RADIANT 2026

Physics

Sound

Lecture - 01

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Topics *to be covered*

1. Sound
2. Sound Propagation Requires a Material Medium
3. Speed of Sound in Different Media
4. ...Introduction to Waves
5. ...


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Sound

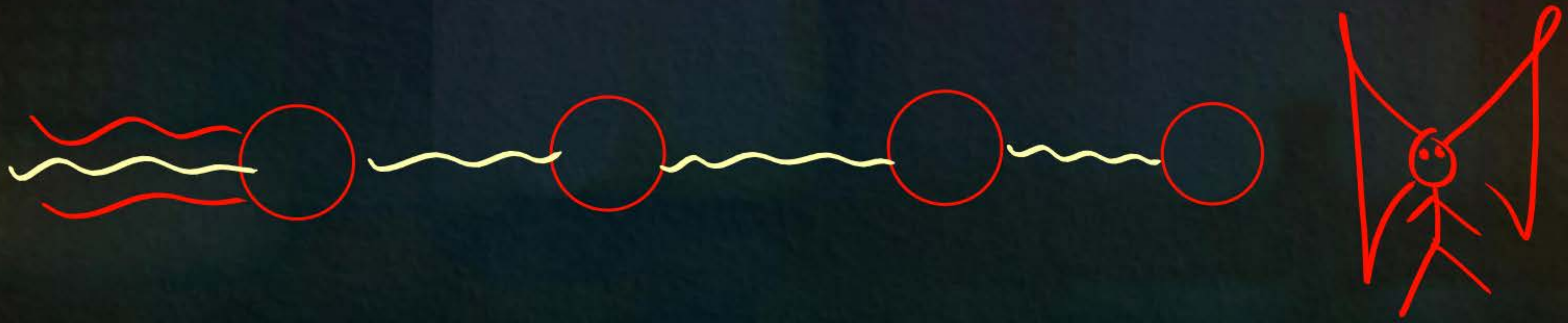
Sound is a form of energy that produces the sensation of hearing in our ears.

Sound is Produced by Vibrations

Sound is produced when a body vibrates. Following experiments demonstrate this fact.

A Vibrating Body is a Source of Sound

- **Sound is a form of energy:**
- Mechanical energy is required to start vibrations in a body producing sound. The vibrations of body are transmitted in medium in form of waves from that point to the next and so on.
- These waves on reaching our ears, produce vibrations in the ear drum which are perceived as sound by us. Thus, sound is a form of energy.



Sound Propagation Requires a Material Medium

A material medium is necessary for the propagation of sound from one place to another.

Requisites of the medium

The medium required for propagation of sound must possess the following three properties:

(i) The medium must be elastic so that its particles may come back to their initial positions after displacement on either side.

(ii) The medium must have inertia so that its particles may store mechanical energy.

Sound Propagation Requires a Material Medium

(iii) The medium should be frictionless so that there is no loss of energy in propagation of sound through it.

- Sound can propagate not only in gases, but also in solids and liquids. Some materials such as air, water, iron etc., can easily transmit sound through them from one place to another. On the other hand, blanket, thick curtains etc., absorb most of the sound incident on them and transmit or reflect only a small fraction of it.
- Sound cannot travel in vacuum. On moon,

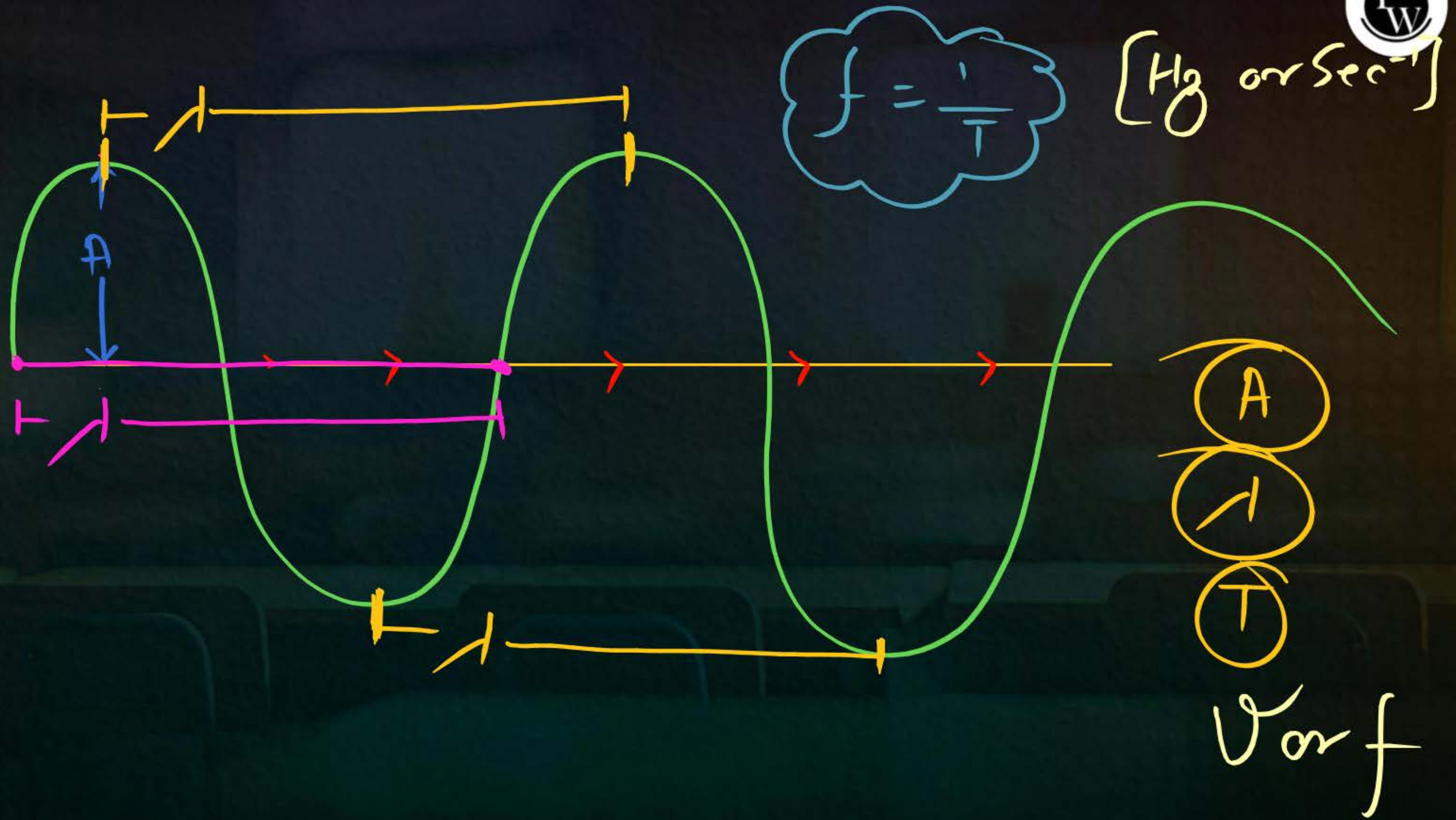
Propagation of Sound in a Medium

When a source of sound vibrates, it creates a periodic disturbance in the medium near it (*i.e.*, the state of particles of medium changes). The distrubance then travels in the medium in form of waves.

Characteristics of Wave Motion

(1) A wave is produced by the periodic disturbance at a point in the medium.

(2) Due to propagation of wave in a medium, the particles of medium vibrate about their mean positions (without leaving their positions) and energy is transferred with a constant speed from one place of medium to the other place.



A
$f = \frac{1}{T}$
[Hz or Sec^{-1}]
A
λ
T
ν or f

Some Terms Related to Wave Motion

(i) Amplitude:

When a wave passes through a medium, the maximum displacement of the particle of medium on either side of its mean position, is called the amplitude of wave. It is denoted by the letter a. Its S.I. unit is metre (m).

Some Terms Related to Wave Motion

(ii) Time period:

The time taken by a particle of medium to complete its one vibration is called the time period of wave. It is denoted by the letter T. Its S.I. unit is second (s).

Some Terms Related to Wave Motion

(iii) Frequency:

The number of vibrations made by a particle of medium in one second is called the frequency of wave. It is same as the number of waves passing through a point in one second. It is denoted by the letter *f*, *n* or *u* (neu). Its S.I. unit is $second^{-1}$ (symbol s^{-1}) or hertz (symbol Hz).

Some Terms Related to Wave Motion

The frequency f and time period T are related as

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

The frequency of a wave is equal to the frequency of vibration of its source. It is the characterstic of its source which produces the disturbance. It does not depend on the amplitude of vibration or on the nature of medium in which the wave propagates.

Some Terms Related to Wave Motion

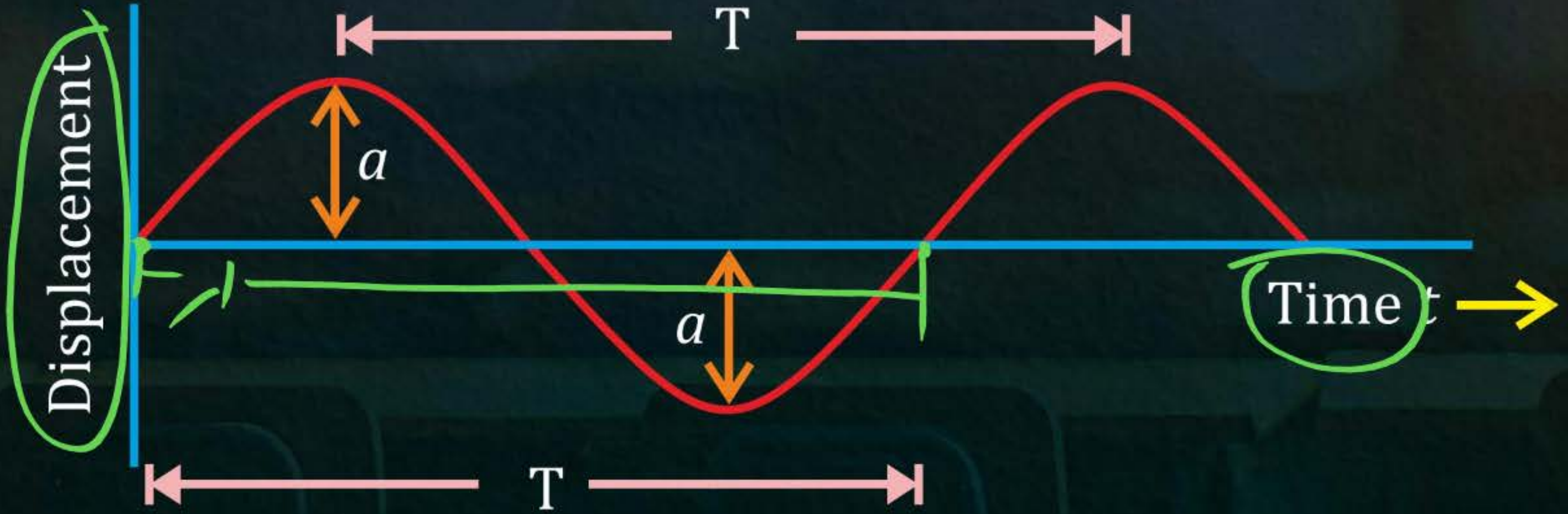
- **(iv) Wavelength:**
- He distance travelled by the wave in one time period of vibration of particle of the medium, is called its wavelength.
- It is denoted by the letter λ (lambda). Its S.I. unit is metre (m). It depends on the medium in which the wave travels.
- In a longitudinal wave, the distance between two consecutive compressions or between two consecutive rarefactions is equal to one wavelength, while in a transverse wave, the distance between two consecutive crests or between two consecutive troughs is equal to one wavelength.

Some Terms Related to Wave Motion

(v) Wave velocity:

- The distance travelled by a wave in one second is called its wave velocity or wave speed. It is the speed with which energy is transferred from one place to the other place by wave motion.
- It is not the velocity of an individual particle vibrating about its mean position. It is denoted by the letter V.
- Its S.I. unit is metre per second ($m\ s^{-1}$).
- It may be noted that the wave velocity is constant for a given medium. It depends on the elasticity and the density of the medium.
- It changes when the wave passes from one medium to the other medium.

Displacement-Time Graph



Displacement-Time Graph

Fig. shows the variation of displacement with time for a particle of the medium at a given position, when a wave propagates through the medium. It is called displacement-time graph. In Fig. the amplitude is represented by the letter a and time period is represented by the letter T.

Note that each particle of the medium goes through such motion, not simultaneously, but one after another as the wave moves in the medium.

In time T s, number of vibrations = 1

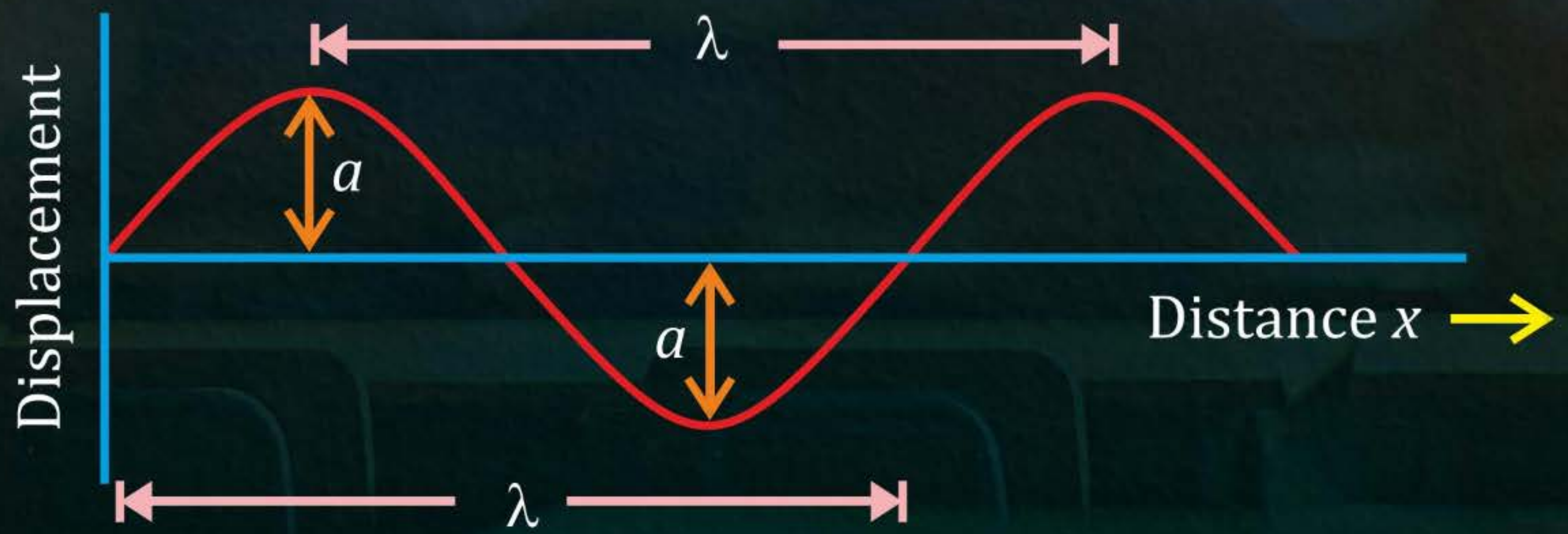
∴ In 1 s, number of vibrations = 1/T = f

Displacement-Distance Graph

- Fig. shows the displacement-distance graph of a transverse wave at an instant. Here amplitude of particles of wave is shown by the letter a and wavelength is shown by the letter λ.
- The curve shows the displaced positions of particles of medium from their mean positions at an instant when wave propagates through the medium. It is also called snap-shot of a wave.

Displacement-Distance Graph

❖ Fig. Displacement - distance graph of *a* wave



Unit of f

A → m^{-1}

B → m/sec

C → Hz ✓

D → λ

Relationship Between The Wavelength, Wave Velocity and Frequency

Let velocity of a wave be V, time period T, frequency f and wavelength λ. By the definition of wavelength,

Wavelength λ = Distance travelled by the wave in one time period i.e., in T second = Wave velocity × Time period = V × T

$\lambda = V \times T$

or $VT = \lambda$

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

$\lambda = V \times \frac{1}{f}$

$V = f\lambda$

From eqn. (i), V x (1)= λ V = fa or Therefore,

$\therefore$ From eqn. $V \times \left(\frac{1}{f}\right) = \lambda$ or $V = f\lambda$

Therefore,

Wave velocity = Frequency × Wavelength

Speed of Sound in Different Media

The speed of sound in a medium depends on the following two factors:

(i) the elasticity E of the medium, and

(ii) the density p of the medium.

The speed of sound in a medium is given by the relation

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

where E is the modulus of elasticity (Young's modulus in case of solids or bulk modulus in case of fluids*) and ρ is the density of the medium.

Speed of Sound in Different Media

Newton assumed that when sound travels in a gas, the temperature of gas does not change (*i.e.*, the propagation of sound is an isothermal change). For isothermal change, modulus of elasticity is equal to the pressure i.e., E = P Thus from eqn., speed of sound in a gas is given as

$$V = \sqrt{\frac{p}{\rho}}$$

$$V = \sqrt{\frac{P}{\rho}}$$

Speed of Sound in Different Media

- For air at normal temperature and pressure (N.T.P.),
- $P = 1.01 \times 10^5\ Nm^{-2}$, $\rho = 1.293\ kg^{-3}$ so V comes out to be $279.5\ ms^{-1}$. But experimentally the speed of sound in air is found to be nearly $330\ ms^{-1}$.
- Thus speed of sound calculated by using eqn. is found to be lower than the experimental value.

Speed of Sound in Different Media

- Later on, the scientist Laplace applied a correction to the above relation. According to Laplace, when sound travels in a gas, during the formation of compression and rarefaction, there is no exchange of heat in the medium i.e., the propagation of sound is an adiabatic change.
- For an adiabatic change, modulus of elasticity $E = \gamma P$ where γ is the ratio of the specific heat at constant pressure to the specific heat at constant volume $(\gamma = C_p / C_v)$ and P is the pressure of the gas.
- Hence from eqn. the speed of sound in a gas is given as
- $V = \sqrt{\frac{\gamma p}{\rho}}$
- The value of γ depends on the nature of the medium. For air, γ is 1-4.

Speed of Sound in Different Media

- The speed of sound is different in different media. The speed of sound is more in solids, less in liquids and least in gases (since solids are much more elastic than the liquids and gases).
- The speed of sound is nearly 5100 m s^{-1} in steel, 1450 m s^{-1} in water and 330 m s^{-1} in air at 0° C.

Speed of Sound in Different Media

Speed of sound in some media

Medium		Speed of sound (in m s^{-1})
Gases		
	Air	330
	Carbon dioxide	260
	Hydrogen	1270
Liquids		
	Alcohol	1210
	Turpentine	1325
	Water	1450
Solids		
	Copper	3560
	Steel	5100
	Glass	5500
	Granite	6000

m/s

Question

The speed of sound in air at 0° C is nearly:

(A) $1450\ m\ s^{-1}$

(B) $450\ m\ s^{-1}$

(C) $5100\ m\ s^{-1}$

(D) $330\ m\ s^{-1}$


Thank You