudness and pitch will tell us whether it is a voice from a man, a lady or a child. The quality will further help us, to find the particular person producing the sound, man, woman or child. That is why quality plays a very important part. Otherwise, voices produced by all men would have been similar.

The roaring of a lion has high amplitude but low frequency. Therefore, the roaring of a lion can be heard even at far away places, but it is not a shrill sound.

The humming of a mosquito or a bee has low amplitude but *high frequency*. The sound is not heard when the mosquito is even a few metres away from the ear but it is a shrill sound.

7.21. Intensity of Sound

The intensity of sound is defined as the average rate of transfer of energy per unit area, the area being perpendicular to the direction of propagation of sound. Determination of the intensity of sound is important in practical acoustics.

Amount of energy transfer per unit area per second

$$I = 2\pi^2 \rho n^2 a^2 v \qquad \ldots (1)$$

Velocity of sound,

$$v = \sqrt{\frac{E}{\rho}} \quad \text{and} \quad E = -\frac{p}{dV/V}$$

dV is the change in volume, V the original volume and p is the excess of pressure

$$v = \sqrt{\frac{-p}{\left(\frac{dV}{V}\right)\rho}}$$

Taking $\frac{dV}{V} = \frac{dy}{dx}$ and simplifying

$$p = -v^2 \rho \frac{dy}{dx} \qquad \ldots (2)$$

A simple harmonic wave is represented by the equation

$$y = a \sin \frac{2\pi}{\lambda}(vt - x)$$

$$\frac{dy}{dx} = -\frac{2\pi a}{\lambda} \cos \frac{2\pi}{\lambda}(vt - x)$$

Substituting this value of $\frac{dy}{dx}$ in equation (2)

$$p = \frac{2\pi a v^2 \rho}{\lambda} \cos \frac{2\pi}{\lambda}(vt - x) \qquad \ldots (3)$$

The maximum excess of pressure

$$p_{max} = \frac{2\pi a v^2 \rho}{\lambda} \qquad \ldots (4)$$

and

$$p = p_{max} \cos \frac{2\pi}{\lambda}(vt - x) \ldots (5)$$

$\therefore$

$$p_{max} = 2\pi a \rho v \left(\frac{v}{\lambda}\right)$$

$$p_{max} = 2\pi a \rho v n \qquad \ldots (6)$$

From equations (1) and (6)

$$I = 2\pi^2 \rho n^2 a^2 v$$

$$I = \frac{(2\pi \alpha \rho vn)^2}{2\rho v}$$

$$I = \frac{p_{max}^2}{2\rho v} \qquad \ldots (7)$$

Equation (7) shows that the intensity of sound varies directly as the square of the excess of pressure. Therefore, in acoustics it is important to measure the excess of pressure to obtain the value of intensity of sound. For ordinary conversation $p_{max} = 0{\cdot}1$ newton/m^2.

In the case of ordinary conversation, the sound output per square metre is $1{\cdot}13 \times 10^{-5}$ watt. Human ear is an extremely sensitive organ and can detect sound intensity lower than this value. It has been found that the ear can detect intensities as low as 10^{-12} watt/m^2.

7.22. Measurement of Intensity of Sound—Decibel and Phon

The intensity of sound is defined as the quantity of energy propagating through a unit area per unit time, the direction of propagation being perpendicular to the area. The unit of intensity in the CGS system is ergs/cm^2-s. and in SI system it is joules/m^2-s. The amount of power transmitted per unit area is measured in watts/m^2. A convenient unit is micro-watts/m^2.

The loudness of sound is just an aural sensation and it is a physiological phenomenon rather than a physical phenomenon. The intensity of sound refers to the external or the objective measurement and the loudness refers to the internal or subjective aspect. Intensity of sound is a definite physical quantity and loudness is merely a degree of sensation. Loudness of sound increases with the intensity of sound according to Weber-Fecher law in physiology. According to this law, the loudness produced is proportional to the logarithm of intensity. This law does not hold good near the lower and the upper limits of audibility. According to this law,

$$S \propto \log I$$

or

$$S = K \log I$$

where K is a constant

or

$$\frac{dS}{dI} = \frac{K}{I}$$

The quantity dS/dI is called the sensitiveness of the ear. The sensitiveness of the ear decreases with increase in the intensity of sound.

In the case of all practical measurements, it is the relative intensity that is important and not the absolute value. Hence the intensity of sound is often measured as its ratio to a standard intensity I_0. The intensity level is equal to $\frac{I}{I_0}$

The standard intensity taken is 0·01 watt/m^2.

Suppose a person speaks in a normal conversational tone, he emits energy at the rate 10^{-5} joule/s. The mouth aperture is about 10^{-3} m^2 while speaking. If he speaks into a short tube the whole of the sound energy spreads along the length of the tube and the intensity of sound is 10^{-2} watt/ m^2. This value of sound intensity is the standard intensity I_0. The person hearing at the other end of the tube gets the feeling of standard intensity. If a person shouts into the tube as loud as he can, the intensity will be 100 I_0. When the intensity is 100 I_0; upto 1000 I the listener feels pain.

The faintest sound that can be heard depends also upon the frequency of the note. The average person's threshold of audibility is about 10^{-10} I_0 for a frequency of 400 hertz. Thus the range of hearing for a human ear is from 10^{-10} I_0 upto 100 I_0. Hence the human ear has a dynamic range of 10^{12} in intensity.

7.23. Bel

Whenever the intensity of sound increases by a factor of 10, the increase in intensity is said to be 1 bel. Therefore, the dynamic range of audibility of the human ear is 12 **bels** or 120 decibels. When the intensity increases by a factor $10^{0 \cdot 1}$, the increase in intensity is 0·1 bel or 1 decibel.

Suppose the loudness is S for intensity I and S_0 for intensity I_0

$$\therefore \quad S = K \log_{10} I \qquad \ldots (1)$$

$$S_0 = K \log_{10} I_0 \qquad \ldots (2)$$

The intensity level L is the difference in loudness.

$$L = S - S_0$$

$$L = K \log_{10} I - K \log_{10} I_0$$

$$L = K \log_{10}\left(\frac{I}{I_0}\right)$$

When the value of $K = 1$,

$$L = \log_{10}\left(\frac{I}{I_0}\right)$$

Here the unit of L is bel

If L is measured in decibels,

$$L = 10 \log_{10}\left(\frac{I}{I_0}\right) \text{ decibels}$$

Suppose the intensity level changes by 1 decibel, then

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

or

$$\frac{I}{I_0} = 1{\cdot}26$$

It means that the intensity level alters by 1 decibel when the intensity of sound changes by 26%.

The lowest change in intensity level that can be detected by the human ear is 1 decibel.

Example 7.28. *Calculate the change in intensity level when the intensity of sound increases 100 times its original intensity.*

Here, Initial intensity $= I_0$

Final intensity $= I$

$$\frac{I}{I_0} = 100$$

Increase in intensity level $= L$

$$L = 10 \log_{10}\left(\frac{I}{I_0}\right)$$

$$L = 10 \log_{10} 100 = \mathbf{20\ decibels.}$$

Example 7.29. *Calculate change in intensity level when the intensity of sound increases by 10^6 times its original intensity.*

Here Initial intensity $= I_0$

Final intensity $= I$

$$\frac{I}{I_0} = 10^6$$

Increase in intensity level, $L = 10 \log_{10}\left(\frac{I}{I_0}\right)$

$$L = 10 \log_{10} (10^6)$$

$$L = \mathbf{60\ decibels.}$$

TABLE 7.1
Intensity Levels of Different Sounds

Source of Sound.	*Intensity Level in decibels*
Threshold of hearing	0
Rustle of leaves	10
Whisper	15—20
Normal conversation	60—65
Heavy traffic	70—80
Roaring of a lion (at a distance of 6 m)	90
Thunder	100—110
Painful Sounds	130 and above

7.24. Phon

The intensity levels given in the above table refer to the loudness in decibels with the assumption that the threshold of audibility is the same, irrespective of the pitch of the sound. However, the sensitivity of the ear and the threshold of audibility vary over wide ranges of frequency and intensity. Hence the intensity level will be different at different frequencies even for the same value of I_0. For measuring the intensity level, a different unit called the *phon* is used. The measure of loudness in phons of any sound is equal to the intensity level in decibels of an equally loud pure tone of frequency 1000 hertz. Thus, the phon scale and the decibel scale agree for a frequency of 1000 hertz but the two values differ at other frequencies.

Suppose the intensity level of a note of frequency 480 hertz is to be determined. A standard source of frequency 1000 hertz is sounded and the intensity of the standard source is adjusted so that it is equal to the loudness of the given note of frequency 480. The intensity level of the standard source in decibels is numerically equal to the loudness of the given source in phons.

Suppose a note of frequency 3000 hertz and intensity level 70 decibels gives the same loudness as a standard source of frequency 1000 hertz at intensity level 67 decibels. The intensity level of the note of frequency 3000 hertz is *67 phons.*

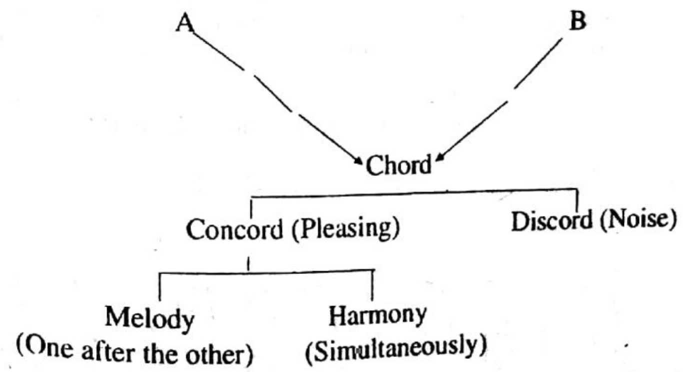
7.25. Musical Scale

Chord. When two or more notes are sounded together, the combined note produced is called chord. If the combined note produces a pleasing effect on the ear, it is called *concord.* If the combined note produces a displeasing effect on the ear, it is called *discord.*

Harmony. When two or more notes are sounded simultaneously, the combined note, producing a pleasing effect on the ear, is called *harmony.*

In English music, where a number of instruments play simultaneously, harmony is produced.

Melody. When two or more notes are sounded one after the other, the combined note producing pleasing effect on the ear, is called melody. In Indian folk music, melody is produced.



Interval. The ratio between the frequencies of two notes is called a musical interval. It is equal to 1 or more than 1. It is never less than 1.

Unison. Here the musical interval = 1

$$\frac{N_2}{N_1} = 1 \quad \text{or} \quad N_2 = N_1$$

The two notes are said to be in unison, when their frequencies are equal.

Octave. Here the musical interval = 2

$$\frac{N_2}{N_1} = 2 \quad \text{or} \quad N_2 = 2N_1$$

Here N_2 is the octave of N_1

Major tone. Here the musical interval $= \frac{9}{8}$

Minor tone. Here the musical interval $= \frac{10}{9}$

Semi tone. Here the musical interval $= \frac{16}{15}$

Fifth tone. Here the musical interval $= \frac{3}{2}$.

Diatonic musical scale. This scale has eight keys and seven intervals (Fig. 7.14).

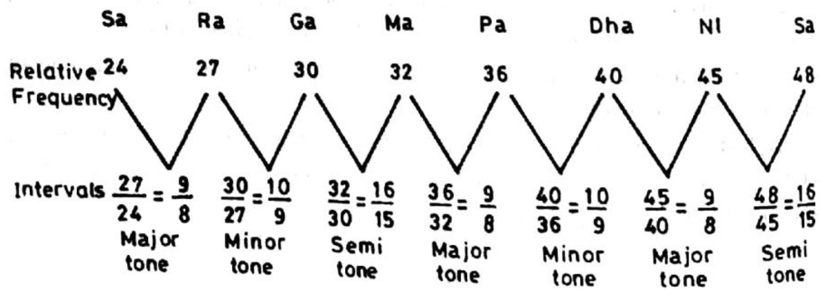


Fig. 7.14.

In an *equally tempered scale*, there ar thirteen keys and 12 intervals (Fig. 7.15). The intervals are equal and each interval $= 2^{\frac{1}{12}}$

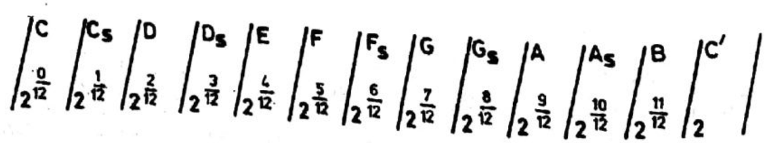


Fig. 7.15.

In this scale five notes have been introduced. They are C_s, D_s, F_s, G_s and A_s. The main advantage of this scale is that the interval is the same between the consecutive notes and a singer can conveniently use any key as his fundamental.

Suppose

$$C = 256$$

$$D = 256 \times \frac{9}{8} = 288$$

$$E = 288 \times \frac{10}{9} = 320$$

$$F = 320 \times \frac{16}{15} = \frac{1024}{3} = 341.33$$

$$G = \frac{1024}{3} \times \frac{9}{8} = 384$$

$$A = 384 \times \frac{10}{9} = \frac{1280}{3} = 426{\cdot}66$$

$$B = \frac{1280}{3} \times \frac{9}{8} = 480$$

$$C' = 480 \times \frac{16}{15} = 512.$$

Example 7.30. *The frequency of the key note $C = 512$. Find the frequency of the note G.*

$$C = 512$$

$$G = 512 \times \frac{36}{24} = 768 \quad (\text{Because if } C = 24, G = 36).$$

7.26. Limits of Audibility

The limits of audibility of sound depend upon the *intensity* and *frequency* of sound. In order that a sound is audible, it must have a certain minimum intensity and a certain minimum frequency. The minimum intensity of sound necessary for the sound to be audible, is called *threshold intensity* of audibility. The minimum audible frequency is called *lower pitch limit* of audibility.

There is also a maximum intensity limit, beyond which the sound produces a sensation of pain on the ear. Similarly, there is a maximum frequency limit, beyond which the sound is not audible. The maximum audible intensity limit is called the threshold intensity of feeling. The maximum audible frequency limit is called upper pitch limit of audibility. The minimum audible intensity and the maximum audible intensity vary with the frequency of sound.

The limits of audibility can be understood with the help of an audiogram drawn by Wegel (Fig. 7.16). In an audiogram, the frequency is plotted along the x-axis on a logarithmic scale and the intensity (pressure in newton/m^2) is

$$n = \frac{150}{60} = 2{\cdot}5 \text{ rotations/s}$$

Frequency of the tuning fork,

$$N = nm$$

$$N = 2{\cdot}5 \times 120$$

$$N = \mathbf{300\ hertz.}$$

10.5. Determination of Frequency of a Tuning Fork by Phonic Motor Method

In Fig. 10.5, F is an electrically maintained tuning fork whose frequency is to be determined. N is a soft iron toothed wheel that can rotate about a horizontal axis. M_1 and M_2 are two electromagnets having their axes passing through the centre of the wheel. The electrical arrangement is shown in Fig. 10.5.

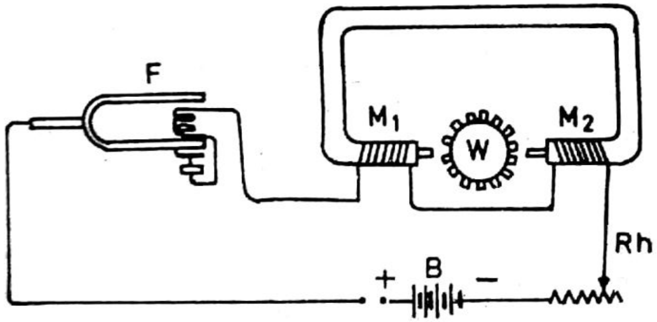


Fig. 10.5.

The tuning fork F is set into vibration. Initially the wheel W is rotated by hand. When only two diametrically opposite teeth of the wheel just pass the electromagnets at the instant of excitation, the teeth get impluses and move forward. The rotor will just advance through one tooth during one full vibration of the fork. The wheel will get an impluse during each excitation and will continue to rotate. The speed of rotation will depend on the frequency of the tuning fork. If the wheel is moving faster, the force of attraction between the tooth and the magnet, retards its motion. If the wheel is moving slower, the force of attraction accelerates it.

Suppose the wheel makes n rotations in one second and the number of teeth on the wheel is m.

Number of impluses received per second = $m \times n$.

If the frequency of the tuning fork is N, then

$$N = \mathbf{m} \times \mathbf{n}$$

The speed of rotation of the wheel is determined by a mechanically geared counter. Knowing m and n the value of N can be calculated.

10.6. Gramophone

It consists of a turn table which is rotated with a clock work mechanism at a constant speed. It is provided with a sound box. The record is placed on the turn table and the needle of the sound box moves over the spiral groove. This groove has a wavy structure correponding to the original sound recorded on it.

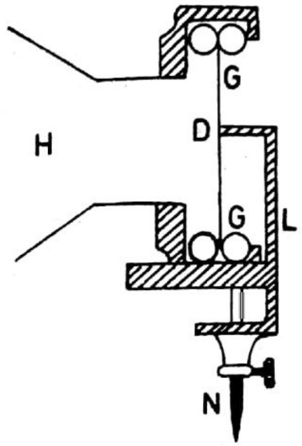


Fig. 10.6.

Sound box. It consists of a diaphragm D and a horn H (Fig. 10.6). The diaphragm is held in position with the help of the rubber gaskets G, G. A lever L is fixed to the middle of the diaphragm. The lever is attached to the needle N. The needle N vibrates and these vibrations are magnfied with a lever system and the diaphragm vibrates accordingly. These vibrations of the diaphragm produce sound.

Recording. To prepare a gramophone record, a circular wax disc with a spiral groove on it is taken. The speaker speakes before the diaphragm and a sharp needle called a style vibrates along the path of the rotating wax record. A transverse wave is formed.

To prepare a large number of records, this wax disc is coated with graphite and electroplated uniformly with copper. The wax coating is removed by gently heating it. The copper disc remains with the grooves projecting outwards. This parent record is pressed against a plastic or shellac disc and the grooves are formed on it. These records prepared from the parent record are called sister records. Thus a large number of records can be obtained.

Sound reproduction. The record is kept on the turn table of the gramophone and the needle of the sound box is gently placed at the starting point of the groove, of the rotating record. When the needle moves along the groove, it vibrates and forces the diaphragm to vibrate accordingly. Thus, the original recorded sound is reproduced. In a modern sound box, a pick up arrangement is used.

10.7. Microphone and Loud Speaker

Telephones are used to send and receive messages through electrical signals between two stations. As the electrical signals can flow round a closed circuit, two line wires are required. At both the ends of the line, a mouthpiece and an ear piece are provided. The mouthpiece works on the principle of microphone and the ear piece works as a small loud speaker.

The microphone consists of a small ebonite box. Between the diaphragm D and the thin metal disc P, the space is filled with carbon granules [Fig. 10.7 (*a*)]. The lead wires are taken from P and D. When a person speaks before the microphone, the diaphragm D vibrates. Due to the vibration of the diaphragm, the pressure on the carbon granules continuously changes. Consequently the resistance offered by the carbon granules in the circuit changes. When they are closely packed, the resistance decreases and the current in the circuit increases. When they are loosely packed, the resistance increases and the current in the circuit decreases. Thus the sound energy is converted into changing electric current.

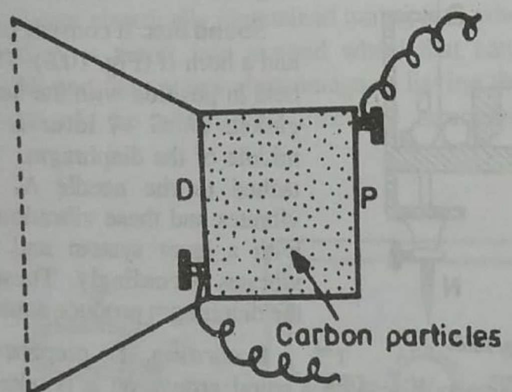


Fig. 10.7 (*a*)

The loudspeaker consists of a diaphragm D and an electromagnet [Fig. 10.7(*b*)]. When the changing current flows through the coil of the electromagnet, the magnetic flux changes. Due to the change in the magnetic flux, the diaphragm is set into vibration. Here electrical energy is converted into sound energy. The original sound is reproduced.

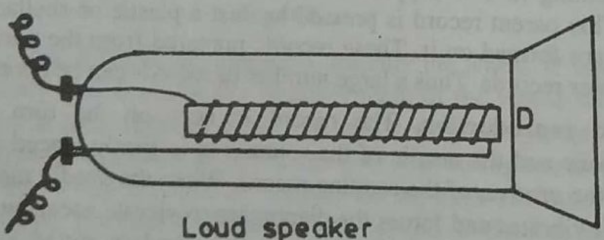


Fig. 10.7 (*b*)

10.8. Tape Recording

The most commonly used tape recorders are based on the principle of magnetism and are called magnetic tape recorders. Magnetic tapes of the form usually employed for tape recording and reproduction behave similar to an assembly of magnetic compass needles.

One side (dull side) of the tape is coated with a paste of ferric oxide (Fe_2O_3) containing needle shaped iron oxide crystals. These crystals can be imagined to be similar to magnetic compass needles. Each needle behaves as a tiny magnet (magnetic dipole) and has south and north polarity.

In an unrecorded tape, the needles point in such directions so that the resultant magnetic effect is zero. When this unrecorded tape is moved in front of an electromagnet, the magnetic needles are deflected and the magnitude of deflection depends upon the strength of the magnetic field. After this orientation, the needles no longer cancel their effect and the tape as a whole behaves as a magnet, magnetised to different extents at different positions of the tape. The specific property of these iron oxide crystals

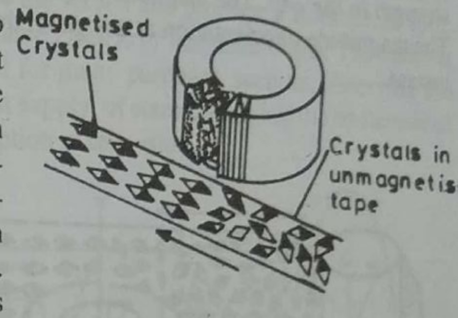


Fig. 10.8

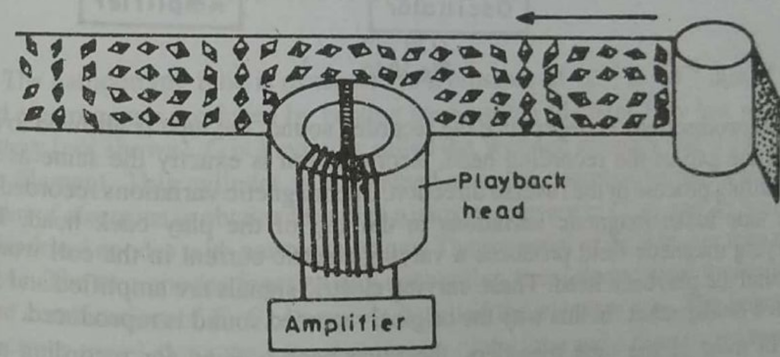


Fig. 10.9.

is that they can retain their oriented positions for a very long time. Once recorded, the tape can serve as a permanent record unless it is erased.

Recording. A magnetic tape has two sides. The dull side is coated with ferric oxide containing needle shaped crystals. The other side is shining. The tape is usually made of *cellulose acetate* or *poly vinyl chloride (PVC)*. The tape is thin so that maximum length can be wound on a reel. The material of the tape must have flexibility but it should not stretch. The stretching of the tape can distort the recording. Sometimes **Mylar**, a kind of terylene is also used for the manufacture of the tape.