Wave Motion and Velocity of Waves

Wave motion

It is a disturbance which travels in a material medium through the repeated periodic motion of the particles of the medium about their mean position. The disturbance being handed over from one particle to the next, resulting in a phase difference between their motion through which energy and momentum is transferred.

Characteristics of a wave motion

The important characteristics of a wave motion are :

1. In wave motion, only the disturbance or energy spreads out from the source through the repeated periodic oscillation of the particles of medium about their mean position, without any bodily movement of the particles of the medium.
2. There is a definite phase difference between every two consecutive particles.
3. The velocity of wave motion is different from velocity of the particle. The wave moves ahead with a constant velocity in a homogeneous medium—whereas the particles vibrate about mean position simple harmonically.
4. For the propagation of mechanical wave, the medium must possess the properties of inertia, elasticity, uniform density and minimum friction amongst its particles.

Types of wave motion

Wave motion has two types :

1. Transverse wave motion
2. Longitudinal wave motion.

1. Transverse Wave Motion. In transverse wave motion, particles of the medium vibrate perpendicular to the direction of propagation of the wave (Fig).

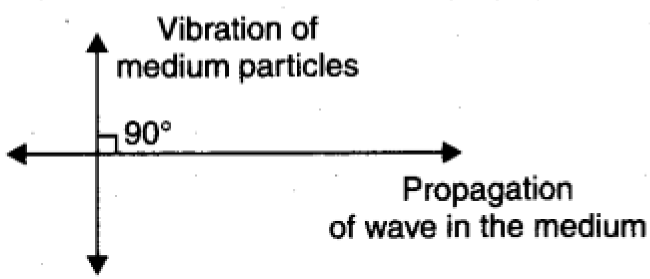

Fig. Transverse wave.

Examples: waves in strings, light waves, etc. Mechanical transverse waves are produced only in solids and on liquid surfaces.

2. Longitudinal Wave Motion. In longitudinal wave motion, particles of the medium vibrate along the direction of propagation of the wave (Fig).

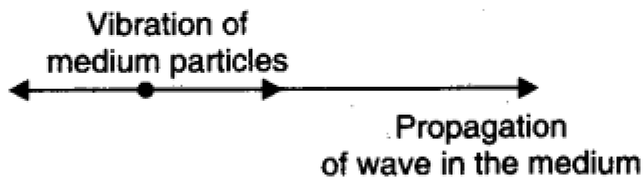

Fig. Longitudinal wave.

Examples : waves in springs, sound waves, etc.
Longitudinal wave are produced in solids, in liquids and also in gases.

Some useful terms and their difinitions

The following terms are commonly used in description of a wave motion :
Amplitude. The maximum displacement of a vibrating particle, on either side of its mean position, is called its amplitude.

Vibration. The motion of the vibrating particle from its mean position to one extreme, then to other extreme (through its mean position) and back to mean position, is called one vibration.
Time period (or period). The time taken by a particle to complete one vibration, is called its time period. It is represented by the symbol T.

Frequency. The number of vibrations made by a particle in a unit time (one second), is called its frequency. It is represented by the symbol v. (nu)
By definition, v = 1/T or vT = 1.

Phase. Phase of a vibrating particle at any instant is the state of the particle, as regards its position and direction of motion at that instant. It is represented in terms of angle or time.
Phase difference. Two vibrating particles, having different positions and directions of motion at same instant, are said to have a phase difference.

Crest. The region of maximum displacement on the positive side (upper side) of a transverse wave, is called crest. In Fig. C denotes the crest in a transverse wave.
Trough. The region of maximum displacement on the negative side (lower side) of a transverse wave, is called trough. In Fig, T denotes the trough in a transverse wave.

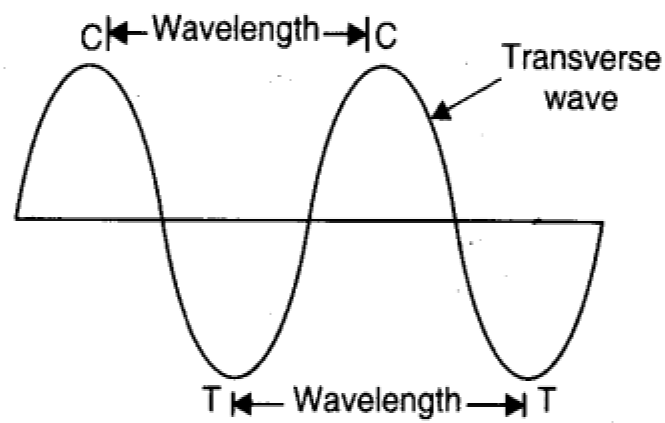

Fig. Crests and troughs in a transverse wave.

Compression. The region of maximum density of the medium in a longitudinal wave, is called a compression. In Fig, C denotes the compression in a longitudinal wave.
Rarefaction. The region of minimum density of medium in a longitudinal wave, is called rarefaction. In Fig, R denotes the rarefaction in a longitudinal wave.

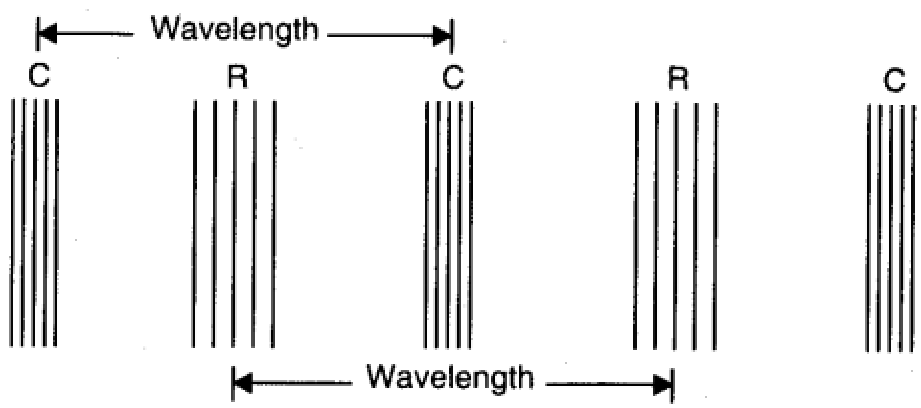

Fig. Compressions and rarefactions in a longitudinal wave.

Wavelength. The distance travelled by the disturbance during the time period of the vibrating particle, is called wavelength (length of the wave). It is denoted by the Greek symbol X.
The wavelength is also equal to the distance between two consecutive crests or troughs in a transverse wave (Fig) or between two consecutive compression's or rarefaction's in a longitudinal wave (Fig).
In general, wavelength is the distance between any two consecutive particles of the medium vibrating in the same phase.

Relation between frequency and wavelength of a wave

Wave frequency is the number of waves produced per second. It is equal to the

frequency of the particle (or the body) whose vibrations produce the waves.
If a vibrating body has time period T and frequency ν, then wave frequency also becomes ν. Let this body produce waves of length λ .

Since the wave travels distance λ in time T, its velocity υ is given by

$$\text{Velocity} = \frac{\text{Distance}}{\text{Time}}$$

or $$\upsilon = \frac{\lambda}{T} = \frac{1}{T} \cdot \lambda$$

or $$\upsilon = \nu\lambda \qquad \left(\because \frac{1}{T} = \nu\right)$$

i.e., **Wave velocity = Wave frequency × Wave length.**

Velocity of trasverse wave along elocity of transverse wave along a streched spring (derivation by method of dimensions)

Let a string having mass m per unit length (linear mass density) be stretched by a force of tension T. Let a transverse wave travel along the string with a velocity υ.

Hence, $$\upsilon = \sqrt{\frac{T}{m}}$$

It means that the velocity of a transverse wave travelling along a string of mass m per unit length, stretched by a tension T is given by

$$\boxed{\upsilon = \sqrt{\frac{T}{m}}}$$

T is measured in newtons (N), m in kg m^{-1} and υ in m s^{-1}.

Velocity of longitudinal waves through an elastic medium

Let an elastic medium have density ρ and elastic constant E. Let a longitudinal wave travel through it with a velocity υ.

Hence, $$\upsilon = \sqrt{\frac{E}{\rho}}$$

For air, $E = K =$ Bulk modulus
$P =$ Pressure

Then $$\upsilon = \sqrt{\frac{\gamma P}{g}}$$

where $$\gamma = \frac{C_p}{C_v}$$

E is measured in newton per metre^2 (N m^{-2}), ρ in kg per metre^3 (kg m^{-3}) and υ in m s^{-1}.

Variation of velocity of sound due to change in different factors

Variation of velocity due to change in temperature

The velocity of sound in air varies directly as the square root of the absolute temperature of air.

$$v_t \propto \sqrt{T}$$

The increase in velocity per degree rise in temperature is 0.61 m s^{-1}.

Variation of velocity due to change in pressure

The speed of sound does not change with change in pressure because

$$\frac{P}{\rho} = \text{constant}$$

Variation of velocity due to change in density of medium

We have, $$v = \sqrt{\frac{\gamma P}{\rho}}$$

For same pressure, $$v \propto \sqrt{\frac{1}{\rho}}$$

It means that the velocity of sound varies inversely as the square root of the density of the medium.

Since density of oxygen is 16 times the density of hydrogen, velocity of sound in oxygen is one-fourth of that in hydrogen.

Variation of velocity due to humidity of the medium

Density of water vapours (humidity) is 0.625 of the density of the dry air. Hence humidity decreases density of the air.

It is due to this reason that after calmness during rains, every sound heard appears loud due to increased velocity.

Variation of velocity due to wind

When sound waves travel in air, air molecules do not move (characteristic of wave motion). When wind blows, air molecules move. This produces variation in velocity of sound waves.

If wind has velocity w, velocity of sound waves in direction of wind becomes, $\upsilon + w$ and the same in opposite direction becomes $\upsilon - w$. (It is assumed that $w < \upsilon$).

Viva Voce

Question. 1. Define transverse wave motion.

Answer. In transverse wave motion, particles of the medium vibrate perpendicular to the direction of the propagation of the wave.

Question. 2. Give examples of transverse wave motion.
Answer. Examples are : waves produced in strings, light waves, waves on surface of water, E.M.W.

Question. 3. In which type of medium transverse waves are produced ?
Answer. Transverse waves are produced only in solids and on liquid surfaces.

Question. 4. Define longitudinal wave motion.
Answer. In longitudinal wave motion, particles of the medium vibrate along the direction of propagation of the wave.

Question. 5. Give examples of longitudinal wave motion.
Answer. Examples are : waves produced in springs, sound waves.

Question. 6. In which type of medium longitudinal waves are produced ?
Answer. Longitudinal waves are produced in solids, in liquids and also in gases.

Question. 7. Define amplitude.
Answer. The maximum displacement of a vibrating particle, on either side of its mean position, is called its amplitude.

Question. 8. Define vibration.
Answer. The motion of the vibrating particle from its mean position to one extreme, then to other extreme (through its mean position and back to mean position), is called one vibration.

Question. 9. Define time period (or period).
Answer. The time taken by a particle to complete one vibration, is called its time period. It is denoted by T.

Question. 10. Define frequency.
Answer. The number of vibrations made by a particle in a unit time (one second), is called its frequency. It is denoted by v.

Question. 11. Define phase.
Answer. Phase of a vibrating particle at any instant is the state of the particle, as regards its position and direction of motion at that instant.

Question. 12. How is the phase represented ?
Answer. The phase is represented in terms of angle or time.

Question. 13. How are phase angle and phase time related ?
Answer. A phase angle of 2n is equal to a phase time T.

Question. 14. What is phase difference ?
Answer. Two vibrating particles having different positions and directions of motion at same instant, are said to have a phase difference.

Question. 15. Define a crest.
Answer. The region of maximum displacement on the positive side of a transverse wave, is called crest.

Question. 16. Define a trough.
Answer. The region of maximum displacement on the negative side of a transverse wave, is called trough.

Question. 17. Define a compression or condensation.
Answer. The region of maximum density of the medium in a longitudinal wave, is called a compression or a condensation.

Question. 18. Define a rarefaction.
Answer. The region of minimum density of the medium in a Iongitudinal wave, is called rarefaction.

Question. 19. Define a wavelength.
Answer. The distance travelled by the disturbance dining the time period of the vibrating particle, is called wavelength (length of the wave). It is denoted by symbol X.

Question. 20.Give definition of wavelength.
Answer. The distance between two consecutive crests or troughs in a transverse wave or between two consecutive compression’s or rarefaction’s in a longitudinal wave, is also called a wavelength.
Or
The distance between any two consecutive particles of the medium in same vibrating phase, is also called a wavelength.

Question. 21. Define wave frequency.
Answer. The number of waves produced per second, is called wave frequency. It is equal to the frequency of the particle or the body, whose vibrations produce the waves.

Question. 22. Give relation between wave velocity, wave frequency and the wavelength.
Answer. The relation is,
Wave velocity = Wave frequency x Wavelength.

Question. 23.What was the reason for Newton's formula to be wrong ?
Answer. Newton's assumption for isothermal changes in the medium (air) was wrong. Actually changes are adiabatic.

Question. 24.What is an isothermal change ?
Answer. A change in pressure and volume of a gas at the same temperature, is called an isothermal change.

Question. 25.What are the conditions for a change to be isothermal ?
Answer. The change must be slow and in conducting surroundings.

Question. 26.What is an adiabatic change ?
Answer. A change in pressure and volume of a gas, without any heat exchange with surrounding, is called an adiabatic change.

Question. 27.What are the conditions for a change to be adiabatic ?
Answer. The changes must be quick and in non-conducting surroundings.

Question. 28.What mistake of Newton was pointed out by Laplace ?
Answer. Laplace pointed out the changes in medium are adiabatic and not isothermal as assumed by Newton.

Question. 29.How does velocity of sound vary with pressure of medium (air) ?
Answer. There is no variation of velocity of sound in air due to change in pressure of medium (air).

Question. 30.How does velocity of sound vary with density of medium (air) ?
Answer. Velocity of sound varies inversely as the square root of the density of the medium (air).

Question. 31.What is the ratio of velocity of sound in hydrogen to that in oxygen under similar conditions ?
Answer. The velocity of sound in hydrogen is four times of that in oxygen.

Question. 32.How does velocity of sound vary with humidity ?
Answer. Velocity of sound increases with increase in humidity in air. Sound travels faster after rains, hence it appears louder.

Question. 33.How does velocity of sound vary with wind velocity ?
Answer. Velocity of sound increases in direction of wind and decreases in opposite direction.