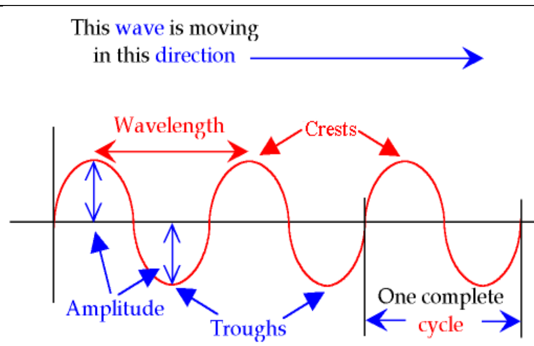
WAVE MOTION AND SOUND:

A wave is a periodic disturbance caused at a point in a medium. Particles vibrate about their mean positions [without leaving their positions] and energy is transferred with a constant speed from one place of the medium to the other. This is how a wave is propagated in the medium.

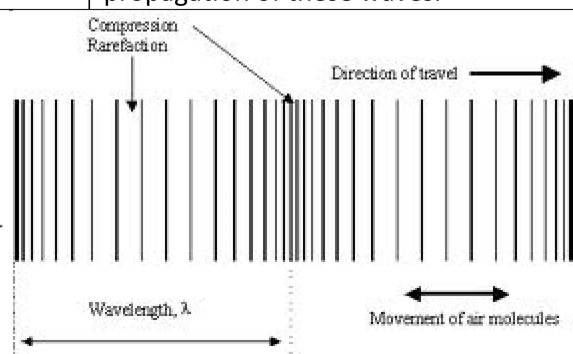
Waves are broadly classified into – 1. Mechanical waves and
2. Electro-magnetic waves.

Mechanical waves are those waves which require material medium for their propagation. They are further classified into – Transverse waves and Longitudinal waves.

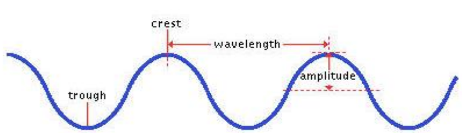
Transverse wave	Longitudinal wave
1. The particles of a medium vibrate in a direction perpendicular to the direction of propagation of the wave.	The particles of a medium vibrate about their mean positions, in the direction of motion of the wave.
2. A transverse wave propagates in the form of crests and troughs. A crest and a trough together forms one wave.	A longitudinal wave propagates in the form of compressions and rarefactions. A compression and a rarefaction together form one wave.
3. At the crest, the displacement of particle of the medium is positive and maximum, while at the trough, the displacement of the particle of the medium is negative and maximum	At the position of compression, the velocity of particles of the medium is positive and maximum, while at the rarefaction, the velocity of the particle of the medium is negative and maximum.
4. These waves can be produced only in solids and on the surface of the liquids. They cannot be produced inside a liquid or in a gas.	These waves can be produced in all the three media – solids, liquids and gases.
5. There is no variation in density and pressure in the medium due to propagation of these waves.	The density and pressure of medium become maximum at the position of compression and minimum at the positions of rarefaction due to the propagation of these waves.

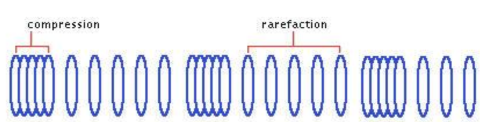


Transverse Wave

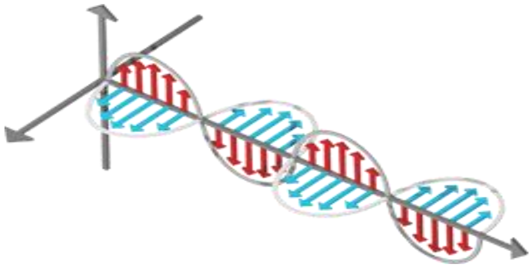


Longitudinal Wave





Electromagnetic waves:



Electromagnetic waves are formed by the vibrations of electric and magnetic fields. These fields are perpendicular to one another in the direction the wave is traveling. Once formed, this energy travels at the speed of light until further interaction with matter.

These waves do not require any material medium for their propagation. The electromagnetic radiations from sun such as visible light, UV rays, Infra red radiations, X-rays, gamma radiations, radio waves, Micro waves, …. are examples of electromagnetic waves.

Some important terms related to wave motion:

1. **Wave length:**
   It is the distance between any two consecutive crests or two consecutive troughs in transverse waves [highest points are crests and deepest point is trough]
   It is also defined as the distance between any two consecutive compressions or two consecutive rarefactions in longitudinal waves.
   SI unit of wavelength is meter [m]. Wavelength is denoted by the symbol **'λ'** [lambda].
2. **Amplitude:**
   It is the maximum displacement of a particle in a wave from its mean position.
3. **Time period:**
   It is the time taken by a particle to completely vibrate once about its mean position.
   It can also be defined as the time taken by a wave disturbance to propagate to a distance equal to the wavelength of the wave. It is denoted by 'T'.
   The SI unit of time period is second [s].

4. **Frequency:**
   It is defined as the number of vibrations of a particle in the medium about its mean position in unit time. It is the reciprocal of the time period. Its SI unit is 'Hertz' [Hz] or per second.

   Heinrich Hertz, a German physicist, applied Maxwell's theories to the production and reception of radio waves. The unit of frequency of a radio wave -- one cycle per second -- is named the hertz, in honor of Heinrich Hertz.

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

5. **Wave velocity:**

   It is the time rate at which a wave is propagated in the medium. It is denoted by 'V'. The SI unit of velocity is ms^{-1}.

$$\boxed{V = \frac{\lambda}{T}}$$

$$\textbf{Therefore, } \boxed{V = f\lambda}$$

Light waves	Sound waves
1. Electromagnetic waves i.e, can travel in vacuum.	**Mechanical waves i.e,. requires a material medium for propogation**
2. The speed of light waves in air is very high.	**The speed of sound waves in air is low**
3. The wavelength of light waves [visible] is very small, of the order of 10^{-6}	**The wavelength of sound waves is in the range of 0.01m to 100m**
4. Light waves are transverse in nature	**Sound waves are longitudinal**

SOUND AND PROPERTIES OF SOUND

Sound is produced by a vibrating body. All vibrating bodies do not produce sound [not in audible range]. The audible range for a normal human being is 20Hz to 20000 Hz.

Sound having less than 20Hz are called infrasonics.

Sounds having frequency more than 20,000 Hz are called ultrasonics.

Reflection of sound waves:

The returning back of sound wave on string a surface such as wall, metal shet, plywood etc., is called the reflection of sound. Sound waves get reflected from any surface whether smooth or hard. But the reflecting surface must be bigger than the wavelength of sound wave.

Echo:

"The sound heard after reflection from a distant obstacle after the original sound has ceased is called as an echo".

An echo is heard only if the distance between the source of sound and the rigid obstacle which is a reflector is such that the reflected sound reaches observer later than 0.1 second after the original sound is heard. This is because persistence of hearing of a normal human ear. The sensation of sound persists in our ear for $1/10^{th}$ of a second. If the reflected sound comes after the first sound has ceased, then we can clearly distinguish between the first sound and the second, second and third, etc.,.

If 'd' is the distance between the observer and the obstacle and 'V' is the velocity of sound in air, then the total distance travelled by the sound the strike the reflecting surface is,

2d = V x t $\qquad d = \frac{Vt}{2}$

If d=0.1s and $V=340ms^{-1}$, then d=17m.

Thus, to hear the echo distinctly, the reflecting surface in air should be at a minimum distance of 17 m from the listener.

Conditions for hearing echo distinctly:

1. The minimum distance in air between the source of sound and the reflector must be 17m. [when speed of sound is 340 ms^{-1}]
2. The size of the reflector must be large enough compared to the wavelength of sound wave.
3. The intensity of sound should be sufficient t so that the reflected sound reaching the ear is in audible range.

Reverberation:

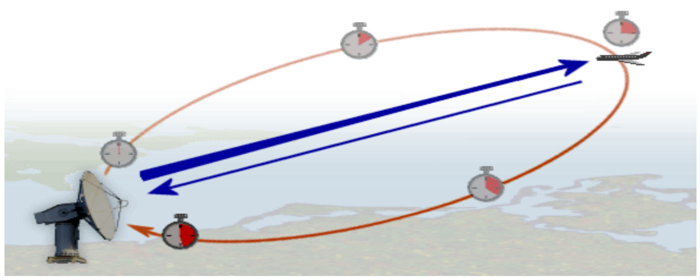
It is a phenomenon by which the sound gets prolonged due to repeated reflections at the reflecting surface.

If the echo is not heard, the original sound mixes up with the reflected sound and due to repeated reflections, the sound gets prolonged. This effect is known as reverberation.

APPLICATIONS OF ECHOES:

1. The phenomenon of echoes is used by bats and dolphins. Bats while flying produce ultrasonic waves. These waves are received by the ears of bat after they have been reflected by the object. The ears of the bats are very sensitive to find the distance of the obstacle and also the nature of reflecting surface. Same is the case with dolphins.
2. The phenomenon of echo is used by the fisherman to know the position of the fish in water. He sends a pulse of ultrasonic waves from a source into the sea and receives in the detector the waves reflected from the shoal of fish. The total time 't' for the onward and return journey is recorded. The position of fish is then calculated using the relation: $d = \frac{Vt}{2}$ where 'V' is the velocity of sound in water.
3. In SONAR [Sound Navigation and Ranging], ultrasonic waves are sent from the ship and they are received on their return after reflection from an obstacle. Its distance from the source can be calculated by measuring the time interval 't' between instant when the waves are produced and the instant when waves are received after reflection from it.
   The depth of sea can also be found by this method. This process is called as echo depth sounding.

4. In RADAR [Radio detection and ranging], the same method of reflection is used but instead of sound wave, electromagnetic waves such as micro waves or radio waves are sent into space which after reflection from the object, returns to the radar.



5. **Medical use of echoes:**
Ultrasonography is a technique in which the ultrasonic waves are used for taking the images of some of the important human organs like gall bladder, lever, womb, uterus etc.,. Using ultrasonic waves, a detailed photograph of human heart can also be taken. This is called echo cardiography.

VIBRATIONS, FREE OR NATURAL VIBRATIONS AND FORCED VIBRATIONS [RESONANCE]:

If a vibrating body is left to vibrate, it vibrates periodically and these vibrations are called free or natural vibrations.

The vibrations which take place under the influence of an external or periodic force are called forced vibrations.

Eg: 1. When a guitar or a veena is played, the artist forces the strings to vibrate and these in turn forces some vibrations on the air molecules in the sound box.

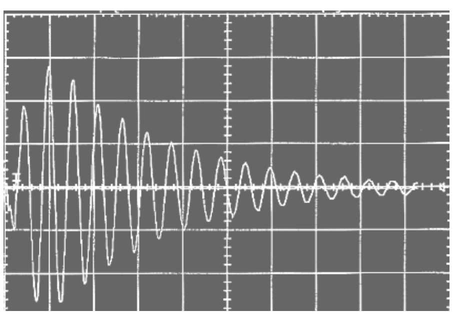
2. when a freely suspended pith ball is touched by a vibrating tuning fork, vibrations are forced on to the pith ball by the vibrating tuning fork.

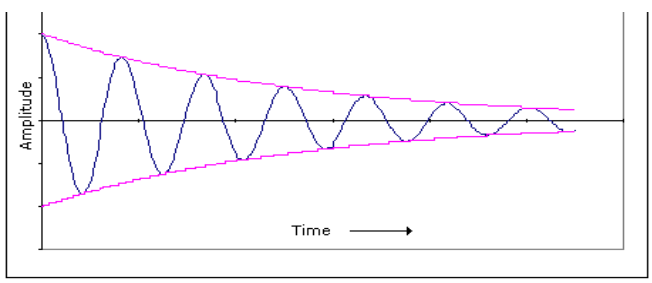
3. When the stem of a vibrating tuning fork is pressed against the top of a table, the tuning fork forces the table top to vibrate with its own frequency. The vibrations produced in the top of the table are forced vibrations. As the area of the table top is large, the sound produced would be louder.

Damped vibrations:

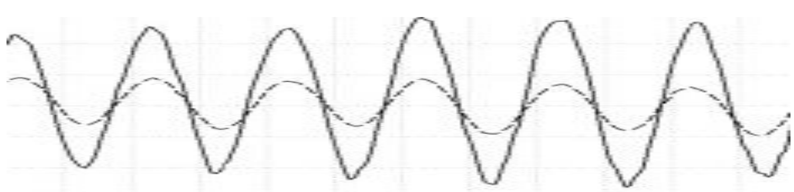
The periodic vibrations of a body of decreasing amplitude are called the damped vibrations.

Eg: When a tuning fork is made to vibrate, the vibrations are damped after some time. This is because of the friction with air molecules.





Forced Vibrations:



Free vibrations	Damped vibrations
1. The amplitude remain constant and continue for ever.	The amplitude of damped vibrations decreases with time and cease.
2. There is no loss of energy.	In each vibration, there is some loss of energy due to friction with the medium
3. No external force acts on the vibrating body.	The frictional or damping forces act to oppose the motion.
4. The frequency of vibrations remains constant equal to natural frequency	The frequency of vibrations is less than the natural frequency.

RESONANCE or Sympathetic vibrations:

When the frequency of externally applied periodic force on a body is equal to or is an integer multiple of the natural frequency of the vibrating body, it starts vibrating with an increased amplitude. This phenomenon is known as resonance. It is a special case of the forced vibrations.

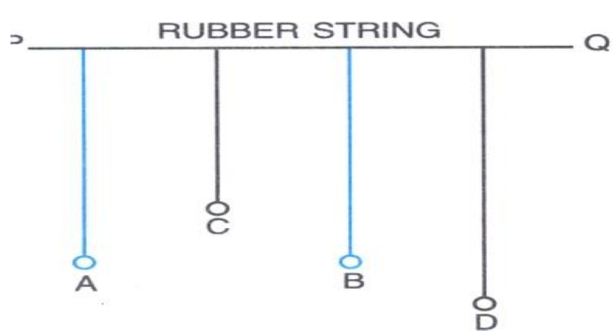
Condition of resonance to occur:

1. The frequency of the applied force is equal to the natural frequency of the vibrating body.
2. The applied force should be a periodic force.

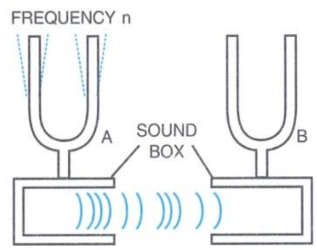
ILLUSTRATIONS OF RESONANCE:

1. To demonstrate free, forced and Resonance using a system of pendulums [Sympathetic pendulums] :

   Four pendulums A, B, C and D are suspended from and elastic support. Pendulums A and B are of same length, C is of a smaller length than that of A & B while D is longer than all the pendulums. When 'A' is set into oscillations, it is observed that 'B' also starts vibrating initially with a smaller amplitude and later acquires the same amplitude 'A' initially had. When the amplitude of 'B' becomes maximum, the amplitude of 'A' becomes minimum since the total energy is constant. After some time, the amplitude of 'B' decreases and that of 'A' increases. The change of energy takes place only between 'A' and 'B' as their natural frequencies are equal. Pendulums 'C' and 'D' also vibrate due to forced vibrations but with smaller amplitudes.



2. Two tuning forks of same frequency, are mounted on separate sounding boards, with their open ends facing each other.
   Fork A is set vibrating for a moment and stopped. Fork B is then found to be vibrating , and can be heard sounding in resonance although it was not struck.
   The vibrations emerging from Fork A is forced into fork B due to resonance as the natural frequency of both the tuning forks are equal and sets B into vibrations. The same occurs in the reverse case when fork B sets fork A into vibrations.



3. A train is not allowed to move on a long railway bridge with uniform speed. This is because, while moving at a constant speed, train applies a periodic force on the rails. If the frequency of this vibration becomes equal to the natural frequency of vibrations of the bridge, there is resonance and the bridge begins to vibrate with large amplitude and there is a danger of braking the bridge.
4. Soldiers in a troop are asked to break steps on a suspension bridge. This is because, while marching the soldiers apply a periodic force on the bridge. If the frequency of this forced vibration matches with the natural frequency of the bridge or becomes equal to the integer multiple of the natural frequency of the vibrating bridge, then the bridge begins to vibrate with greater amplitude due to resonance and the bridge may collapse.
5. When a motor vehicle is running and the accelerator is raised increasing the speed of rotation of the engine, the frequency of rotation increases. If this is done slowly and gradually, one notices that at a certain speed the rear view mirror or any other machinery part vibrates violently sometimes even producing noise. This is due to the phenomenon of resonance. The vibrations produced in the engine forces the vibrations into the machinery parts and if the frequency of the forced vibration is either equal to or the integer multiple of the natural frequency of the vibrating machinery part, it starts vibrating with greater amplitude due to resonance.
6. <u>Radio and TC reception:</u>
   Radio and Television waves are broadcasted in the form of communication waves from a ‘transmitter’ at a particular frequency ‘f’. The value of ‘f’ is adjusted by adjusting the value of electronic component of the electronic circuit in the transmitter. To receive these signals, a radio or TV set is provided with t tuner LC circuit. The natural frequency of this circuit can be adjusted by tuning. When the frequency of the receiver is equal to the frequency of the transmitter at the broadcasting station, the energy transfer takes place due to resonance and a good reception.

6. <u>Sound box of musical instruments and sonometer:</u>
   All musical instruments and sonometer are provided with a sound box. The box is hollow and has an air column inside it. When the string of the musical box is made to vibrate, the air

column also vibrates with it. At resonance a large sound is produced.

7. Resonance can cause disaster during earthquakes. If the natural frequency of a building becomes equal to the frequency of periodic oscillation generated in the earth, then the building will start oscillating with large amplitude leading to its collapse.

Characteristics of sound:

1. **Loudness:**

   It is the property by virtue of which a loud sound can be distinguished from a faint one, but both having the same pitch and quality.

   Louder sound corresponds to the wave of larger amplitude.

   Loudness of sound depends on amplitude or intensity of the wave.

   Loudness is not the same as intensity as intensity is a measurable quantity and loudness is a sensation.

   Intensity at any point in the medium is the amount of sound energy passing per second normally through unit area at that point.

   Loudness is a subjective quantity while intensity, being a measurable quantity, is an objective quantity for a sound wave.

$$\boxed{\mathbf{L = K \log I}}$$

   Where 'K' is a constant of proportionality and I is the intensity of sound.

   Factors affecting the loudness of sound:

   i). Loudness is directly proportional to the square of amplitude

   ii). Loudness is inversely proportional to the square of the distance.

   iii). Loudness is directly proportional to the surface area of the vibrating body.

   iv). Loudness is directly proportional to the density of the medium

   v). Loudness depends on the presence of resonant bodies.

   Units of loudness:

   The unit of loudness is phon. One phon is the loudness in decibel of an equally loud pure sound of frequency 1kHz.

   The level of loudness is usually expressed in decibel [dB]

   1 dB = 1/10th of a bel.

2. **Pitch:**

   It is that characteristic of a sound which distinguishes a shrill note from that of a flat note.

   Pitch refers only to musical sounds and each musical note has a definite pitch.

   Pitch of a note depends on its wavelength or frequency.

   Eg: a). Voice of women is usually of higher pitch than that of men.

   b). In musical instruments such as guitar or violin, the pitch is adjusted by adjusting the tension in the string.

   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 just hearing the sound from a distance, one can get a rough idea of water level in the bucket even without seeing it.

Pitch is not same as frequency. Pitch is subjective while frequency is objective.

3. **Quality of sound or timbre:**

It is the characteristic which distinguishes the two sounds of the same loudness and same pitch, but emitted by the two different instruments.

Eg: In a musical concert, when different instruments are played with the same pitch and same loudness, we can clearly distinguish the sound produced by a violin and the sound of a flute or a guitar.

Quality of sound depends on the wave form.

The vibration of lowest frequency and maximum amplitude is called the principal or fundamental note and vibrations of frequency integer multiples of it, are called the subsidiary or secondary vibrations.

The quality of a musical sound depends upon the number of the subsidiary notes and their relative amplitudes present along with the principal note.

Eg: the sound produced by a tuning fork is of a pure note or single frequency while the sound produced by on piano of the same frequency and same amplitude as that of the tuning fork has a complex wave form due to the presence of a mixture of subsidiary vibrations along with the principal vibrations.

Music	Noise
1. It is pleasant, smooth and gives a soothing sensation to the listener.	It is harsh, discordant and displeasing to the listener.
2. It is produced by the periodic vibrations	It is produced by irregular or non periodic vibrations.
3. There is no sudden changes in amplitude or loudness.	Very often, there are irregular and sudden changes in the amplitude or loudness.
4. The loudness is within the limits i.e., 30 dB	The sound level is very high sometimes above 120 dB.
5. the waveform is regular	Irregular waveform.