Wave Motion

Oscillation :-

The to and fro motion of a particle about its mean position is called its oscillation.

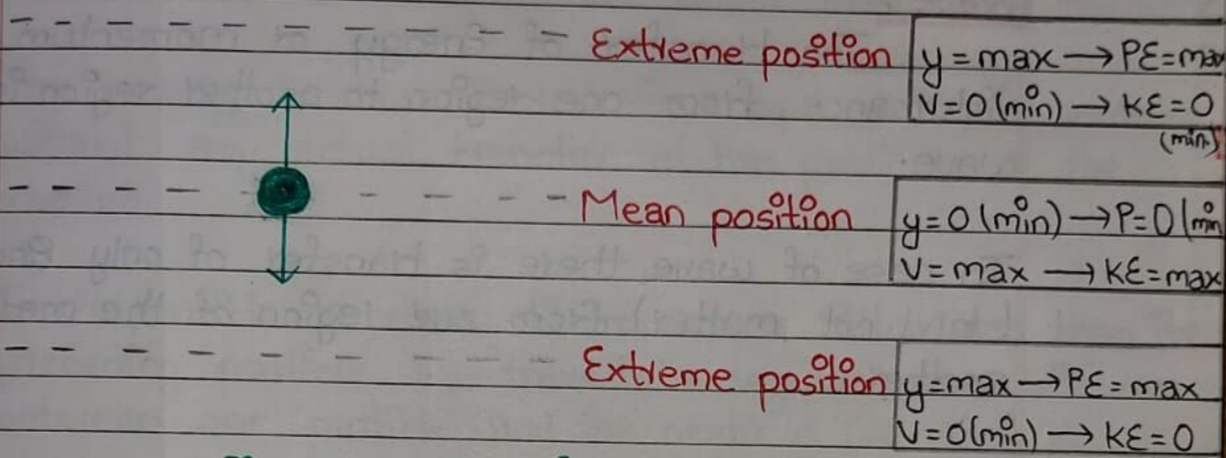


Fig:- Oscillation of a particles

The PE of a particle is the function of the displacement of the particle from its mean position.

The K.E of a particle is the function of the velocity of the particle $\left(K.E. = \frac{1}{2} mv^2\right)$.

As the particle moves from its mean position to extreme position, its KE gradually changes to PE.

The total energy of the particle at any point of its motion is given by,

$$\boxed{\text{Total Energy} = K.E + P.E}$$

In one completes oscillation of the particle,
Total distance travelled by the particle = 4a
& Net displacement of the particle = 0

Wave :-

The transfer of energy or momentum or disturbance from one region to another region is called wave.

In case of wave, there is transfer of only energy (and not matter) from one region of the medium to another.

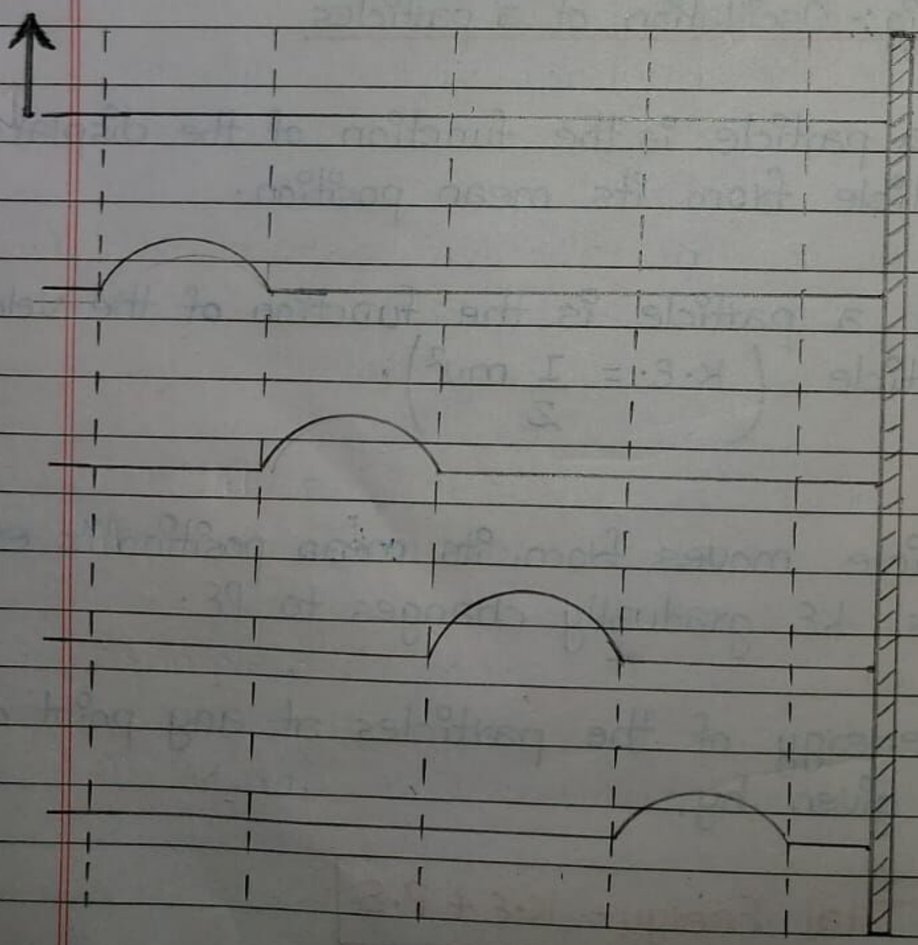


Fig :- Wave pulse in a rope.

Characteristics of wave motion

i) In a wave motion, the disturbance travels through the medium due to the repeated periodic oscillations of the particles of the medium about their mean positions.

ii) The energy is transferred from one place to another without any actual transfer of the particles of the medium.

iii) Each particle receives disturbance a little later than its preceding particle i.e. there is a regular phase difference between one particle and the next.

iv) All particles of the medium vibrate with the same amplitude, same frequency and same time period.

v) At any instant of time, different particles of the medium have different displacements about their mean positions.

vi) The velocity with which a wave (Disturbance / Energy / momentum) travels in a medium is called the wave velocity while the velocity with which the particle oscillate about its mean position is called the particle velocity. Wave velocity is different from the particle velocity.

vii) In a given medium, the wave velocity remains constant while the particle velocity changes continuously during its oscillation about the mean position. Particle velocity is maximum at the Mean position and Zero at the Extreme positions.

viii) For the propagation of Mechanical waves, the medium must possess the properties of elasticity, inertia and minimum friction amongst its particles.

Types of waves on the basis of necessity of the medium :-

On the basis of necessity of the material medium, there are basically two types of waves. They are :-

01) Mechanical waves
02) Electromagnetic waves (or Non-Mechanical waves)

01) Mechanical waves :-

Mechanical waves are those waves which require material medium for their propagation from one point to another.

⇒ Such waves are also called elastic waves because their propagation depends upon the elastic properties of the medium.

⇒ The Mechanical waves exist in all three states of Matter :- solid, liquid and gas.

⇒ Example :- Sound waves, waves on the surface of water, seismic waves, waves in pipes, waves in strings, etc.

02) Electromagnetic waves (or Non-Mechanical waves) :-
Electromagnetic waves are those waves which propagate in the form of oscillating electric and magnetic fields, the direction of propagation of wave being perpendicular to both electric field ($\vec{E}$) as well as magnetic field ($\vec{B}$).

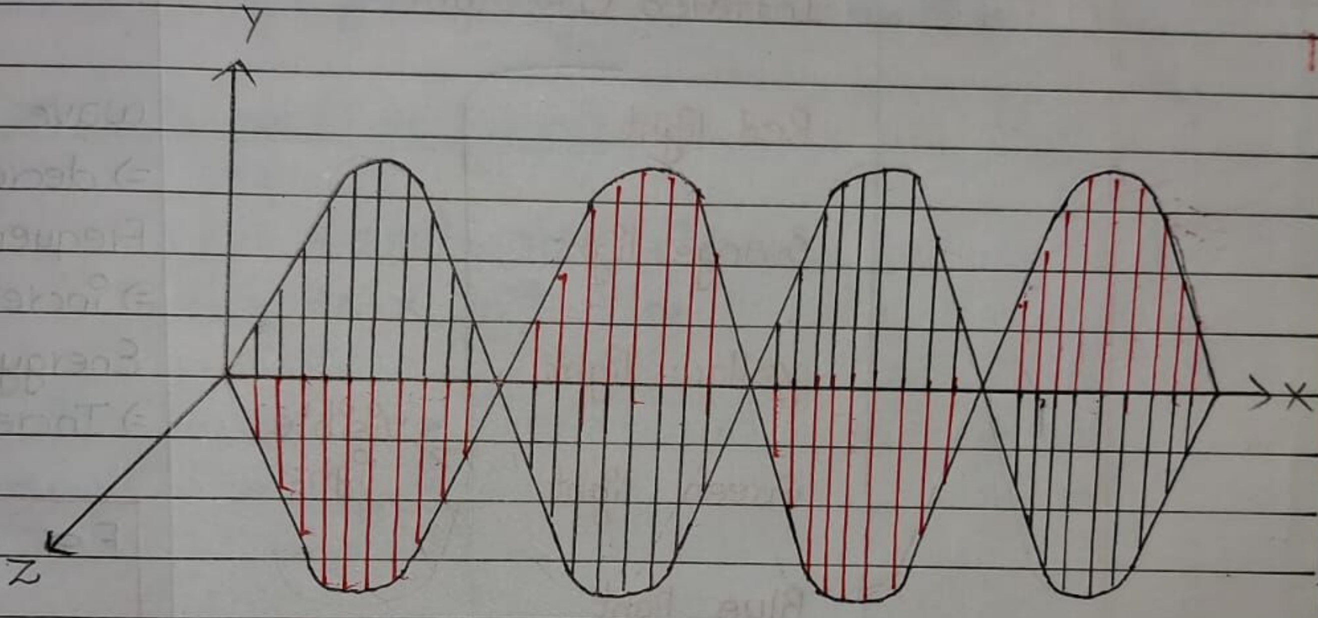
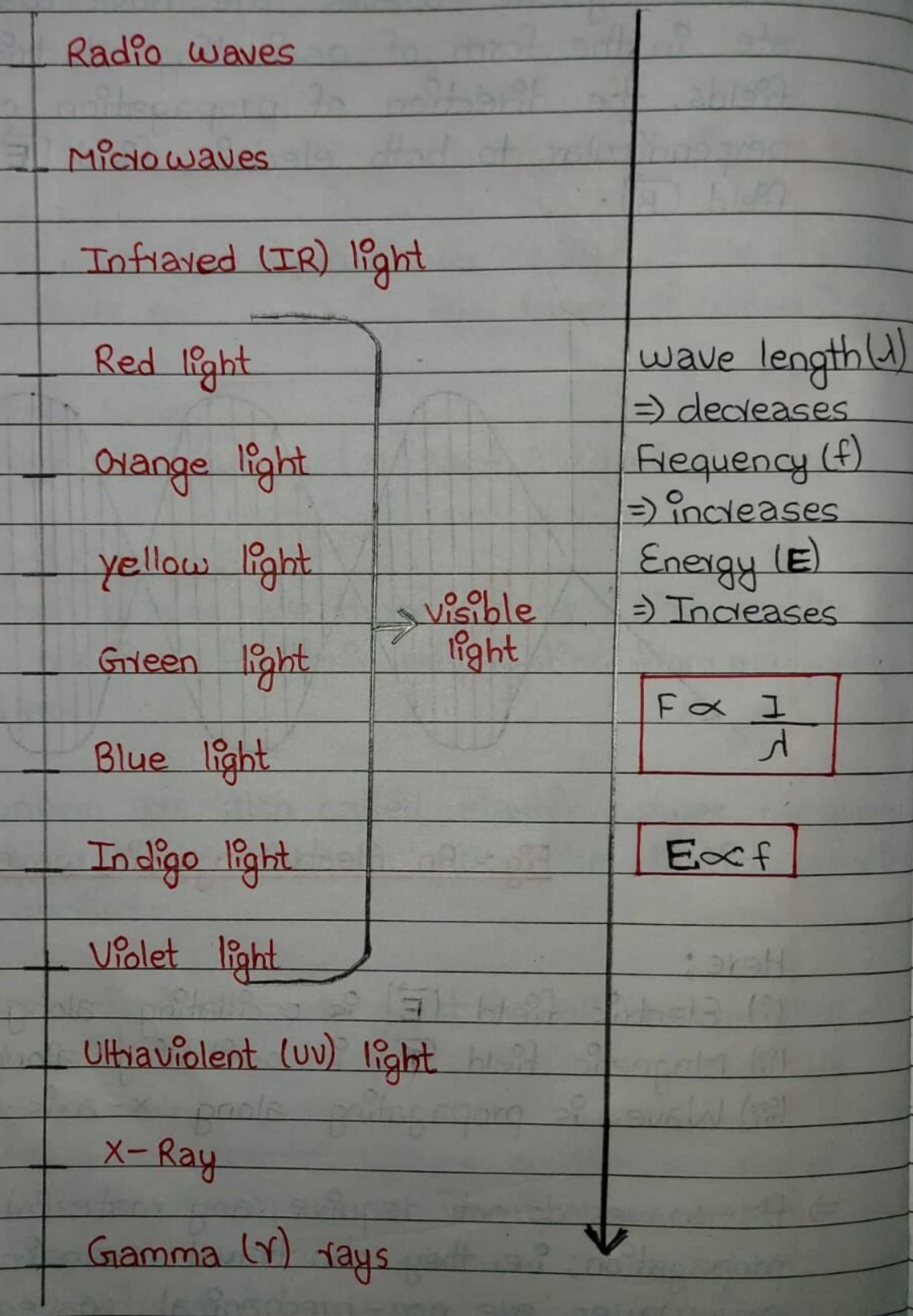


Fig :- An Electromagnetic wave

Here;
(i) Electric field ($\vec{E}$) is oscillating along y-axis.
(ii) Magnetic field ($\vec{B}$) is oscillating along z-axis.
(iii) Wave is propagating along x-axis.

⇒ EM-waves do not require any material medium for their propagation, i.e. they can travel even in vacuum. Therefore em-waves are non-mechanical waves.

Example :-



$$F \propto \frac{1}{\lambda}$$

$$E \propto f$$

Fig:- Electromagnetic Spectrum

The velocity of electromagnetic wave in any medium is given by,

$$v = \frac{1}{\sqrt{\mu \epsilon}}$$

where,

μ = permeability of the medium
ϵ = permittivity of the medium

λ) # For Vacuum (Free space)

$$v = c$$
$$\epsilon_0 = 8.854 \times 10^{-12}\ C^2/Nm^2$$
$$\mu_0 = 4\pi \times 10^{-7}\ H/m$$

Thus,

$$c = \frac{1}{\sqrt{\mu_0 \epsilon_0}}$$

$$\Rightarrow c = \frac{1}{\sqrt{(4\pi \times 10^{-7})(8.854 \times 10^{-12})}}$$

$$\Rightarrow c \sim 3 \times 10^8\ m/s$$

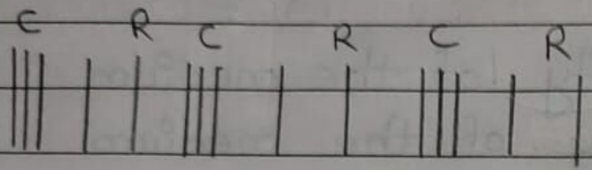
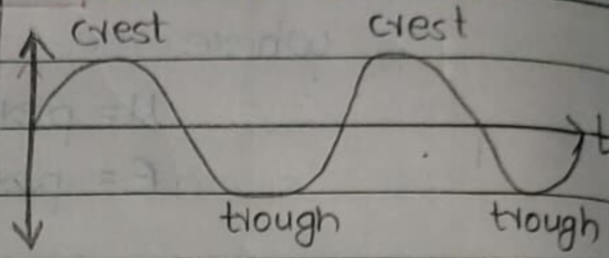
All the em-waves travel through vacuum at the same speed "c" (3×10^8 m/s).

↳ Types of Mechanical Waves

On the basis of direction of oscillation of particle of the medium, there are two types of waves. They are:-

i) longitudinal waves
ii) Transverse waves

• Differentiate between longitudinal and Transverse waves.

S.N	longitudinal Waves	S.N	Transverse waves
	 Fig:- longitudinal waves		 Fig:- Transverse wave
1)	longitudinal waves are those waves in which the particles of the medium vibrate along the direction of propagation of wave.	1)	Transverse waves are those waves in which the particles of the medium vibrate perpendicular to the direction of propagation of wave.
2)	They exist in all three states of matter: solid, liquid and gases.	2)	They exist only in solids and on the surface of the liquid.
3)	They propagate in the form of compressions and rarefactions.	3)	They propagate in the form of crests and trough.
4)	These waves cause variation in density and pressure in the different regions of the medium.	4)	These waves do not cause any variations in density and pressure in the different regions of the medium.

5) These waves cannot be polarized. (They are already polarized)	5) These waves can be polarized.
6) E.g:- Sound waves, waves in springs, Tsunami waves, seismic P-waves, etc.	6) E.g:- lights waves, waves in ropes and strings, Ripples on the surface of water, seismic S-waves, etc.

* Some terms related to Wave motion

1. Compression and Rarefaction

A longitudinal wave propagates in the form of compression and Rarefaction.

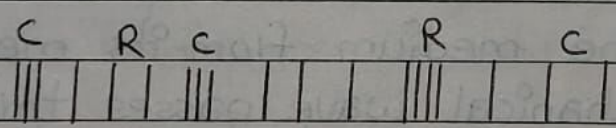


Fig:- Longitudinal waves

The region of the medium where the particles come closer is called the compression and the region of the medium where the particles lie apart is called the rarefaction.

At compression, the medium has maximum density and maximum pressure while at rarefaction, the medium has minimum density and minimum pressure.

2. Crest and Trough

A transverse wave propagates in the form of crest and trough.

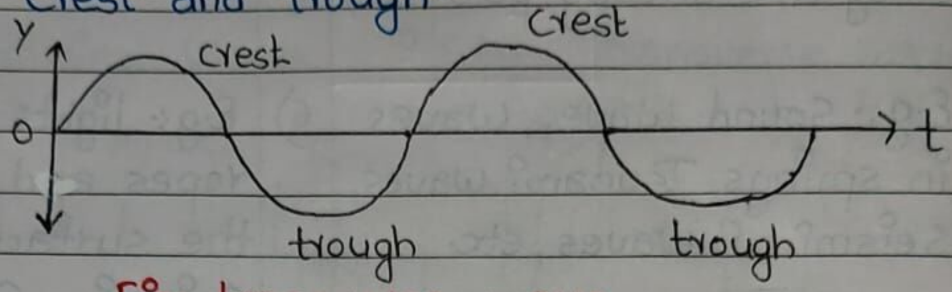


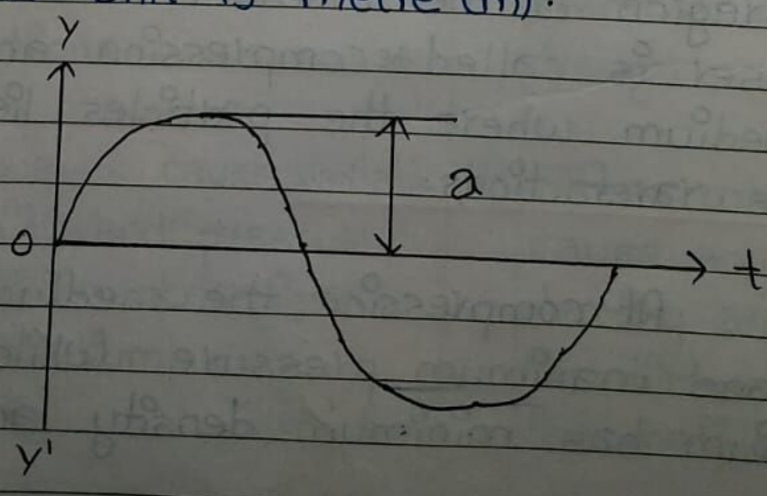
Fig:- transverse wave

The maximum upward position of the particle of the medium from its mean position is called crest and the maximum downward position of the particle of the medium from its mean position is called trough.

3. Amplitude (a)

The maximum displacement of the particle of the medium from its mean position, when a mechanical wave passes through the medium, is called the amplitude of the wave.

→ It is denoted by 'a'.
→ It's SI unit is metre (m).



4. Time period (T)

When a wave propagates through a medium the time taken by the particle of the medium to complete one oscillation is called the time period of the wave.

→ It is denoted by 'T'.
→ It's SI unit is second (s).

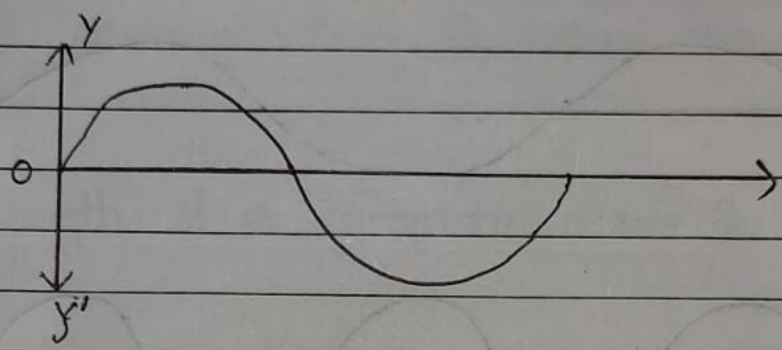


Fig:- A complete cycle of wave

The time taken by a wave to complete one cycle of its variations is called its time period.

5. Frequency (f)

When a wave propagates through a medium the number of oscillations completed by a particle of the medium in unit time is called the frequency of the wave.

→ It is denoted by 'f'.

The frequency of the wave is given by,

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

where, T is the Time period of the wave.

SI unit of 'f' = Per second (s^{-1})

or

hertz (Hz)

The number of cycles completed by a wave in unit time is called its frequency.

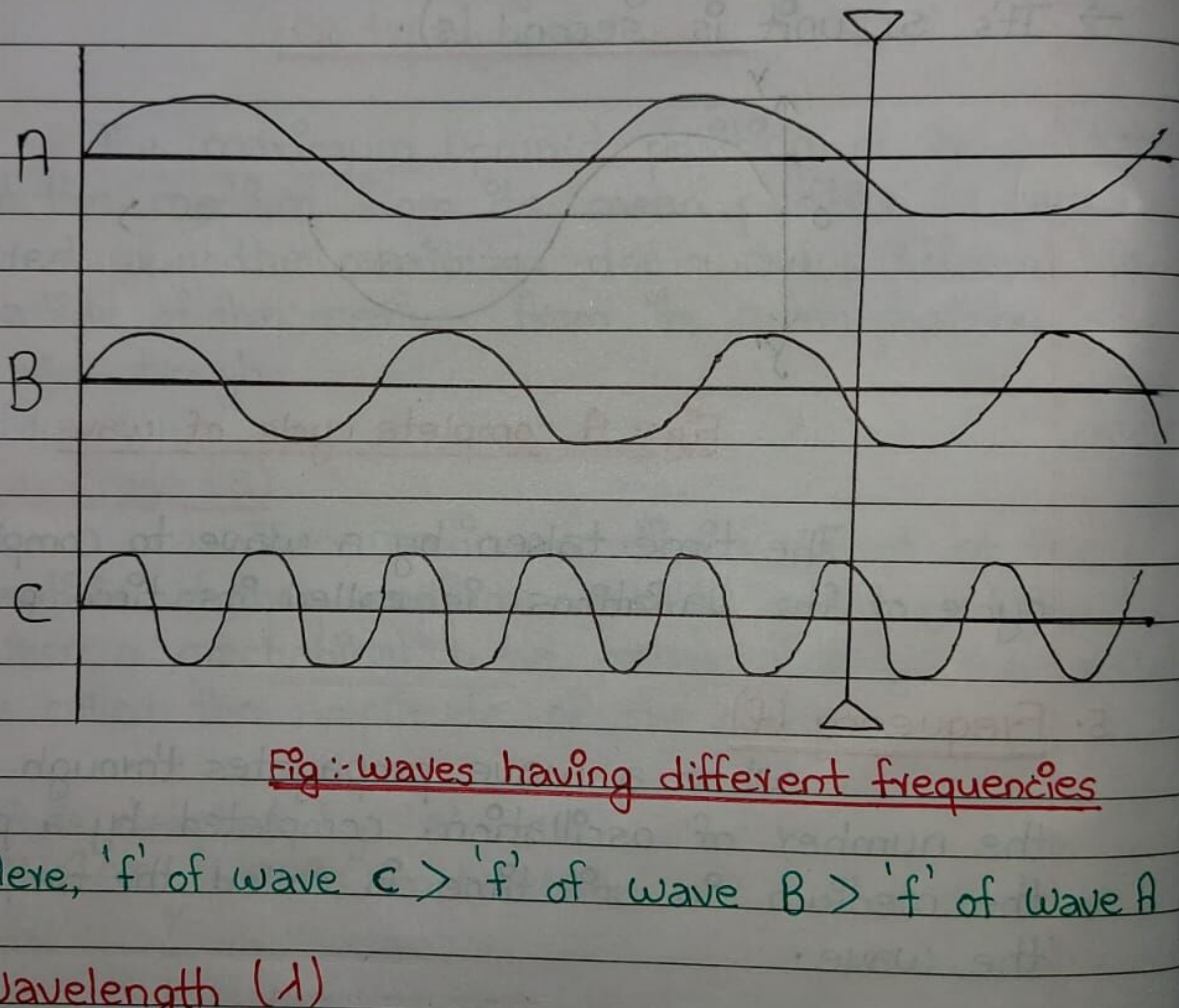


Fig :- waves having different frequencies

Here, 'f' of wave C > 'f' of wave B > 'f' of wave A

6. Wavelength (λ)

The distance travelled by the wave during the time in which any particle of the medium complete one oscillation about its mean position is called the wavelength of the wave.

OR

The distance travelled by the wave during the time equal to its time period (T) is called the wave length of the wave.

⇒ It is denoted by 'λ'.
⇒ Its SI unit is metre (m).

The linear distance travelled by a wave in one cycle of its variations is called the wave length of the wave.

The length of a complete wave is called its wavelength.

The distance between two consecutive compression or rarefactions of a longitudinal wave is called the wavelength of the longitudinal wave.

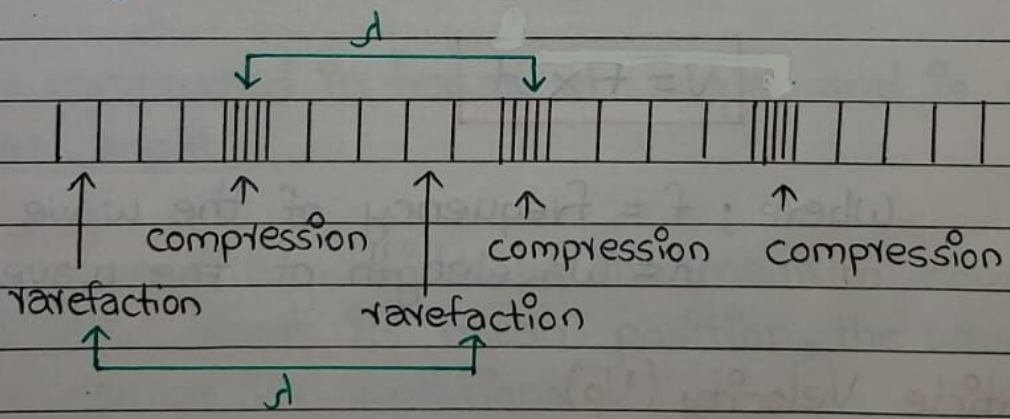


Fig:- longitudinal wave

The distance between two consecutive crests or troughs of a transverse wave is called the wavelength of the transverse wave.

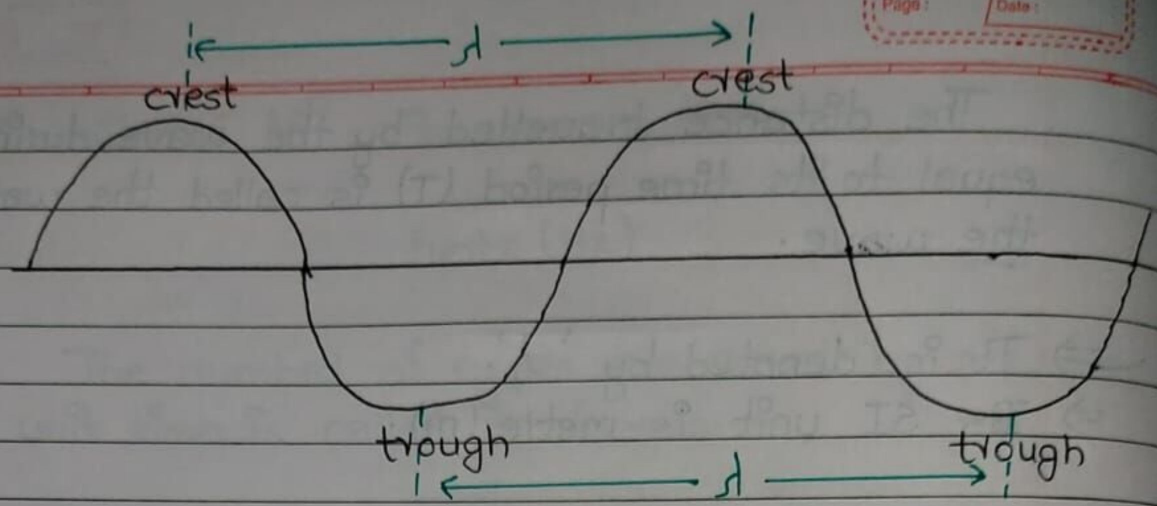


Fig:- Transverse wave

7. Wave Velocity (v)

The velocity with which a wave (disturbance Energy / momentum) travels in a medium is called the wave velocity.

In a given medium, the wave velocity remains constant.

The wave velocity is given by,

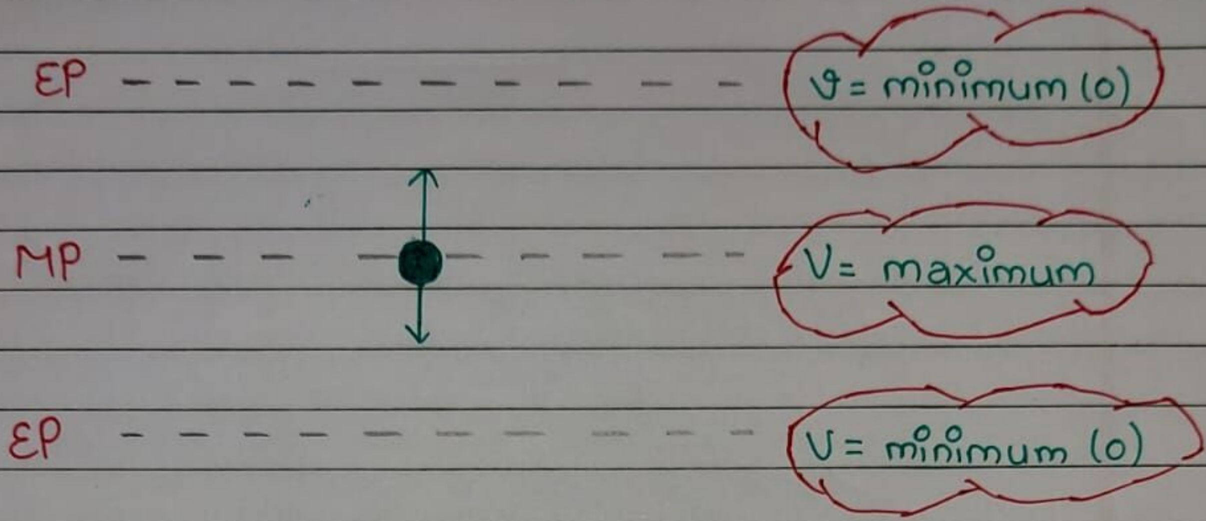
$$V = f \times \lambda$$

where ; f = frequency of the wave
λ = wavelength of the wave

8. Particle Velocity (V_p)

The velocity which the particles of the medium oscillate about their mean positions, when a wave propagates through it, is called the particle velocity.

In a given medium, the particle velocity changes continuously during its oscillation about the mean position. Particle velocity is maximum at the mean position and zero at the extreme position.



9. Phase (ϕ)

The state of motion of a particle of the medium at a particular position and time is called the phase of the wave at that point and time.

⇒ It is measured in terms of angle and is called as phase angle.

NOTE

When a particle of the medium completes one oscillation about its mean position, the wave completes one cycle of its variations.

In one complete oscillation of the particle (or in one complete cycle of the wave),

Time taken by the wave ⟶ T

Distance travelled by the wave ⟶ λ

Phase angle ⟶ 2π (360°)